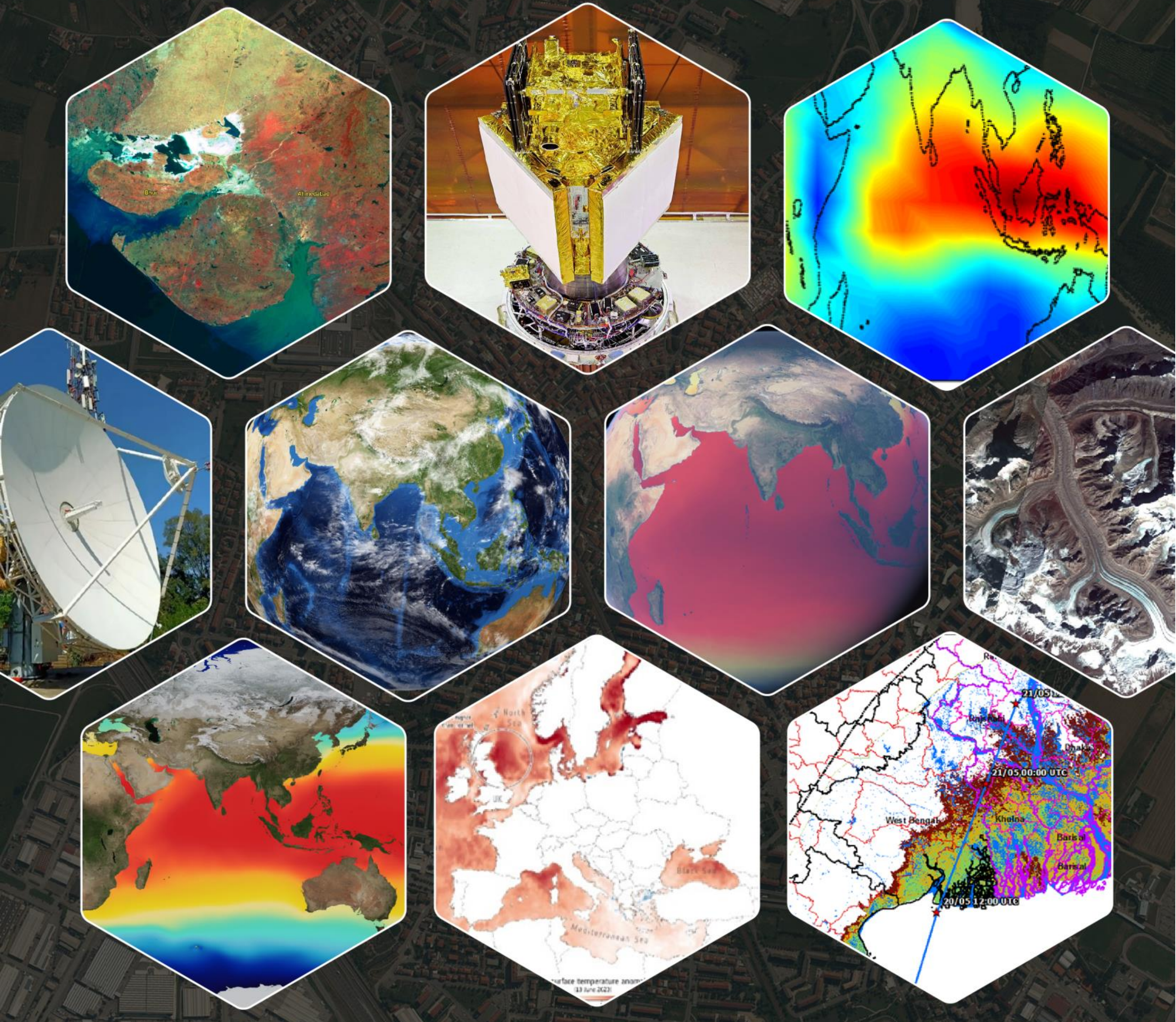
Geospatial Applications



GEOSPATIAL

APPLICATIONS

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FOREWORD

Geospatial science is an interdisciplinary field that combines many technologies and has an impact on numerous fields. Geospatial technology has a wide range of applications in practically every domain of natural resources, including agriculture, forestry, industries, rural, urban, water, and marine, and contributes significantly to the development of national infrastructure. These technologies are vital for land revenue, banking and finance, resource mapping and management, social planning, disaster management, e-governance, food security, and other purposes.
The National Geospatial Policy, 2022 aims to make India a world leader in global geospatial map with the best in class ecosystem for sustainable growth and economy for the nation through the integration of geospatial data/technology/concepts with industry 4.0 revolutionary technologies by growing web, cloud, and network infrastructure. The demand for qualified human resources for adopting technology for social and economic development across the country is growing by the day.

To fulfil the ever-increasing need, there is a need to build capacity through effective training and raise awareness among the many stakeholders, which include state and central ministries, industry, academics, entrepreneurs, and educated youth.

ISRO has launched many space missions for Earth observation applications. The Resourcesat, Cartosat, Oceansat, RISAT, INSAT2D/3DR class of satellite are providing temporal, multi-platform, multi-sensor satellite data of earth surface. The satellite data are critical inputs for geospatial technology for different thematic applications.

I am pleased to see that a course material encompassing all important topics in geospatial technology and applications has been created by various ISRO centres / institutions. A few practical sessions are also planned to provide hands-on experience.

I am confident that knowledge sharing will assist students, academics, industries, and researchers in improving their capabilities in the geospatial area and capitalising on growth possibilities.

S Somnath

PREFACE

In a frame work of National Geospatial Policy-2022, DOS accorded in principle approval for conducting an integrated course on Geospatial Technology and its applications for various user ministries and NGEs as a part of capacity building in space domain. Subsequently, CBPO in consultation with ISRO centres SAC, NRSC, IIRS and NE-SAC brought out the course curriculum.

The book on Geospatial Technology and its applications covers the chapters on Fundamental of Remote Sensing, Geographical Information System (GIS), Digital Image Processing, Advances in Remote Sensing, Microwave Remote Sensing, UAV Remote Sensing, Agriculture and Soils, Water Resources, Forestry and Ecology, Geoscience, Urban Development, Marine Applications, Atmospheric Science and Disaster. To have hands on different tools on Geo Spatial Applications the five demonstration topics are also covered in this programme e.g. on Remote Sensing, Geographical Information System, Digital Image processing, Geo portals and data dissemination and Open-source platforms for Geo-data processing.

The topics are contributed by Scientists across above ISRO centres and two books comprising twenty (20) topics on theory and five (5) practicals are brought out for Geospatial Technologies and its Applications. This book will be a basis for conducting the one-week training programme for BE/B Tech in Engineering or equivalent, BSc in any discipline, BA in Geology/Environment studies or 3 years Diploma in Engineering or equivalent fields. The students should have proficiency with Windows, MS Word and Excel.

The course will be conducted at eight identified Outreach & Training Centres (OTCs) at NRSC-RRCS North Delhi, RRSC South-Bengaluru, RRSC East-Kolkata, RRSC West-Jodhpur, RRSC Central-Nagpur, MCF-Bhopal, IIRS Dehradun, NESAC-Shillong.

Online course will also be made available in collaboration with iGOT Karmayogi (Department of Personnel & Training, GoI) platform.

N Sudheer Kumar
Director CBPO

GEOSPATIAL

APPLICATIONS

Chapter 1

GEOSCIENCE APPLICATIONS

A. Geological Mapping

1.1 Introduction

Remote Sensing is broadly defined as collecting and interpreting information about a target without being in physical contact with the object. Aircraft and satellites are the common platforms for remote sensing data collection. In general, the data collected by remote sensing system is commonly presented in the form of an image. An image is any pictorial representation, irrespective of the wavelength of imaging device used to produce it. A photograph is an image that records wavelengths of 0.3 to 0.9 µm that have interacted with light sensitive chemicals in photographic film. In initial period of remote sensing applications, aerial photographs proved useful in mapping geological structures. Images derived from multispectral sensors showed tremendous potential as an important source of application in various branches of geology- specially in geomorphology, structural and lithological mapping. These maps proved useful in different applications like geo-hazards and geo-environmental appraisal projects, mineral exploration projects, geotechnical projects. But it has to be understood that remote sensing images will be of little use for geological mapping if terrain is covered with forest, soil or other land use cover, other than rock exposures. Moreover, many of the times, geological mapping is accomplished from the rock exposures exposed at the roadcut, river or other vertical section. Therefore, maps prepared from the remote sensing images are essentially needed to be validated in the field with ground truths. Pertinently, with the advancement of sensor technology, the applications of remote sensing have increased manifold in the field of geological mapping. Hyperspectral images collected within narrow and continuous spectral channel can detect the spectral signatures characteristic to minerals and therefore help immensely in lithological mapping based on mineralogy. Microwave sensor, on the other hand, due to its side looking imaging capability enhances the geological structures by creating shadow etc.

1.2 Image Interpretation for geological application

Image interpretation is the act of examining images/photographs for the purpose of identifying objects and judging their significance. The interpretation is not restricted to identifying object on the image; it also usually includes determination of their relative locations and extents and changes in dimension. Visual interpretation of satellite image is being applied successfully in many fields, including geology, geography, agriculture, water resources, forestry, etc. A systematic study of satellite images usually involves a consideration of two basic elements, namely image elements and terrain elements. Image interpretation of terrain elements and image elements with identification of geological features based on variations in spectral signatures help in satellite based geological mapping. A broad geological knowledge about the terrain is a prerequisite for interpretation and delineation of rocks, structures and other relevant geological features from satellite image. Collateral data such as existing regional geological maps, toposheets, reports/available literature guide the interpretation of satellite image to derive updated, detailed or large-scale geological map.

Moreover, the synoptic coverage and multispectral information provided by the remotely sensed data have proved to be advantageous over conventional methods for geological mapping. The synoptic view helps in visualizing the terrain as a whole and comprehends to the spatial relationship between different features. These maps can be used in varied applications like mineral exploration, engineering geological studies, environmental geology related studies, geohazard analysis, etc.

1. Image Elements for geological application

Following are the eight characteristic image elements that aid image interpretation. These are: Tone/colour, Texture, Pattern, Shape, Size, Shadows, Site and Association.

Tone/Colour: Refers to relative shades of Gray on black and white images or colours on normal colour composite, False Colour Composite (FCC) or images. Tone is directly related to reflectance of light from terrain features. For example, water which absorbs nearly all incident light produces dark tone, whereas, a dry sand reflects a high percentage of incident radiation. Consequently, it produces very light tone on the image. Tone/colour is a fundamental property of an image and conveys more information to an interpreter than any other image elements. Without tonal differences, shapes, patterns and texture of objects described below, could not conspicuously be discerned. Some of the terms often used to describe relative tonal values are light, medium, dark etc. Absolute tonal values in terms of photo density have no physical significance for interpretation purposes and practically never used. The variation in Gray tones can be transformed into corresponding colours of various shades/lines on FCC. Colour imagery normally provides better thematic information than single band B/W imagery, by virtue of the more spectral information it contains.

Texture: Refers to the frequency of tonal changes in an image. Texture is produced by an aggregate of unit features, which may be too small to be clearly discernible individually on the image. It is a product of their individual shape, size, pattern, shadow and tone. By definition, texture is dependent on the scale. As the scale of the photograph is reduced the texture of a given object becomes progressively finer and eventually disappears. Some of the terms often used to describe relative texture values qualitatively are coarse, fine, medium, smooth, rough, etc., it is rather easier to distinguish various textural classes visually than in the digital-oriented techniques.

Pattern: The pattern relates to the spatial arrangement of the objects. The repetition of certain general forms or relationships is characteristic of many objects, both natural and manmade, and gives objects a pattern which aids the image interpreter in recognizing them. For example, interbedded sedimentary rocks consisting of sandstone and mudstone typically give an alternating tonal pattern which aids in their identification.

Shape: Shape relates to the general form, configuration or outline of an individual object. Shape is one of the most important single factors for recognizing objects from images. For example, a railway line is usually readily distinguished from a highway or a kuchha road because its shape consists of long straight tangents and gentle curves as opposed to the shape of a highway. The shape of an object viewed from above may quite different from its profile/perspective view. However, the plan view of object is more important and sometimes provides conclusive indication of their structure, composition and function.

Size: The size of an object can be important tool for its identification. Objects can be misinterpreted if their sizes are not evaluated properly. Although, the third dimension, i.e., height of the objects, is not readily measurable on satellite images, but valuable information can be derived from the shadows of the objects. Images with stereoscopic coverage, such as those from SPOT and CARTOSAT-1 & 2 provide information on third dimension (height). For planar objects, it is easier to calculate the areal dimensions on imagery, for example-alluvial fan, flood plain, etc.

Shadows: Shadows are of importance to photo interpreters in two opposing respects (1) The outline or shape of a shadow affords a profile view of objects, which aids interpretation, and (2) objects within shadow reflect little light and are difficult to discern on photographs, which hinders interpretation.

Association: It is one of the most helpful clues in identification of land forms. For example, a flood plain is associated with several fluvial features such as terraces, meanders, ox-bow lakes, abandoned channel, etc. Similarly, a sandy plain in a desert is associated with various types of sand dunes. A landslide will differ in association of geomorphological features from its surroundings.

2. Terrain Elements used in space based geological application

In addition to the image elements described above, the terrain elements listed below are also very useful for image interpretation. The terrain elements include drainage patterns, drainage density, topography/land form and erosion status.

Drainage pattern: The drainage patterns and texture seen on images are good indicators of landform and bedrock type and also suggest soil characteristics and drainage condition. For example, dendritic drainage pattern is the most common drainage pattern found in nature. It develops under many terrain conditions, including homogeneous unconsolidated materials, rocks with uniform resistance to erosion such as horizontally bedded sedimentary rocks and granitic gneissic terrains.

Drainage Density: Drainage density refers to the concentration of drainage lines within a given unit area. In a given climatic region, coarse-textured pattern would tend to develop where the soils and rocks have good internal drainage with little surface runoff, whereas fine textured pattern would tend to develop where the soils or rocks have poor internal drainage and high surface run-off. The following three drainage density classes have been recognized:

Fine: Average spacing between tributaries and first-order streams is less than ¼ inch in 1:50.000 scale. Fine-textured drainage is indicative of high levels of runoff, suggesting impervious bedrock type and/or fine-textured soils of low permeability.

Medium: Average spacing between first-order streams is roughly ¼ to 2 inches in 1:50000 scale. Runoff is medium in relation to fine-and coarse-textured drainages. Soil textures and underlying rock are typically neither fine not coarse but contain mixtures of particle size.

Coarse: First-order streams are greater than 2 inches apart, and they carry little runoff. Such textures are indicative of resistant, permeable bedrock materials and coarse, permeable soil materials.

Shale would tend to develop fine textured drainage patterns, whereas sandstone develops coarse textured drainage patterns. Drainage analysis is an important parameter to understand the geomorphic and structural variants of a terrain indirectly. Drainage analysis includes the study of drainage pattern, drainage texture, and individual stream pattern and drainage anomalies. It provides clues to the distribution and attitude of the underlying rock formations and geologic structures, such as bedding plane, joints, fractures, faults, folds, etc. The basic drainage patterns and their significance in geologic interpretation are summarized in Drainage texture is also an important parameter for studying the rock type distribution as it indicates the infiltration capacity of the rocks. Higher the infiltration Capacity of the rocks, coarser is the drainage texture and vice versa. Drainage anomalies, i.e., the local deviation from the regional drainage/stream pattern in the form of linear stream segments, active stream courses, appearance/disappearance of braided and meandering streams, change in drainage texture, etc., also indicate a change in underlying rock types and geologic structures. Drainage varies from dendritic (unjointed) to rectangular (jointed) in igneous rocks. Drainage density is an important criterion particularly with regard to the permeability of the sedimentary rock types.

Topography/ Landform: The size and shape of a landform are probably most important identifying characteristics. There is often a distinct topographic change at the boundary between two landforms as can be seen in several images. Identification of landforms can help deciphering the underlying geology. Often many of the rock types have distinct topographic expressions. Similarly, basaltic flows occur in the form of mesa hills, granitic bodies typically form hummocky topography, etc. Differential erosion is most effective. Shales are weak and form depressions or valleys, whereas sandstones and conglomerates form cuesta/ hogback in titled strata, ridges. In case of horizontal strata scarped plateau, mesas/ buttes capped by sandstones form. The stratification and alignment of ridges is the best indication. Limestones are an exception as they are normally characterized by solution topography.

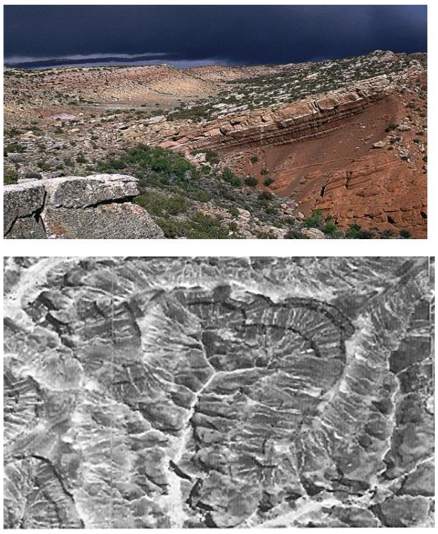

Fig 1.1 (Top Fig) Field photograph showing questa with hard and resistant rock on the top. (Bottom Fig) part of aerial photograph showing horizontally bedded sandstone layers on the less resistant siltstone

Erosion: In general, the deformation status and overall erosion within a given area can be assessed from the image which aids interpretation, particularly for geological mapping. For Example, a highly deformed and eroded rock unit can be considered older than the surrounding less eroded rock units. It also implies the physical competence, chemical susceptibility of underlying rocks to the weathering process.

1.2.1 Spectral Signature of Rock

The spectral signatures of rocks depend mainly on the spectral characteristics of constituent cations, anions and internal molecular structure and chemical bonds. Spectral measurements, made in the laboratory and field, of various minerals have indicated that spectral features in visible and near infrared region (0.4-1.0 µm) are dominated by transition metals, such as Fe, Mn, Cu, Ni, Cr etc. due to electronic crystal field effect, and in short wavelength infrared region (1.0-3.0 µm) are dominated by hydroxyl ions, carbonates and water molecules owing to vibrational processes. Interestingly, silicates (tectosilicates), oxides, nitrates, nitrites and phosphates which form abundant rock forming minerals, do not have diagnostic spectral features in the reflected region (0.4-3.0 µm) of electromagnetic spectrum. However, thermal infrared region (3-14 µm) has characteristic spectral features of these constituents. The diagnostic spectral characteristics of various cations and anions in terms of wavelength at which the absorption peak/minima occurs in different regions of electromagnetic spectrum.

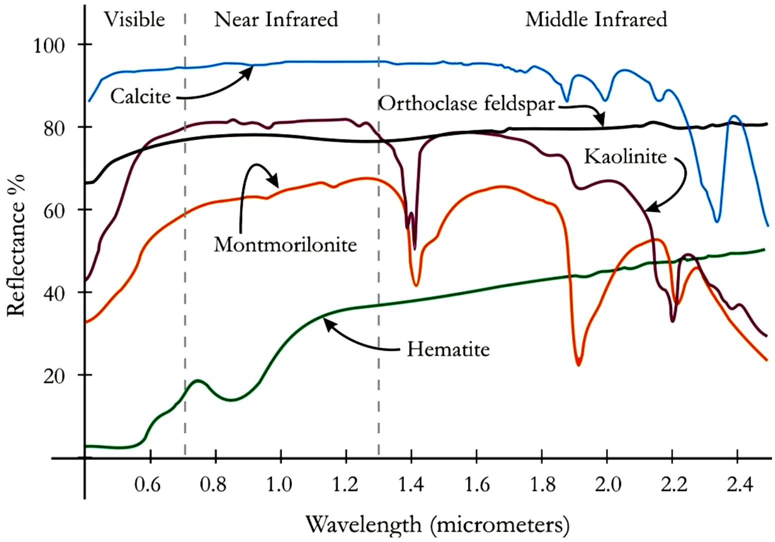

Fig. 1.2 Standard spectral signature of common rock forming minerals

Hyperspectral images require specialized software tools and the Environment for Visualizing Images (ENVI), one of the commercially available off-the-shelf software provides end-to-end capability to analyses hyperspectral data. The tools include correction of data to apparent reflectance using standard atmospheric correction methods, use of a linear transformation to minimize noise (MNF-Minimum Noise Fraction) and visualization in n-dimension, locating the most spectrally pure pixels (PPI-Pure Pixel Index), extraction and automated identification of end member spectra (SAM-Spectral Angle Mapper), spatial mapping and abundance estimates for specific image end members using spectral un-mixing methods.

1.2.2 Identification of different types of Landform/Geomorphic Units

Landforms are characteristic to the processes which operated to develop their sculpture. Landforms can be broadly subdivided in broad seven categories based on the processes or medium played role in their formations. These are: Aeolian Landform, Coastal Landform, Denudational Landform, Fluvial Landform, Glacier Landform, Tectonic Landform and Volcanic landform.

Aeolian Landform: Aeolian landform is a feature of the Earth’s surface produced by either the erosive or constructive action of the wind. The word derives from Aeolus, the Greek god of the winds. Wind erosion processes consist of abrasion, the scouring of exposed surfaces by the sand-blasting action of wind-borne material; and deflation, the removal of sand-sized and smaller particles by the wind. Sand is transported short distances as individual grains or by saltation (a form of movement in short leaps) to form distinct constructional bed forms at various scales: aeolian ripple ridges (a few centimeters in width), meso-dune forms (a few meters in diameter), dunes (several tens to a hundred metres in size), and, finally, ergs (several square kilometers or more). The finer silt-sized particles are transported by airflow turbulence in suspension over much greater distances to form loess. Wind transportation causes attrition of the moving particles, which rub one another and develop characteristic surface frosting and pitting.

Coastal Landform: Coastal landforms are those which are influenced or controlled by the proximity to the Sea. The three types of movement that carry on gradational work to create the coastal land forms are waves, currents, and tides. There are two broad types of coastal Landforms: erosional coastal land forms and depositional coastal landform. Most prominent among erosional coastal landforms are those which are cliffs, terraces, benches, shelves, caves etc and significant depositional landforms are beaches, spit, bars, tidal flats and deltas. Thus, based on the above criteria, the coasts can be classified as follows: (1) Ria Coast – it is a deeply embayed coast resulting from submergence of a land mass dissected by streams. Ria coast has many offshore islands. (2) Fiord Coast – it is deeply embayed by steep-walled fiords or submerged glacial troughs. (3) Barrier Island Coast – it is associated with a recently emerged coastal plain. The offshore slope is very gentle, and a barrier island of sand is usually thrown up by wave action at some distance offshore. (4) Delta Coast – large rivers build elaborate deltas and produce Delta Coasts. (5) Volcano coast – it is formed by the eruption of volcanoes and lava flows, partly constructed below water level. (6) Reef-building Coast – it is formed by reef building process. (7) Fault Coast - down-faulting of the coastal margin of a continent can allow the shoreline to come to rest against a fault scarp, producing a fault coast.

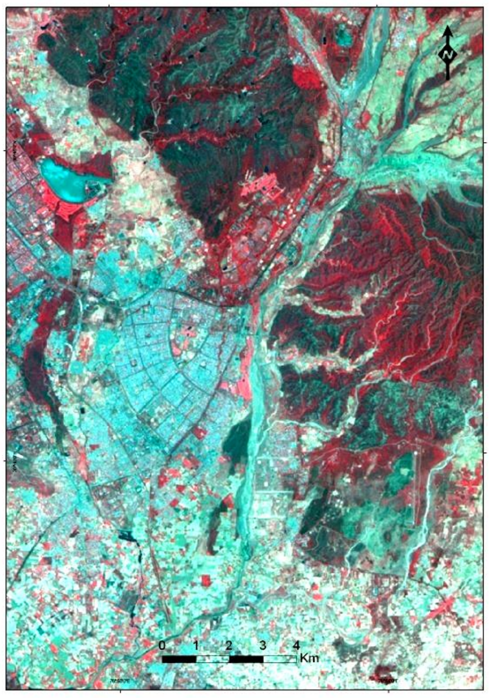

Fig. 1.3 Multi-spectral satellite image showing alluvial fan (of Ghaggar River, which is believed to be the lost Saraswati River) modified by human activity (Panchkula, near Chandigarh City)

Denudational Landform: Denudational landforms are exogenic and are formed by the continued process of erosion of original landscapes by repeated action of denudational agents like river, wind and climate components like rainfall, temperature etc., Few major denudational landforms are pediplain, pediment, denudational hill etc.

Fluvial Landform: Fluvial landforms are created by the action of rivers or streams and the processes associated with them. This is one of most widely distributed landforms on the earth surface. The landform associated with fluvial erosions are gorges, canyons, V-shaped valleys, steep hill slopes, water falls etc. Typical depositional landforms include alluvial fans, cones, alluvial plain, flood plain, natural levees, river terraces, meander scars, channel fills, point bars and delta.

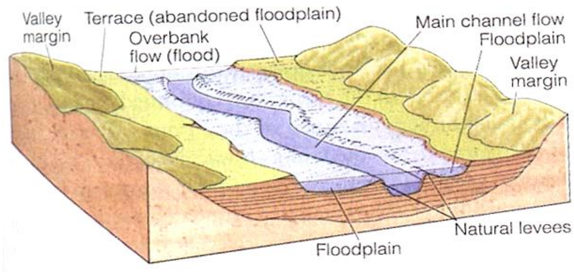

Fig. 1.4 Fluvial landforms along the transverse profile of a river channel

Glacial Landform: Glaciers are stream-like features of ice and snow, which move down slopes under gravity. Glaciers occur at high altitudes and latitudes and about 10% of earth surface is covered by ice. Areal extent of glacier is difficult to measure by field method and remote sensing data images provide information of much practical utility in this regard (Gupta, 2003). Remote sensing technology is an economical and promising tool for obtaining information on snow-cover. Satellites are well suited to the measurement of snow-cover because the high albedo of snow presents a good contrast with most other natural surfaces except clouds. Typical erosional landforms of glaciers are U shaped valley, hanging valleys, cirques etc. Main depositional landform of glaciers is moraine. Below streamline, glaciers melt down and form streams. Typical glacio-fluvial landforms are outwash plan, end morain, eskers, etc.

Tectonic Landform: Tectonic landform may be defined as structural landforms of regional extent. Davis in 1899 considered that structure, processes and time constitute the three most significant factors shaping the morphology of a land. Scarp, shutter ridge, structural hill, monocline, etc are few noteworthy tectonic landforms. Active faulting causes variety of landforms features, including fault scarps, wraped and tilted ground, subsidence features such as sag ponds, and off set features such as stream channels. Each major category of faulting-strike-slip, normal, and reverse-may be discussed in terms of a characteristic assemblage of landforms.

Volcanic Landform: Volcanic Landforms are mainly constructional and are resulted from extrusion of magma along the vents or fracture of the earth's surface. Cinder cones, crater lava ropes, Lahars etc are few noteworthy volcanic landforms.

Alluvial fan: A low, outspread, relatively flat to gently sloping mass of loose rock material; shaped like an open fan or a segment of a cone, deposited by a stream (esp. in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases. Alluvial fan develops at a place where a stream after going through a narrow mountain valley enters into a plain or a broad valley. It also develops at places where a tributary stream meets the main stream. Alluvial fan generally develops when a constricted valley widens up and the stream gradient suddenly decreases.

Alluvial plain: A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or alluvial fan. It is a horizontal, gently sloping or slightly undulating tract of land produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks. It may be situated adjacent to a flood plain, a delta, or an alluvial fan.

Anticline: A fold, the core of which contains the stratigraphically older rocks.

Alluvial terrace: A stream terrace composed of unconsolidated alluvium (including gravel), produced by renewed down cutting of the flood plain or the valley floor by a rejuvenated stream, or by the later covering of a terrace with alluvium.

Antiform / Anticline: A breached/unbreached uplift, where the structure is shown directly in the topography and perhaps by drainage pattern. In case of the presence of older rock in the core of the uplift the antiform is called as anticline.

Arete: The knife edge caused by the intersection of two adjacent cirque walls or indeed at sharp mountain ridge. Avalanche Chute / Track: These are distinct channels in bedrock formed due to repeated debris avalanches. When a ridge of cirques exists on the opposite side of the peak, the dual carving action meets to form a steep and serrated-looking crest of rock. This knifelike edge is called an arete.

Bajada: A broad, continuous alluvial slope or gently inclined detrital surface extending along and from the base of a mountain range out into and around an inland basin, formed by the lateral coalescence of a series of separate but confluent alluvial fans, and having an undulating character due to the convexities of the component fans; it occurs most commonly in semiarid and desert regions.

Barchan: A moving, isolated crescent shaped sand dune lying transverse to the direction of the prevailing wind, with a gently sloping convex side facing the wind so that the wings or horns of the crescent point downward (leeward) and an abrupt or steeply sloping concave or leeward side inside the horns.

Barrier beach: A single, narrow, elongate sand ridge slightly above the high-tide level and extending generally parallel with the shore, but separated from it by a lagoon or marsh; it is extended by longshore drifting and is rarely more than several kilometres long.

Barrier island: A detached portion of a barrier beach between two inlets. It is a subdued ridge made of sand by the waves and further increased in height by the growth of sand dunes. Behind the barrier island lies a lagoon, which is a wide expanse of shallow water, several kilometers long and in places filled largely with the tidal deposits. A characteristic feature of the barrier islands is the presence of gaps, known as tidal inlets.

Basin: A general term for a depressed, sediment filled area. It may be an elongate, fault-bordered intermontane basin within an orogenic belt.

Beach: A gently sloping zone, typically with a concave profile, of unconsolidated material that extends landward from the low-water line to the place where there is a definite change in material or physiographic form (such as a cliff) or to the line of permanent vegetation (usually of the effective limit of the highest storm waves).

Beach ridge: A low, essentially continuous mound of beach or beach and dune material (sand, gravel, shingle) heaped up by the action of waves and currents on the backshore of a beach beyond the present limit of storm waves or the reach of ordinary tides, and occurring singly or as one of a series of approximately parallel deposits. The ridges are roughly parallel to the shoreline and represent successive positions of an advancing shoreline. During the progradation of the shore, the sand particles are deposited parallel to the coast and develop a landform which is raised above the sea level. Such linear and parallel landforms are known as beach ridges. Each beach ridge represents a former berm crest. Beach ridges are separated from each other by the narrow belts of low marshy land known as swales.

Bornhardt: A residual peak having the characteristics of an inselberg; specifically, a large granite-gneiss inselberg associated with the second cycle of erosion in a rejuvenated desert region.

Braided stream: A stream that divides into or follows an interlacing or tangled network of several, small, branching and reuniting shallow channels separated from each other by branch islands or channel bars, resembling in plan the strands of a complex braid. Such a system is generally believed to indicate the inability to carry its entire load such as an overloaded and aggrading stream flowing in a wide channel on a flood plain. Syn: an anastomosing stream.

Buried / Palaeo Channel: Deep valleys cut in the bedrock terrain and today filled largely with alluvium, glacial outwash gravels and sands or with tills. These are good source for underground water. These are the previous channels those are presently filled up largely by alluvium, glacial outwash gravels and sands, and tills.

The Delhi Supergroups of rocks are deposited in a synclorium and the trend of Delhi fold belt is WSE. The fold axis or orogeny of Delhi fold belt or Delhi orogeny is well depicted in the satellite data. Moreover, many fault and fractures are also delineated in Delhi group of rocks; which represent the pattern of brittle deformation in the area.

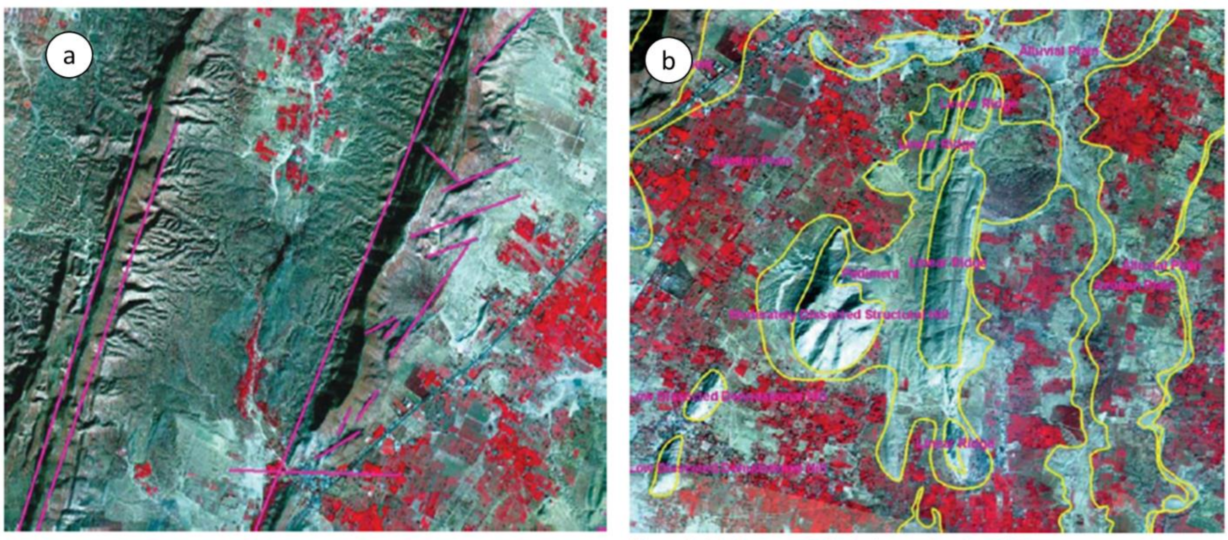

Fig. 1.5 (a) Lineament map of parts of Jaipur, and (b)Geomorphological map of parts of Jaipur

The geomorphology of this area is very conspicuous and guided by the competence/strength of the rocks. There are four major divisions in geomorphology. These are structural hill, denudational hill, pediment, alluvial plain and aeolian plain.

B. Planetary geology

1.3 Identification of magmatic differentiated regions on lunar surface

Mineral/lithological mapping of the lunar surface has been one of the important applications of planetary hyperspectral remote sensing in the past decade. It helps to understand the magmatic evolution of the moon and also for understanding the distribution of economic minerals on the planetary surface. The distribution of different minerals on the lunar surface may also allow us to understand the nature of horizontal segregation of different minerals in different geological provinces of the Moon. This in turn would help to understand the role of tectonic (if any) and magmatic differentiation on the lunar surface.

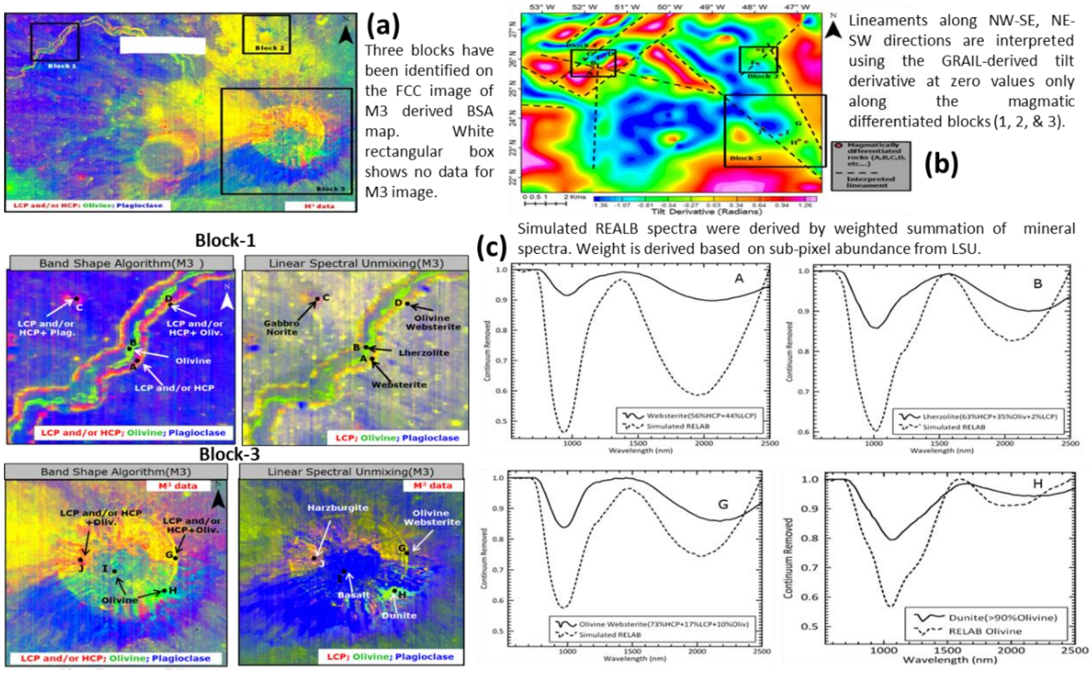

Fig. 1.6 (a) Band Shape Algorithm derived mineral mapping over Aristarchus Plateau. Three blocks have been identified on the FCC image of M3 derived BSA map. White rectangular box shows no data for M3 image. (b) Lineaments along NW-SE, NE-SW directions are interpreted using the tilt derivative at zero values only along the magmatic differentiated blocks (1, 2, & 3). (c) Mineralogical information observed in few sites (marked as A, B, G, H) in BSA image composite of M3 data for the block-1 and block-3 demarcated in a. Linear spectral un-mixing (LSU) map highlighting the presence of few rocks based on the relative abundance of each dominant mineral derived from the LSU method at those points at block 1 & 3

A case study over Aristarchus Plateau: In this study, we implemented a band shape algorithm (BSA) to identify the surface distribution of different minerals on parts of the Aristarchus Plateau using selected bands of hyperspectral Moon Mineralogy Mapper (M3) data. M3 based BSA mineral map could detect mineralogical details in selected places, especially around Vallis Schroteri, Aristarchus etc. areas. Therefore, we implemented linear spectral un-mixing (LSU) method on hyperspectral bands of M3 data using the reference spectra of Reflectance Experiment Laboratory (RELAB) to estimate the relative abundance of different minerals in above-mentioned areas. Based on the relative abundance of minerals in the LSU map, we could infer the presence of different rocks such as dunite/troctolite, norite, harzburgite, olivine-pyroxenite in those sites of the study area. The relative abundance of each mineral in a particular place was used as the basis for delineating specific rock in that place of the study area. These mineralogically diverse rocks with distinct proportions of mafic mineral and plagioclase content are exposed along a lunar structure that has been delineated using Gravity Recovery and Interior Laboratory (GRAIL) data. We hypothesize that some of these rocks might have formed by a magmatic differentiation process triggered by the structure by separating magma from the crystallized rocks and allowing the magma to compositionally evolve to produce different rocks under the influence of syn-magmatic structural activity.

1.4 Automated lunar geological mapping using machine learning

We utilized the Moon Mineralogy Mapper (M3) data to implement two machine learning algorithms (random forest and support vector machine algorithms) for mapping geological units in the surrounding area of Posidonius crater and the eastern rim of Mare Serenitaties. The geological boundaries of published maps served as a reference for machine learning algorithm (MLA) that was used to derive an automated geological map. Each geological unit has unique lithology and impact structures related to geological time scale. Additionally, each unit has variable space weathering imprint. Spectral profiles of each geological unit were used as one of the parameters for geological mapping along with few other parameters that have been derived from digital elevation model derived from Lunar Orbital Laser Altimeter (LOLA) data. The inclusion of derived parameters in digital elevation models aids in enhancing the contrast in geomorphic and weathering between various lithological units that might have been resulted from the contrasting geological age, mechanical competence, textural contrast of the rocks in addition to their respective mineralogical variation.

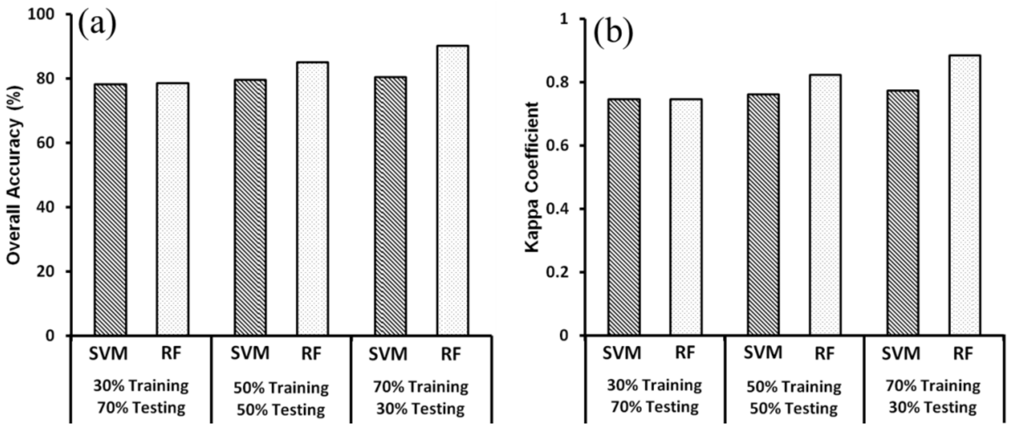

Fig. 1.7 Bar chart representation of an overall accuracy, and b. kappa coefficient in confusion matrices derived from three testing datasets of geological classification achieved from support vector machine and random forest.

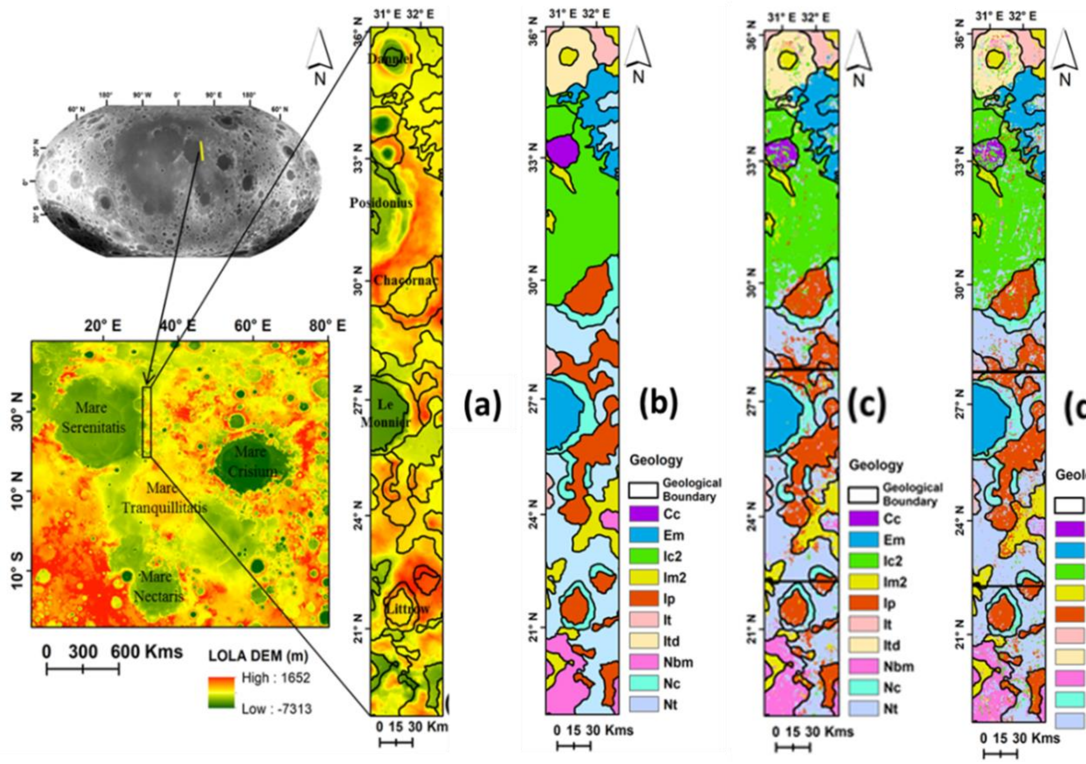

Fig. 1.8 Study map located at the eastern boundary of Mare Serenitatis in the north-eastern part of the Moon's near side. a. Local topography map derived from the digital elevation model of Lunar Orbiter Laser Altimeter (LOLA) with 118m spatial resolution highlighting some important geomorphologic units. b. Reference geological map. The acronyms of geological units used in the map are, Cc: Copernican crater; Em: Eratosthenian mare; Ic2: Imbrian upper crater; Im2: Imbrian upper mare; Ip: Imbrian plains; It: Imbrian terra; Itd: Imbrian tera dome; Nbm: Nectarian basin massif; Nc: Nectarian crater; and Nt: Nectarian terra. Geological classification maps derived from c. support vector machine (SVM) and d. random forest (RF) models trained by 70% training datasets using multi-sensor parameters

C. Groundwater

1.4.1 Introduction

The distribution of groundwater is not uniform throughout the country. The spatio-temporal variations in rainfall and regional/local differences in geology and geomorphology have led to uneven distribution of groundwater in different regions across the country. Unplanned and haphazard development of groundwater in some areas has further compounded the problem and has led to a sharp decline in groundwater levels. As a result, a large number of shallow wells have gone dry, resulting in a huge loss and shortage of drinking water in 20 to 25% of the habitation in the country. Similarly, along the coastal zones also the delicate balance between sea water and the groundwater has been disturbed leading to sea water intrusion into the freshwater aquifers causing irreparable damage and environmental degradation. Systematic estimation and budgeting of groundwater resource based on its spatiotemporal distribution, its allocation for meeting the competing demands for irrigation, industrial and domestic usage, and conjunctive use of surface and a groundwater resource are, therefore, pre-requisite for optimal utilization of available groundwater on a sustained basis. Groundwater study of an area requires the knowledge of the nature of lithological units occurring in the area, their structural disposition, geomorphic set up, surface water conditions and climate. These had been studied by the conventional method of extensive field work till recent past. With the development of remote sensing sensors accompanied with improvement of interpretation techniques of the remotely sensed data, focus has turned to this technique. World-wide professional organizations involved with groundwater investigation in an area commence their work with analysis of remotely sensed data. Although remote sensing data can't directly detect subsurface resources, its importance lies in providing indirect but reliable inferences about the groundwater potentiality of the region. Analysis and interpretation of remote sensing data followed by selective ground check is important to obtain an idea about the probable groundwater potential areas. This should be substantiated through surface and subsurface geophysical methods best suited for groundwater exploration.

1.4.2 Factors Controlling Groundwater Regime

The groundwater regime is a dynamic system wherein water is absorbed at the surface of the earth and eventually recycled back to the surface through the geological strata. In this process, various elements like relief, slope, ruggedness, depth and nature of weathering, thickness and nature of deposited material, distribution of surface water bodies, river / stream network, precipitation, canal command areas, groundwater, irrigated areas, etc., also influence the groundwater regime, besides the geologic framework. Thus, the framework in which the groundwater occurs is as varied as that of rock types, as intricate as their structural deformation and geomorphic history, and as complex as that of the balance among the lithological, structural, geomorphic and hydrologic parameters. The possible combinations of variety and intricacy are virtually infinite leading to the unavoidable conclusion that the groundwater conditions at a given site are unique and not completely amenable to scientific understanding. Some of the conditions are often obscured and not readily apparent even from the field observations. However, factor-wise analysis, systematic mapping, data integration and interpretation based on conceptual understanding will help in overcoming this problem to some extent. Though, there are a large number of variables that are important in understanding the groundwater conditions of an area, it is not possible to separately map and study all the variables individually during the course of the investigation. Rarely is it possible for an investigator to complete all the examinations to eliminate uncertainties and provide quantitative information about the type, thickness and depth of aquifer, its yield potential, success rate, etc with complete confidence. Varying degrees of uncertainty and inconsistency are inherent in the present methodology (conventional hydrogeological mapping). Hence, the entire procedure of mapping has to be made more systematic and simpler with well-defined units based on which better inferences can be made. For this purpose, all the variables that control the groundwater regime have been grouped into the following 4 factors -

- Geology / Lithology
- Geological Structures
- Geomorphology / Landforms
- Recharge conditions

Once, information on these 4 factors is precisely known, it is possible to understand the groundwater regime better by visualizing the gross aquifer characteristics of each unit. Systematic visual interpretation of satellite imagery in conjunction with existing geological / hydrogeological / geomorphological maps and data supported by limited field checks / observations provide the information related to these 4 factors. By integrating the lithological, structural, landform and hydrological information, the groundwater prospects map can be prepared which provide better understanding of groundwater regime as compared to the conventional hydrogeological map.

1.4.3 Role of Space Technology in Groundwater Studies

The launch of Earth Resources Technology Satellite (ERTS-1), later renamed as Landsat-1 with the Multispectral Scanner System in 1972 ushered in a new era in mapping and updating of geological, geomorphological and structural features using the optical sensors data. Subsequently, Landsat-Thematic Mapper and the India Remote Sensing Satellite (IRS-1A LISS-II) sensors have been operationally used in India to generate groundwater potential maps at 1: 250,000 scale. Remote sensing data have been widely used in groundwater prospecting. The LISS-III multispectral data from IRS- 1C and 1D satellites have been used later for preparing groundwater potential maps at 1:50,000 scale under "National Rural Drinking Water Programme". In last decade, NRSC, ISRO has developed and operationalized the methodology for village level groundwater prospects and sustainability planning on 1: 10,000 scale for major hydro-geological provinces in India under the Ground Water Recourses Assessment & Management (GRAM) project & to follow ISRO's decadal vision of making country's groundwater sustainable and provide safe and sustainable drinking water under Jal Jeevan Mission program of Ministry of Jal Shakti. Pilot studies have been planned in 9 different hydro-geological provinces. Presently, 6 pilot studies are being carried out in Granitic area, Eastern ghats, Basaltic rocks, Gondwana rocks, Vindhayan rocks and hilly terrain of North East.

In addition to optical sensors data, microwave data have also been used at experimental level for deriving information on lithology, landforms and structures. Microwave (Synthetic Aperture Radar) data have a very limited capability for direct measurement of groundwater because the depth of penetration is limited to a few centimetres except in extremely dry sand covered areas. Imaging radar data has proven to be very useful in discrimination of surface lithology buried palaeo-channels, dykes, sand-covered bed rock to a depth ranging from 1.5 to 6.0 m. Apart from optical and microwave data thermal infrared sensor data have also been used for identification of groundwater potential zones under certain conditions. Geophysical measurements, namely geo-electrical, seismic refraction and electromagnetic systems, have also been commonly used for groundwater exploration. Besides, Ground Penetrating Radar (GPR) operating in low frequency (100 to 500MHZ), nuclear magnetic resonance, magnetic and gamma ray spectrometric techniques have been tried out at experimental level for detection of shallow groundwater table, phreatic surface, crustal structures and bedrock profile.

1.4.4 Lithology mapping

The synoptic view and multispectral nature of the satellite imagery help in discrimination and mapping of different lithologic units. Geological mapping is carried out mainly based on visual interpretation of satellite images (Fig. 1.5) adopting deductive approach by studying image characteristics and terrain information in conjunction with a prior knowledge of general geological setting of the area. The tone (colour) and landform characteristics combined with relative erodibility, drainage, soil type, land use/ land cover and other contextual information observable on the satellite image are useful in differentiating different rock groups / types. The direct clue for interpretation of rock type / lithologic unit comes from the tone (colour) of the image. For example, the acidic and arenaceous (sandy) rocks appear in lighter tone as compared to the basic / argillaceous (clayey) rocks. Similarly, coarse grained rocks having higher porosity and permeability appear brighter on the image as compared to fine-grained rocks having higher moisture retaining capacity. The highly resistant rock formations occur as different types of hills depending upon their texture and internal structure; whereas, the easily erodible rocks occur as different types of plains and valleys. While dendritic drainage indicates homogeneous rocks, the trellis, rectangular and parallel drainage patterns indicate structural and lithological controls. The coarse drainage texture indicates highly porous and permeable rock formations; whereas, fine drainage texture is more common in less pervious formations. The coarse textured and light-coloured soils indicate the acidic / arenaceous rocks rich in quartz and feldspars; whereas, the fine textured and dark coloured soils indicate basic / argillaceous rocks. Thus, by combining all these evidences, it is possible to interpret different rock groups / formations. Though, one or two recognition elements, mentioned above, may be diagnostic for the identification of a particular rock type, the convergence of evidences must be considered by studying all the recognition elements conjunctively 1. However, limited field checks are a must to identify the rock types and to make necessary corrections in the interpreted map based on field evidences. Once, the rock types are identified, the contacts can be extended over large areas with minimum ground control. The identification, correlation and extrapolation of rock types are possible based on similar spectral and morphological characters.

For preparation of lithological map overlay (Fig. 1.6 b), information from the following sources is required

- Consultation of existing geological / hydrogeological maps or literature
- Interpretation of satellite imagery
- Field visits / surveys

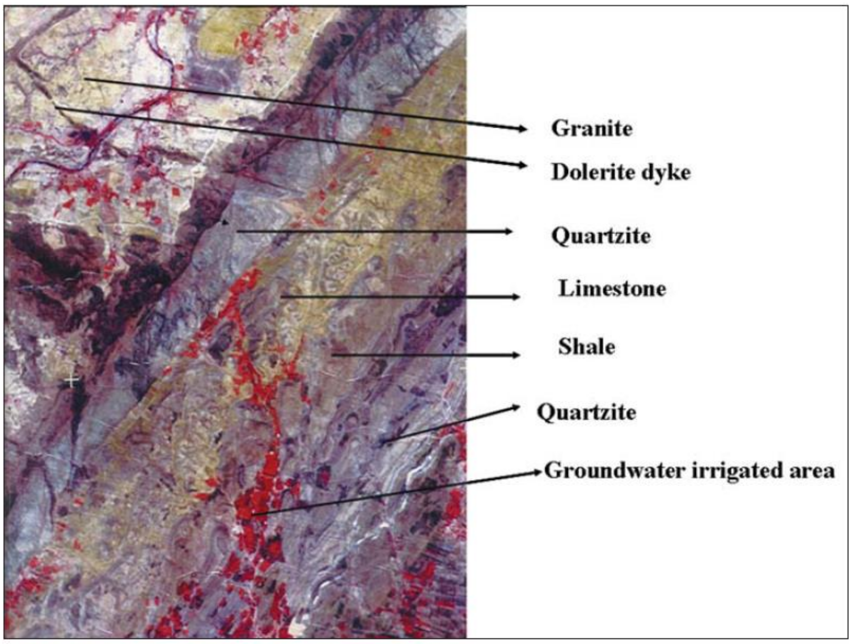

Fig. 1.9 Interpretation of Lithological assemblage from satellite imagery

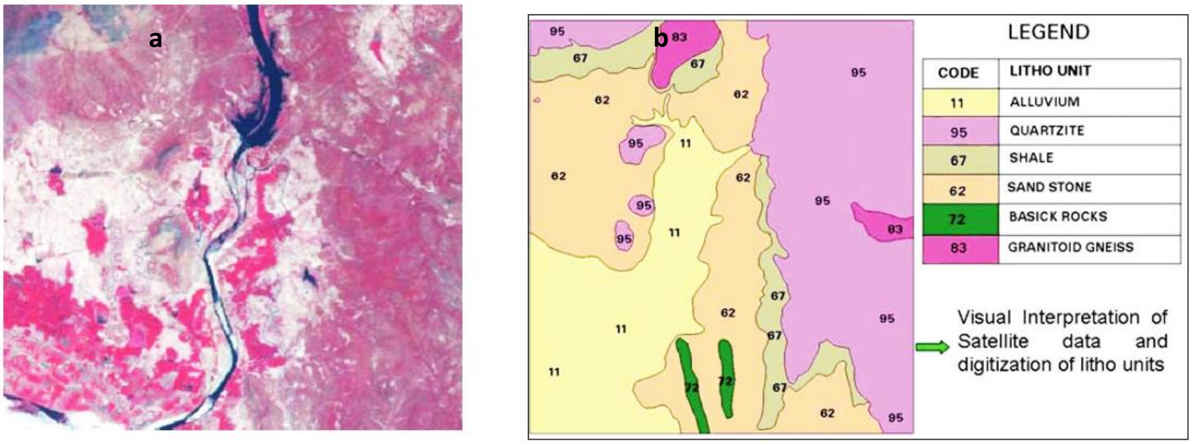

Fig. 1.10 (a) Satellite imagery of the study area and (b) Preparation of lithological map

1.4.5 Geological Structure mapping

Various workers have emphasized the utility of satellite imagery for mapping the geological structures. The synoptic coverage provided by the satellite imagery enable mapping regional structures which is difficult in conventional ground surveys due to scanty rock exposures, soil cover, lack of continuous observations, etc. The different types of primary and secondary geological structures (attitude of beds, schistosity / foliation, folds, lineaments etc.) can be interpreted from satellite imagery by studying the landforms, slope asymmetry, outcrop pattern, drainage pattern, individual stream / river courses, etc. Structural lineaments representing the faults, fractures, shear zones, etc., are the most obvious structural features interpretable on the satellite imagery (Fig. 1.7). They control the occurrence and movement of groundwater in hard rock terrain and their significance in groundwater exploration has been proved beyond doubt. They occur in parallel sets in different directions indicating different tectonic or orogenic events. They appear as linear to curvilinear lines on the satellite imagery and are often marked by the presence of moisture, alignment of vegetation, straight stream / river courses, alignment of tanks / ponds, etc. These lineaments can be further subdivided into faults, fractures and shear based on their image characters and geological evidence. The attitude of beds (strike and dip) can be estimated broadly by studying the slope asymmetry, landform, drainage characteristics, etc.

For example, horizontal to sub-horizontal beds show mesa / butte type of landform, dendritic drainage pattern and tonal / colour banding parallel to the contour lines. Inclined beds show triangular dip facets, cuestas, homoclines and hogbacks. The schistosity / foliation of the rocks is depicted on the satellite imagery by numerous thin, wavy and discontinuous lines. Folds can be identified on the satellite imagery by mapping the offset of marker horizons. Further classification into anticline or syncline can be made on the basis of dip direction of beds.

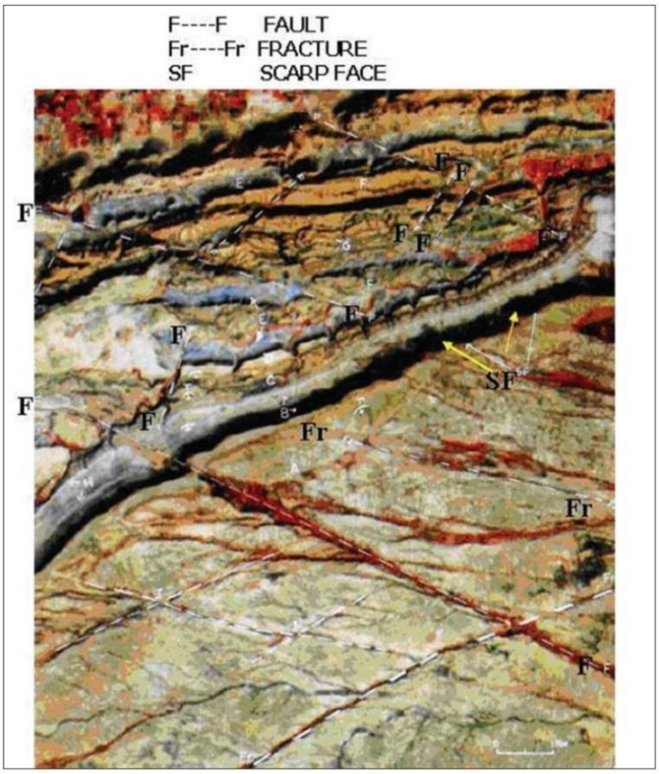

Fig. 1.11 Interpretation of structural features from satellite imagery

For preparation of structural overlay, information from the following sources is required:

- Existing geological / hydrogeological maps and literature
- Interpretation of satellite imagery
- Field visits / survey

1.4.6 Geomorphology mapping

The synoptic view of satellite imagery facilitates better appreciation of geomorphology and helps in mapping of different landforms and their assemblage. The photo-interpretation criteria, such as tone, texture, shape, size, location, association, physiography, genesis of the landforms, nature of rocks / sediments, associated geological structures, etc., are to be used for identification of different landforms / geomorphic units (Fig. 1.8 a). Initially, the entire image has to be classified into 3 major zones, i.e., Hills & Plateaus, Piedmont Zones, and Plains considering the physiography and relief as the criteria. Then, within each zone, different geomorphic units have to be mapped based on the landform characteristics, their aerial extent, depth of weathering, thickness of deposition etc., as discussed earlier. Subsequently, within the alluvial, deltaic, coastal, eolian and flood plains, individual landforms have to be mapped and represented on the map using the standard alphabetic codes. These geomorphic units / landforms interpreted from the satellite imagery have to be verified on the ground during the field visit to collect the information on the depth of weathering, nature of weathered material, thickness of deposition and nature of deposited material, etc. For this purpose, nala / stream cuttings, existing wells, lithologs of the wells drilled have to be examined. By incorporating these details in the pre-field interpretation map, the final geomorphic map overlay has to be prepared.

For preparation of geomorphic map overlay, information from the following sources is required:

- Lithological map overlays;
- Interpretation of satellite imagery;
- Field visits / surveys.

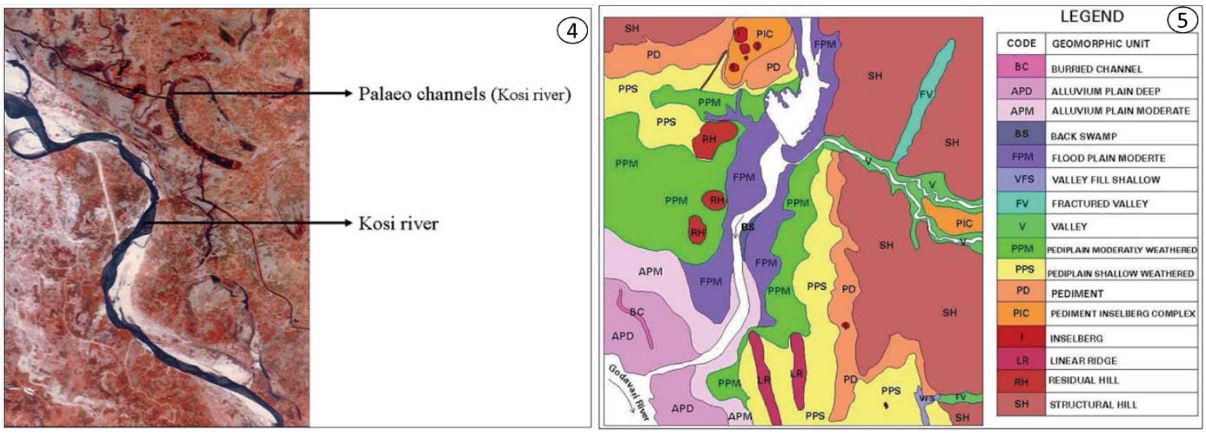

Fig. 1.12 Interpretation of Lithology from satellite imagery and Preparation of Geomorphological map from satellite imagery

If previous maps / literature are available, the job becomes easier; even otherwise also, a good geomorphological map showing assemblage of different landforms can be prepared based on the above sources of information (Fig. 1.8 b). The satellite image along with the interpreted lithological map overlay should be kept on the light table. A fresh transparent overlay should be kept on the top and each rock type should be classified into different geomorphic units / landforms as per the classification system suggested. Sometimes one lithologic unit may be classified into 2 or more geomorphic units/ landforms and vice versa. This is to note that wherever the lithologic/ geomorphic boundaries are common, they should be made co-terminus. All the geomorphic units / landforms should be labelled with alphabetic annotation as RH, PPS, VFD, etc.

1.4.7 Hydrological Mapping

Satellite imagery provide excellent information on hydrologic aspects like stream/river courses, canals, major reservoirs, lakes, tanks, springs / seepages, canal commands, groundwater irrigated areas, etc. Based on visual interpretation of satellite data, all the above information can be derived and mapped. The hydrologic information, derived from satellite imagery in conjunction with collateral data has to be shown on a separate map overlay in a classified manner with appropriate symbols. Further, the observation wells of State and Central Groundwater Departments and the wells inventoried during field visit have to be marked on this map overlay in a classified manner with appropriate symbols.

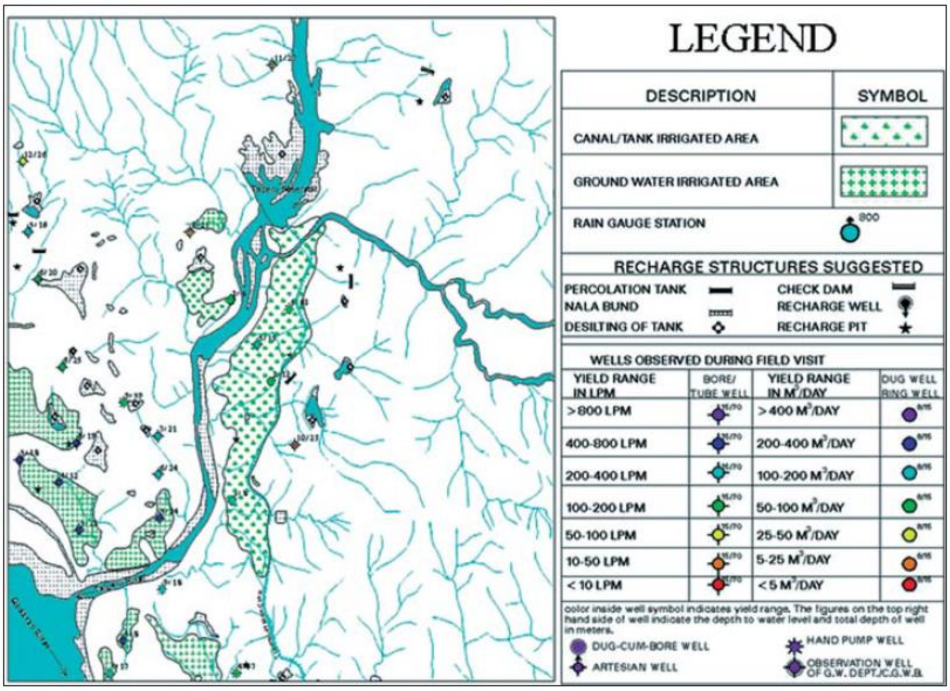

Fig. 1.13 Preparation of Hydrological map from satellite imagery

For preparation of hydrological map overlay, the following sources of information are required,

- Interpretation of satellite imagery;
- Field visits / surveys;
- Observation well data and
- Meteorological data.

The following details are shown in the hydrological map overlay (Fig. 1.9)

- Canal / tank commands;
- Groundwater irrigated areas;
- Well observation data collected in the field and Govt. Depts;
- Rain gauge stations indicating average annual rainfall.

In case of absence of rain gauge station in a Toposheet, average annual rainfall in mm shall be given in the legend. Source of rainfall data shall be either IMD or District Gazetteer.

1.4.8 Groundwater Prospects

For preparing the groundwater prospects map first integrate manually the lithological, structural, geomorphological and hydrological map overlays in the following manner: Integrate lithologic-geomorphic units by superimposing the lithological and geomorphological map overlays. These integrated lithologic-geomorphic units are the 'hydrogeomorphic units' and have to be annotated with alphanumeric codes, e.g., PPS-71, PPD-81, UPM-32, etc. wherein the alphabetic code represents the geomorphic unit and the numeric code represents the lithologic unit. Hydrogeological and geo-environmental controlling variables geomorphology, lineament density (LD), lithology, landuse/groundwater irrigated area, slope, drainage density (DD) and rainfall are used as these variables primarily control groundwater storage, occurrence and movement. Lithology boundary is modified to 1:10,000 scale based on the image interpretation, DEM derivatives (LSCs) and hand specimen analysis and field observations. Fourth level of geomorphological classification is introduced based on the objective, application and delineation of micro-geomorphological landforms. Statistical analysis of well inventory data is carried out to understand the groundwater regime and province wise behavioral differences. Aquifer characteristics and health is assessed through ground water exploitation data from the field and satellite images. Long term rainfall analysis was carried out to understand run-off and recharge conditions. Aquifer sustainability management plan is prepared at village level.

All the hydrogeomorphic units occurring in the area have to be listed in the legend following the geological sequence. Then, the groundwater prospects of each hydrogeomorphic unit have to be evaluated by considering the lithological, structural, geomorphological and hydrological information (Fig. 1.14).

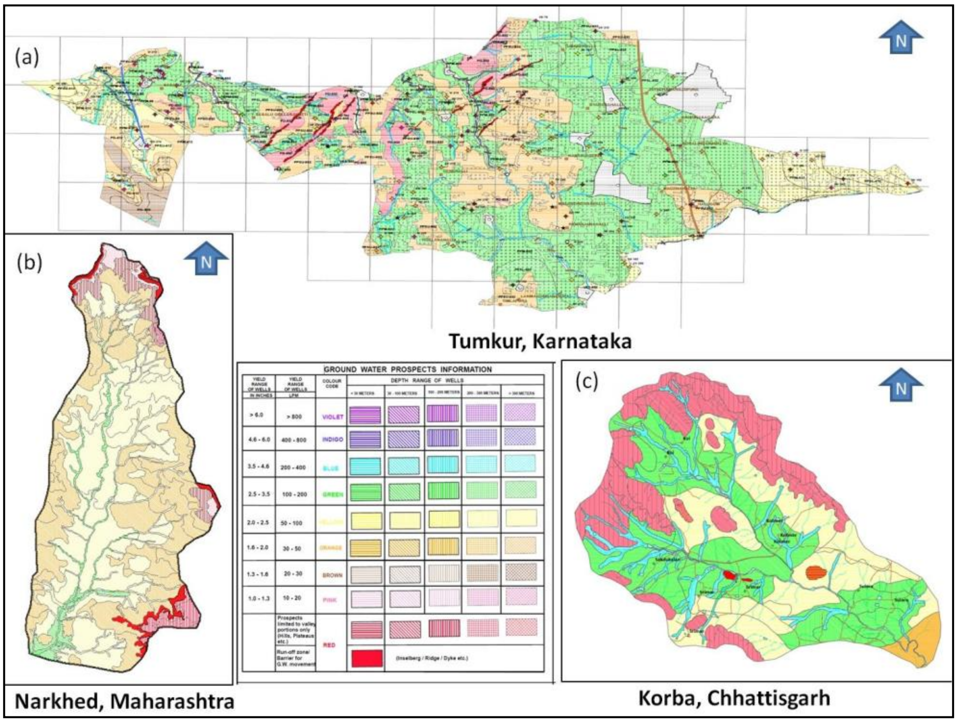

Fig. 1.14 Village level groundwater prospects map of (a) JCPura, GP, Karnataka, (b) Narkhed, Maharashtra, (c) Korba, Chhattisgarh (Maps are not to scale)

D. Landslide Hazard Assessment

Landslides are one of the prominent natural hazards which are triggered either by natural phenomena, such as extreme rainfall, earthquakes and volcanic eruptions or by human activities, such as quarrying and road construction. This is especially true in high relief areas of young mountains, which experience recurring landslides and slope failure phenomena due to geological reasons, climatic conditions and extensive human interference.

Earth Observation from remote sensing satellites can provide authentic and timely information on extent of landslides in a cost effective and timely manner. It also provides information on causative factors such as rock type, geomorphology, geological structure (fold, fault, joints etc.) land use, vegetation cover etc. Aerial photographs and high-resolution satellite images have been used extensively to map, monitor and predict landslide hazard prone areas in different mountainous regions of the world. The major application of RS in landslide related studies include detection and direct mapping of landslides and associated mass wasting features, monitoring of existing landslides using optical and DInSAR based methods; derivation of information on causative factors of landslides.

Fig. 1.15 IRS-PAN image of Uttarkashi before landslide, after landslide and PAN image

E. Engineering Geology

Engineering geologic investigations and mapping aim at providing basic information for planning optimal land use as well as design, construction and maintenance of Civil Engineering works. The information provided greatly helps to assess the feasibility of the proposed site for engineering structure, and consequently in adopting suitable design parameters. For proper planning, an important phase of any geo-engineering project is to collect, measure and record the data pertaining to physical characteristics of the project area. The preliminary information provided by terrain investigations forms an essential element of the initial planning stage of a project and is useful for solving technical problems. Remote sensing in the form of aerial and satellite photographic, scanning and processing systems has proved to be one of the most appropriate means of recording existing ground conditions, assessing their potential for engineering project, and also of evaluating the effect or potential effects of the subsequent construction activity on the environment. It greatly aids engineering geological mapping which is mainly directed towards understanding the inter-relation between geological environment and the engineering situation, the active geodynamic processes and the prognosis of processes likely to result from changes being made due to construction activities.

The multifaceted thematic information may be varied in nature depending upon the objective of engineering geological surveys, like location of construction materials, site selection for settlements, dams, airstrips, route alignment studies for railways, road, tunnel or canals, slope stability analysis etc. Remotely sensed data, when used judiciously and properly interpreted provides valuable information for a variety of engineering geological studies for development projects. Remote sensing techniques are now routinely used in engineering geological geotechnical investigations. A great value of remote sensing data in such cases lies in their synoptic view, which can be highly useful in predicting likely engineering geological problems and hazards, and suggesting alternative possibilities and solutions. Moreover, repetitive satellite coverage provides vital data on geo-environmental changes with time. Usually, different stages of engineering investigations require data on different scales and the present-day remote sensing techniques can readily supply inputs on the various scales required. The geological features to be studied depend on the type of engineering project – the commonly required parameters being landform, topography, drainage, lithology structure, orientation, soil, surface moisture and weathering properties.

For example, in reservoir of Bhakra dam, do dealt with the problematic silt-laden water, major silt hazard zones in the reservoir on the basis of multiple converging evidence observed on the remote sensing images has been located.

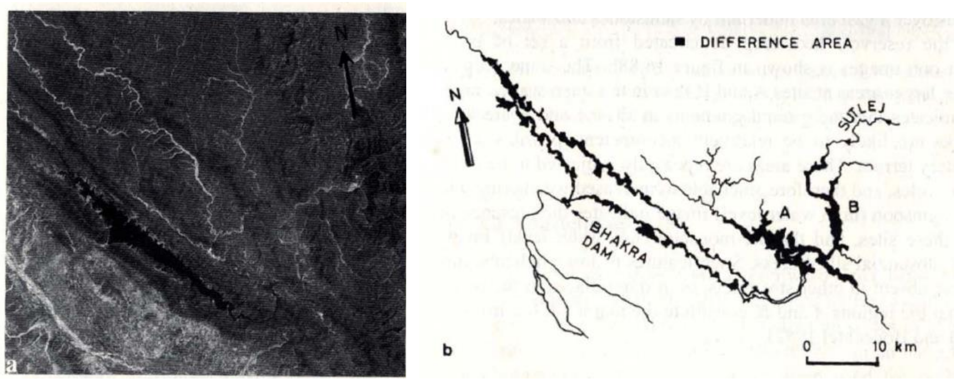

Fig. 1.16 Landsat MSS2 (red-band) image of the Bhakra dam reservoir in the sub-Himalayas. Note the turbid water and sub-dendritic drainage in broader valley sections, at A and B (locations shown in b). b Temporal variations in reservoir lake area; the difference area is marked from a set of post-monsoon and pre-monsoon images. Regions A and B are identified as silt problematical zones.

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Chapter 2

AGRICULTURE AND SOIL

2.1 Introduction

Effective monitoring of crop growth and health, along with timely interventions, is essential for enhancing crop productivity while minimizing environmental impact. This will ensure the optimal utilization of key resources and inputs for crop production. Technological advancements have the capability to revolutionize our approach to agriculture and mitigate climate change's impact on food security. Recent decades have seen a significant increase in the application of geospatial tools for diverse applications in agriculture at local, regional, national, or global scales. These applications most often involve the use of Geographic Information System (GIS) along with partner technologies such as Remote Sensing (RS), Global Positioning System (GPS), and data analytics towards an in-depth understanding of a given farm or a region and facilitating intervention or corrective measures for the crops and/or the soils.

Agriculture and allied sectors are the economic engine for India as more than 60% population livelihood directly and indirectly depend on it. After the era of green revolution, food security for all citizen is a prime focus for all government agricultural polices to feed the growing population. This requires sustainable growth of agriculture to safeguard our existing natural resources. The sustainable resource planning necessitates continuous assessment and monitoring of the natural resources and the impact of the change on agricultural production so that intervention could be made to improve the production through proper management and remedial strategy. The rapid development in the field of geospatial technologies especially the RS and GIS play a key role to the sustainable management of natural resources through extraction of the precise and desired information to save the costly and infinitive natural resources for the future generation. Remote sensing data at the optical, microwave, thermal, and hyperspectral domain has proved to be a powerful tool to assess the crop and soil properties in varying spatial and temporal scales with cost-effectiveness. The adoption of Geospatial Technologies encompassing techniques and tools related to RS, GIS, GPS, advanced data processing, Information Technology (IT) can pave way for significant improvements in efficiency of input-use, resulting in cost savings on inputs and precious resources.

Geospatial tools are being used and proved to be efficient and cost effective for soil resource mapping in digital form, generation of Soil information system, and spatial soil property assessment. It can also be effectively used for monitoring soil environmental degradation, quality assessment at different spatial scale over a large area. Geospatial applications also have proven to be a game-changer in the field of Agri-informatics. In the field of Agri-informatics the geospatial tools can be used for crop monitoring including crop classification, crop health monitoring, crop nutrient management, irrigation water management, crop stress monitoring. crop yield mapping etc. In addition, it is of enormous importance for precision agriculture and supply chain management.

One of the major apprehensions for the agriculture and the farming community is increase in crop losses due to erratic and anomalous weather. Agrometeorology link the complex system of soil plant atmosphere continuum (SPAC). The developed understanding of exchange processes using geo-spatial technology provides reasonable operational applications and recommendations for farming community. To improve the quality and coverage of current advisory framework for farmers require near real-time assessment of crop and soil condition. The advances in the spectral sensing through polar and geostationary satellite provide an opportunity to capture the near real-time synoptic continuous coverage of crop condition throughout the crop season. This open up a new pathway to enhance the scope of agro-meteorogical advisory services to farmers by integrating the satellite derived agro-meteorogical products and value-added products in the current framework to address location specific advisory.

Forecasting Agricultural Output using Space, Agro-meteorology, and Land-based observations (**FASAL**) and National Agricultural Drought Assessment and Monitoring System (**NADAMS**) are operational programs in India that utilize remote sensing and other data sources for agricultural monitoring and drought management. FASAL focuses on providing accurate agricultural production forecasts by integrating satellite data, agro-meteorological information, and ground observations. This helps in crop planning, pest management, and ensuring food security. NADAMS, on the other hand, aims to monitor agricultural drought conditions and provide early warning systems to farmers and policymakers. It combines remote sensing data, meteorological information, and ground-based observations to assess drought severity and implement mitigation measures. Both programs demonstrate the effective use of remote sensing in supporting agricultural practices and managing the challenges posed by climate variability.

Crop insurance schemes such as the Pradhan Mantri Fasal Bima Yojana (**PMFBY**) and the Yield Estimation Crop Insurance Scheme (**YES-TECH**) are vital initiatives in India that utilize remote sensing technology. PMFBY integrates satellite imagery to assess crop conditions and losses, enabling accurate claim settlements. YES-TECH leverages remote sensing data for yield estimation and insurance coverage determination. These schemes provide financial security to farmers by mitigating the risks associated with crop losses caused by various factors. By incorporating remote sensing, these programs enhance the accuracy and efficiency of assessing crop conditions, estimating yields, and facilitating insurance coverage. Ultimately, they contribute to promoting sustainable agricultural practices and supporting the livelihoods of farmers.

Understanding the importance of using geospatial tools and techniques for these four important contributors (Soil resource mapping, Agri-informatics, Soil environmental monitoring and Satellite agrometeorology) of food security and sustainable production system is the need of the hour. Hence, this chapter on 'Application of geospatial technology for agriculture and soil' contains four sub-sections each on these four topics. Authors have highlighted the use of all geospatial tools (RS, both aerial and satellite, GIS, GPS, IT and IoT along with various modeling approaches to assess crops and soils. The objective of this chapter is to document the applications of space-based technologies for agriculture and soil assessment for sustainable development of agriculture. In general, this is suitable for students, researchers, agronomists, soil scientists, environmentalists and policymakers.

2.2 Application of Geospatial Technology in Soil Resource Mapping

Soil is a natural body consisting of layers (soil horizons) that are composed of weathered mineral materials, organic material, air and water (Bockheim et al., 2005). The proportion of each of these components together with other factors such as climate, vegetation, time, topography, and, increasingly, human activities are important in determining the type of soil at any location in a landscape. For a long time, scientists have endeavoured to develop appropriate and efficient methods for predicting the spatial distribution of soils and their occurrence in the landscape. Soil mapping is the term often used to describe the process of understanding and predicting the spatial distribution of soils. It is a process that involves collecting field observations (including recording soil profile descriptions), analysing soil properties in the laboratory, describing landscape characteristics, and, ultimately, producing soil maps. Soil resource inventories describe the types, attributes and geographic distributions of soils in a given area. Soil mapping has traditionally involved the development of a conceptual understanding of soil forming processes, which is applied to predict the spatial distribution of classes of soil. Often, descriptive and diagnostic soil profile characteristics are used to classify soil at sampled locations (Hole and Campbell, 1985; Boul et al., 1997). Soil maps developed by the conventional approach are generally hard copy maps and therefore are not easily accessible to end users. Moreover, mapping units of these maps are delineated based on soil profile data and surveyor's field experience. These mapping units sometimes represent quite a large area in the field, and thus soil properties of interest vary considerably within a unit. With the advancement of geostatistics and abundant availability of digital information on earth features, there is a possibility to map soil properties utilizing available soil data and auxiliary information on earth features and environmental variables. Through this approach, available legacy soil data may be converted to digital products for its better accessibility and utility. Moreover, in the context of digital India and soil health missions, it is timely and apt to prepare the digital soil maps for different regions of the country.

2.2.1 Methodology for Standard soil survey and mapping

Standard soil survey helps to gather information about soil in a systematic manner regarding their genesis, extent, potentiality, limitations and to predict their behaviour for specific purpose and classify them. Standard soil survey and mapping involves the following steps.

1. Preliminary reconnaissance of the area to investigate the major soils and their pattern of occurrence.
2. Procurement of required base maps. Aerial photographs, satellite imagery and topographical maps are useful references and used as mapping base.
3. Preparation of mapping legend based on the preliminary field studies.
4. Stereoscopic study of aerial photographs and satellite imagery for the identification and delineation of land forms (hills, valley, terraces, flood plains, coastal plains, sand dunes etc.) based on the differences in tone, relief, vegetation etc.
5. Plotting of soil boundaries, mostly by RS data and verified by observations.
6. Classification of soils and naming of map units
7. Preparation of final legend and finalization of soil map.

2.2.2 Components of soil resource

The soil resource consists of

1. Site characteristics such as geology, geomorphology, drainage, slope, erosion, land use, natural vegetation, depth of ground water table, stoniness, gravelliness, presence of salt;

2. Morphological properties such as horizon thickness, colour, mottles, texture, structure, calcareousness, concretions, abundance and size of roots and pores, permeability, presence of clay films/ slicken sides; and
3. Horizon wise analytical properties like soil physical properties including soil texture, structure, consistency under dry, moist and wet condition, bulk density, moisture capacity at field capacity and permanent wilting point.

Chemical property such as pH, EC, CaCO3, organic carbon, total Nitrogen, CEC etc. The description of these profile and site characteristics that are used as criteria for placing different soil under various taxa in Soil taxonomy are described in Soil Survey Manual (Soil Survey Staff,1993).

2.2.3 Use of remote sensing (RS) in soil resource mapping

Remote sensing is the acquisition of information about an object or phenomenon, without making physical contact with the object. It involves sensing or detection of electromagnetic radiation (EMR), which are either reflected or scattered or emitted by an object. It includes both aerial photography and images from satellite sensors.

- **Use of aerial photograph in soil mapping**

Among the different aerial photograph, black and white, colour and colour Infra-red (CIR) aerial photographs are used in soil mapping. Aerial photographs with a scale of 1: 40,000 to 1: 60,000 for reconnaissance soil mapping and 1: 10,000 to 1: 25,000 for detailed soil mapping are used. Aerial photographs permit 3D view through stereoscopes and hence slope, drainage pattern, natural features like hills, valleys and plains can be easily distinguished in a given geological formation. Sub divisions of landform (hills, pediment, Pedi plain valley, alluvial plain etc) can be delineated using photo elements (slope, erosion, tone, texture, density of reservation, land use etc.). Physiographic units for each land form are identified. The physiographic units are studied in detail for the soil composition.

- **Use of satellite RS for soil resource mapping**

Satellite remote sensing data has emerged as a vital tool in soil resource survey and generation of information, which help to evolve the optimum land-use plan for sustainable development at scale ranging from regional to micro levels. Earth orbiting satellites equipped with sensors including cameras provide both analog and digital data. The sun's energy commonly referred as electromagnetic spectrum (EMS) is an EMR that moves with constant velocity of light characterized by wave length and frequency. Non-photographic sensors perceive the part of EMS from ultraviolet (UV) with wavelength less than 0.38 µm through microwave with wavelength more than 100cm. Different remote sensing techniques use different wavelengths of energy such as Visible (0.4-0.7 µm), Infrared (0.7-3 µm), Thermal infrared (3-5 and 8-14 µm) and Microwave (0.1-30 cm) regions of EMS to collect information about various objects on earth's surface. Whichever the RS technique, the general principle involves acquisition of the characteristic of an object through radiations, which have been reflected or emitted by the object. Imaging from space has two main advantages - Information over a large area and repetitive information of the same area on a regular basis that enables repeated collection of data for the same area at the same local time. It can be used for semi-detailed or reconnaissance survey of a district or a region for planning. The surface features reflected on satellite image provide enough information to accurately delineate the boundaries, which is accomplished effectively through systematic interpretation of satellite imageries. The properties of the soils that govern the spectral reflectance are colour, texture, mineralogy, organic matter, free carbonates, moisture and oxides and hydroxides of iron and manganese (Baumgardner et al., 1985). The dynamic inter-relationship between physiography and soils is utilized while deriving information on soils from satellite data (Kudrat et al., 1992).

Satellite imageries at 1:1 million, 1: 250,000, 1: 50,000 and 1: 25,000 scales are available for generating soil maps for different levels of planning (Arunkumar et al., 2020). Digital image processing using supervised classification and unsupervised classification under maximum likelihood function are employed for soil mapping. In supervised classification, training sets (cluster of pixels with known composition after field work) are engaged in generation of soil maps. In case of unsupervised classification, cluster map showing the pixels with similar digital number (DN) is prepared. Fieldwork to assess the soil composition is carried for each cluster. This ground truth information is then fed into the computer to generate soil maps.

2.2.4 Soil Information System (SIS) and role of Geographical Information Systems (GIS)

SIS is a computerised database system containing a wide range of information on soil and related land. It is a system where soil and related data can be organized, stored, retrieved, analysed and processed to make it accessible to the end user in form of maps and table. SIS is based on a database obtained through RS and ground survey in combination with GIS and Decision Support System (DSS). Initially the mapping was carried out manually and the generated resource maps were overlaid to study the soil resources in an integrated form. Later with the advent of GIS technology this interpretation is being carried out by more efficient computers. The voluminous data provided by satellite imageries both in analogue and digital format reinforced the use of computers. The various sources of locational information give us spatial data in different scale, time and format. This spatial data with location and shape of features along with its descriptive information in form of attributes are integrated to derive meaningful interpretation and assist the user for planning using the GIS tool. The concept of SIS is depicted in Fig. 2.1.

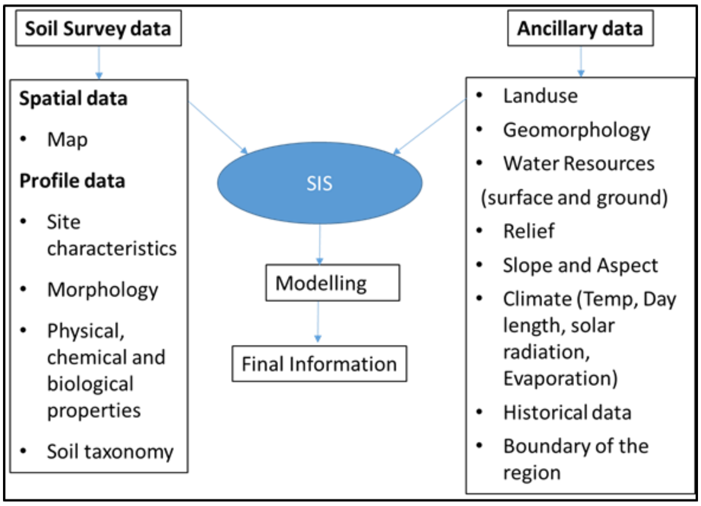

Fig. 2.1 Soil information system (SIS)-Concept (ref: Fundamentals of Soil Science, 2002)

SIS helps in easy handling of voluminous data; Reproduction of maps derived suitability and other interpretative maps; Linkage with other georeferenced coverage to generate new composite overlays; Cost effective and time-saving periodic updating of map/information and quick monitoring and impact assessment of development measures. All of these make the SIS a useful tool for generating action plan and its implementation for land resource management of a region or watershed.

2.2.5 Digital Soil Mapping (DSM)

DSM evolved from the state-factor soil forming paradigm developed by Jenny (1941) for describing the relationship between soil formation and distribution. In this paradigm, the soil profile characteristics are governed by climate, organisms, relief, parent material, and time, which are known as soil forming factors. If the relationship between soil profile characteristics and soil forming factors is known, as well as the distribution of soil forming factors, then the distribution of soil profile characteristics can be inferred (or predicted) from the distribution of soil forming factors. In early soil mapping activities, the empirical relationship between soil profile characteristics and soil forming factors was related to Jenny's equation and was implemented by surveyors/pedologists using conceptual soil-landscape relation models (Hudson, 1992). Improvements in technology for data capture coupled with computational advances have helped to improve predictive soil mapping. Soil maps and spatial soil information systems can now be created by mathematical models that account for the spatial and temporal variations of soil properties based on soil information and environmental surrogates of soil forming factors. This is the new paradigm in soil mapping (McBratney et al., 2003). It relies on quantitative relationships between easily measured and extensive environmental covariates and more difficult to measure and less extensive observations of soil attributes to predict the soil attributes in locations for which direct measurements/observations were not made. The results of such quantitative prediction eventually help to populate the target geographic area (at a given spatial interval, which is known as pixel size/resolution) with the soil information.

Stages in DSM

The DSM process characteristically involves three stages (Fig. 2.2). Stage I is concerned with development and assessment of inputs; Stage II is where the choice of methods and tools is made; and Stage III is where the spatial inference system is developed and applied.

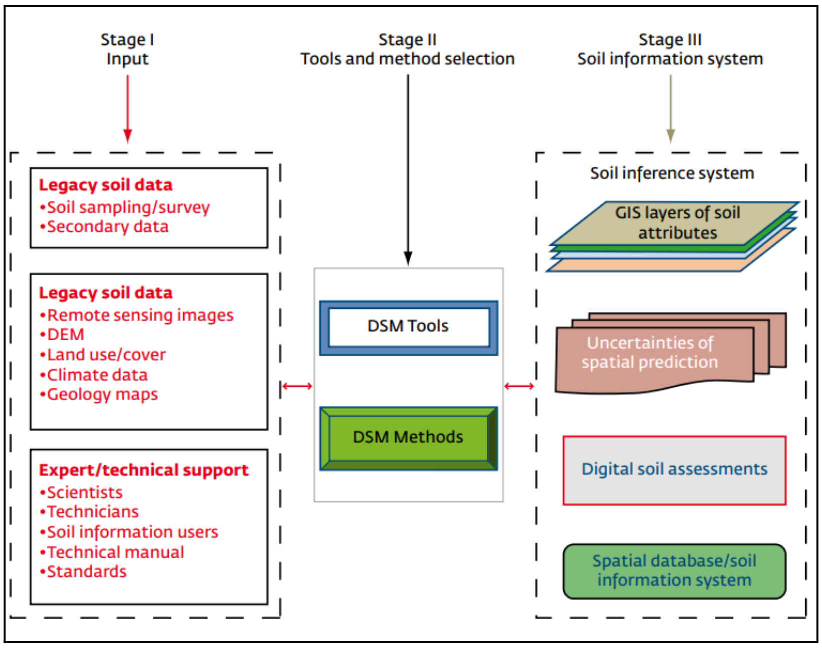

Fig. 2.2 Processes in DSM (Omuto et al., 2013).

Spatial prediction methods for DSM

All spatial prediction methods can be categorized into three broad groups: non-geostatistical, geo-statistical, and mixed methods. Non-geostatistical methods include, Nearest neighbours, Simple kriging, Universal kriging, Inverse distance weighting (IDW), Ordinary kriging, Kriging with an external drift, Regression models, Block kriging, Cokriging, Natural neighbours, Triangular Irregular Network (TIN), Trend surface analysis, Splines, Classification and regression trees, Kalmer filters, Bayesian Maximum Entropy etc. Statistical methods include Factorial kriging, Principal component kriging, Indicator kriging, Multivariate factorial kriging, Disjunctive kriging etc. Mixed method includes, Regression kriging, Linear mixed model, Trend surface analysis combined with kriging, Regression trees combined with kriging, Classification combined with other interpolation methods, Bayesian Maximum Entropy etc.

2.2.6 Global soil mapping initiatives

Global soil mapping initiatives aim at developing soil maps, harmonizing and coordinating global soil information systems, and archiving and disseminating world soil databases.

1. Globalsoilmap.net (www.globalsoilmap.net): It is a global consortium that has been formed to make a new digital soil map of the world using state-of-the-art and emerging technologies. This new global soil map will predict soil properties at fine spatial resolution (~100 m). This is an initiative of the Digital Soil Mapping Working Group of the International Union of Soil Sciences (IUSS).

2. Global Soil Information Facilities- ISRIC: The ISRIC's data products include the SoilGrids 250m, predictive maps of soil properties and classes, their generalizations to 1km and 5km resolutions, the WoSIS Soil Profile Database and the WISE v3.1 harmonized Global Soil Profile Dataset.

2.2.7 Digital database on soils of India

Some available digital soil databases of India are, Soil and terrain digital database (SOTER), National natural resource information system (NRIS) by the Department of Space, Govt, of India, National informatics centre (NIC) by the planning commission, Agricultural resource information system (AGRIS) by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP).

2.2.8 Soil site suitability assessment

Soil site suitability assessment is a crucial step in agricultural planning and decision-making. Geospatial technology plays a significant role in analyzing soil characteristics and determining the suitability of a site for specific crops by integrating various data sources, creating detailed soil maps, conducting spatial analysis, applying multi-criteria evaluation techniques, and supporting decision support systems. These capabilities enable farmers and agronomists to identify suitable areas for crop cultivation, optimize resource allocation, and make informed decisions regarding land use and agricultural practices. Geospatial analysis enhances the efficiency, accuracy, and sustainability of crop area site suitability assessments, contributing to improved agricultural planning and management.

2.2.9 Future thrust areas

Information on spatial and temporal variations in soil properties are required for use in conservations efforts, climate and ecosystem modelling, as well as engineering, agricultural, forestry applications, erosion and runoff simulations. Conventional soil sampling and laboratory analyses cannot efficiently provide the needed information, because these analyses are generally time consuming, costly, and limited in retrieving the temporal and spatial variability. The application of geospatial technologies and tools, has been universally recognized as a highly effective and inevitable tool for soil resource mapping in digital form.

Currently, the soil science community is limited in its capacity to provide accurate and updated information to the different soil users. Rich soil information is available in various national and regional soil mapping/information systems organizations. Coordination or understanding are the only ways to associate them with global mapping initiatives that use geospatial technology.

2.3 Geospatial technology for Agri-informatics

Geospatial applications refer to technologies that use location-based data to provide insights and solutions (Kumar & Joshi, 2018). The integration of geospatial applications and Agri-informatics can enhance decision-making, increase productivity, and improve sustainability. For example, the use of GIS software can help to map crop health, optimize irrigation and fertilizer use, and monitor and manage pests and diseases (Singh et al., 2020). RS can provide early warning of crop stress, monitor crop growth and development, and assess soil properties and water availability. GPS can enable precision farming, track and optimize the movement of vehicles and machinery, and monitor and control pest and disease outbreaks (Thenkabail & Knox, 2016). Unmanned Aerial Vehicles (UAV) can provide high-resolution images of crops and fields, which can be used to assess crop health, detect weeds, and count plants. RS data can be combined with ground-based data such as soil moisture measurements to provide more accurate information on crop stress factors. By combining these data sources, farmers can make more informed decisions about when to apply irrigation or fertilizer, and in what quantity.

Components of Agri-informatics

Agri-informatics involves crop monitoring that include crop classification, stress detection, crop yield mapping; precision agriculture and supply chain management. Geospatial tools and techniques are of enormous importance when large area crop monitoring is required at different spatial scale, for variable rate application of fertilizer and irrigation in precision farming. The methodology with few practical applications are given in separate section for each of these Agri-informatics component.

Crop monitoring

Satellite data have been used to track a variety of elements of vegetation monitoring, including but not limited to: crop classification and assessment of crop acreage, estimation of biomass and yield, monitoring and detection of crop stress and assessment of crop phenology.

2.3.1 Crop Classification

Crop classification using RS is a technique that uses satellite or drone data to identify and map different types of crops across a field or region. RS data can be used to distinguish between different crops based on their spectral characteristics. Each crop has a unique spectral signature, which can be identified using algorithms that analyse the reflectance of different wavelengths of light. Optical and microwave sensors play a vital role in crop classification, providing valuable information about vegetation characteristics and crop types. The combined use of optical and microwave sensors provides complementary information for crop classification. Optical sensors excel in capturing detailed spectral information, identifying crop types, and assessing vegetation health. On the other hand, microwave sensors are effective in penetrating vegetation canopies, providing structural information, and mapping soil moisture content. Integrating data from these sensors enhances the accuracy and reliability of crop classification, allowing for improved agricultural management, yield estimation, and precision farming practices. The most common approach for crop classification using RS is different types of supervised classification, including maximum likelihood, support vector machines, random forest (RF) and decision trees. These algorithms use statistical techniques to assign each pixel in the RS data to a specific crop type. Another approach for crop classification using RS is unsupervised classification. This involves clustering the pixels in the RS data based on their spectral characteristics, without prior knowledge of the crop types present. The resulting clusters can then be interpreted to identify different crop types. Crop classification using Sentinel 1 SAR data and RF classifier is depicted in Fig. 2.3.

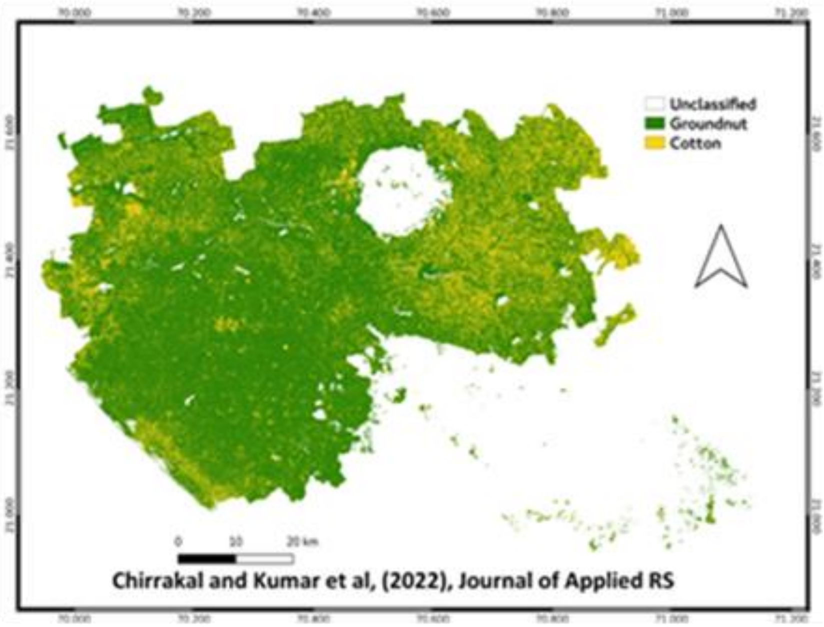

Fig. 2.3 The classified crop map for Junagadh district of Gujarat

2.3.2 Crop Yield Mapping

Pre-harvest prediction of a crop yield may prevent a disastrous situation and help decision-makers to apply more reliable and accurate strategies regarding food security. RS helps in large area yield estimation at different spatial scale using multispectral and hyper spectral data, radar and LiDAR data.

There are several techniques for crop yield mapping using RS such as:

1. Statistical empirical models that use spectral vegetation indices such as the normalized difference vegetation index (NDVI) or Enhanced Vegetation Index (EVI) or spectral profile characteristics, as the independent variable. Weather based regression model are also used for crop yield estimation where the weather data is derived from satellite input.

2. RS based semi-physical models that uses mostly input data from satellite RS for crop yield estimation. The Input data for the semi-physical model for crop yield estimation are maximum radiation use efficiency (RUE max), photosynthetically active radiation (PAR), Fraction of absorbed PAR by the crop (FAPAR), temperature scalar, water scalar and Harvest index of the crop (Tripathy et al., 2021). Cotton yield map using this technique is given in Fig. 2.4. The process-based crop

simulation models simulate the crop biophysical processes that govern crop growth and development, such as photosynthesis, respiration, and transpiration, as well as the interactions between crops, soil, and the environment. RS data from space aids in getting the intensive input data required by the crop simulation model for yield simulation at different spatial scale and over large region. There are several crop simulation models available for yield estimation, including the widely used WOFOST (WOrld FOod STudies), DSAAT series of models including CERES (Crop Environment Resource Synthesis), CropSyst, Infocrop etc (Singh et al., 2008). Input for any crop simulation model include Daily weather data (temperature, rainfall, solar radiation, wind speed, relative humidity); Soil data (soil type, texture, soil moisture, and nutrient availability); Crop Parameters (Phenology, morphology, physiological parameter); Management parameters (planting date, irrigation, fertilizer application, etc). A crop biophysical parameter like leaf area index (LAI) derived from satellite data can be assimilated in the crop CSM through different techniques such as forcing for correcting the simulated growth curve as per the actual condition of the crop. Some of the weather data also can be assimilated in the weather database required by the CSM.

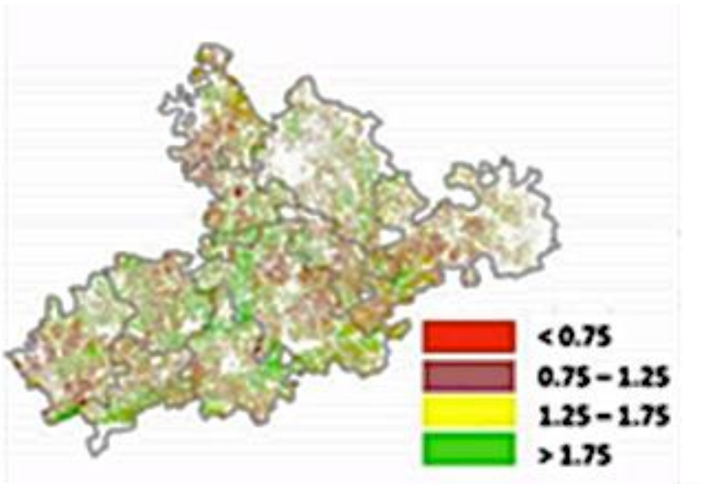

Fig. 2.4 Estimated seed yield of cotton (t/ha) in Rajkot district of Gujarat using Semi-physical model

3. AI-ML based approaches involve the use of machine learning algorithms and techniques to analyse and model the relationships between input data (such as weather, soil, and management practices) and crop yield output. The advantages of AI-ML based approaches for crop yield estimation include their ability to account for the non-linear behaviour of the relationship between the crop yield and the factors of crop production. However, this requires large good quality training dataset at the required spatial scale (Kumar et al. 2020).

2.3.3 Crop Health Monitoring

The objective of crop health monitoring is to detect early signs of abiotic stress like water and nutrient stress or biotic stress like disease in crops. The most common sensors used for crop health monitoring are multispectral sensors that capture data in different bands of the electromagnetic spectrum, including visible, near-infrared, and thermal infrared (Idrees & Hussain 2020). The data captured by these sensors is used to generate spectral indices that are indicative of crop health. The most widely used spectral index for crop health monitoring is the NDVI. In addition to NDVI, several other spectral indices are used for crop health monitoring, including the EVI, the green chlorophyll index (GCI), and the normalized difference water index (NDWI). These indices capture different aspects of crop health, including biomass production, chlorophyll content, and water stress.

2.3.4 Precision Agriculture

Precision agriculture is a farming management approach that uses geospatial technology, to optimize crop production and reduce waste. Geospatial technology, allows farmers to create detailed maps of their fields and crops, and apply inputs such as fertilizers and pesticides more precisely (Gebbers & Adamchuk, 2010; Zhang et al., 2018). As the global demand for food continues to rise, precision agriculture is becoming increasingly important, and its applications are expected to continue to expand in the coming years. Unmanned Aerial Vehicles (UAVs), commonly known as drones, are emerging as an important component in precision agriculture, particularly when combined with other technologies like Internet of Things (IoT) sensors. The integration of UAVs and IoT sensors in precision agriculture enables farmers to gather detailed, real-time data on crop conditions, environmental factors, and field variability. This data-driven approach enhances decision-making, improves resource efficiency, and promotes sustainable agricultural practices. By leveraging UAVs and IoT sensors, farmers can implement precision agriculture techniques, reduce inputs, minimize environmental impacts, and increase overall crop productivity.

2.3.5 Geospatial Technology in Supply Chain Management

Geospatial technology can be used to track the location of trucks and other vehicles carrying agricultural products, providing real-time information about their location and estimated arrival times. This information can be used to optimize logistics and reduce the risk of spoilage or damage to products. GPS technology can be used to track the location of vehicles carrying agricultural products. This technology can be integrated with logistics software to provide real-time information about the location and status of shipments. This information can be used to optimize delivery routes and reduce transportation costs. In addition to tracking the location of shipments, geospatial technology can be used to monitor the environmental conditions that affect product quality. For example, sensors can be used to monitor temperature, humidity, and other environmental factors that can affect the quality of agricultural products during transportation (Mishra & Mishra, 2017). By monitoring environmental conditions, supply chain managers can take corrective action to prevent spoilage or damage to products. Geospatial technology can also be used to monitor inventory levels and track the movement of products through the supply chain (Srinivasan et al., 2020).

2.3.6 Limitations of Geospatial techniques for Agri-informatics

Geospatial techniques rely on data from a variety of sources, including satellite imagery, weather stations, and ground-based sensors. The accuracy and resolution of these data sources can vary significantly, which can affect the accuracy of the results obtained from geospatial analyses. Secondly, geospatial data is often voluminous, heterogeneous, and complex, making it difficult to analyse and interpret, hence requires specialized knowledge and expertise in RS, GIS, and statistical methods. Third limitation of geospatial techniques for Agri-informatics is the cost of the technology.

2.3.7 Future thrust areas

Geospatial applications have proven to be a game-changer in the field of Agri-informatics. This has enabled farmers and other stakeholders to make data-driven decisions that improve agricultural productivity, reduce environmental impacts, and enhance food security. Geospatial applications have also facilitated the development of precision agriculture, a farming approach that uses real-time data to optimize inputs and outputs. The future of geospatial applications in Agri-informatics looks promising, with several potential research areas to explore. Hyperspectral imaging and thermal imaging can provide more detailed information on crop health and yield. Artificial intelligence and machine learning can be used to analyse geospatial data and predict crop yields, pest infestations, and disease outbreaks. The development of open-source geospatial tools can make these technologies more accessible and affordable for farmers and other stakeholders, particularly in low- and middle-income countries. In conclusion, geospatial applications have transformed the way we manage agriculture and have the potential to address some of the most pressing challenges facing the sector today. Continued innovation and collaboration in this area will be essential for realizing the full potential of geospatial applications in Agri-informatics and ensuring sustainable and resilient food systems in the future.

2.4 Environmental Monitoring of Soil using Remote Sensing

Soil quality can be defined as the ability of the soil to function within the boundaries of natural or managed ecosystems to sustain biological productivity, maintain water and air quality, and support human habitation (Doran and Zeiss, 2000; NRCS, 2012). Unfortunately, human activities such as cropping, grazing, and forestry have led to the degradation of soil quality, which poses a threat to the sustainability of these practices worldwide. Consequently, there is a growing need to map the precise location and severity of soil degradation to inform land management decisions ranging from a farmer deciding whether to rent a particular piece of land to national or international organizations attempting to project future food supplies. The recognition of the need to monitor soil degradation at broad scales dates back to the 1970s, and in the late 1980s, the first major assessment of human-induced soil degradation, known as the Global Survey of Human-Induced Soil Degradation (GLASOD), was completed. The primary objective of this program was to increase awareness of the risks associated with the mismanagement of land resources and provide a basis for prioritizing remediation actions.

In recent decades, several efforts have been made to move beyond broad, subjective assessments and towards more quantitative and detailed descriptions of soil degradation. Many researchers have focused on mapping a specific type of degradation, such as the GLASOD activity, which distinguished between four types of soil degradation: water and wind erosion, physical and chemical deterioration. Physical deterioration includes compaction, waterlogging, and subsidence of organic soils, while chemical deterioration includes nutrient mining, salinization, acidification, and contamination. Despite expert opinion continuing to play a crucial role in regional and global assessments, there is a trend towards more quantitative approaches.

2.4.1 Assessing Wind Erosion

Remote sensing is a powerful tool for assessing soil quality, especially for identifying wind erosion. Due to the expansion of agriculture to marginal areas, wind erosion has intensified in recent years. There are direct and indirect indicators of wind erosion that can be detected through remote sensing. Direct indicators include surface lowering, which can be identified through the use of Lidar and Interferometric Synthetic Aperture Radar (InSAR) techniques. Changes in soil roughness can also be detected through radar backscattering and LiDAR mapping. However, the usefulness of phase or coherence changes in detecting roughness variation due to wind erosion is limited by mutual influences of soil moisture, height, and roughness. Indirect indicators of wind erosion include spectral information about surface properties. Studies have shown that vegetation cover typologies based on satellite imagery and digital elevation model (DEM) data can facilitate the mapping of potential wind erosion on a regional scale. Grazing areas have been mapped for wind-erosion intensities by attaching a characteristic surface roughness length to each typology, derived from field estimation.

2.4.2 Assessing Water Erosion

Water erosion can occur in three forms: sheet, rill, and gully. Sheet and rill erosion involve the detachment and transportation of soil particles by runoff. Gullies are formed by the concentrated flow of excess runoff water during or immediately after an intensive rain event. Direct assessment of erosion intensities requires estimating the metric dimensions and volume of individual patches of sheet, rill, and gully erosion, as well as their densities. This information can only be obtained using high-spatial resolution instruments, limiting the geographical extent of water-erosion surveys. Previous studies have relied on aerial photographs to interpret high-resolution data for mapping gullies. Barber and Mahler (2010) reported high-resolution mapping of gullies using 0.2 m resolution photographs with an RGB camera mounted on a light aircraft flying at a height of 800 m above the ground. Indirect methods for detecting water erosion involve wide-coverage assessment of surface changes from gully erosion. Studies have employed merging high-resolution imagery (QuickBird) with medium-resolution imagery (Landsat Enhanced Thematic Mapper (ETM) and Système Pour l'Observation de la Terre 5 (SPOT 5)) to detect gully erosion areas (Igbokwe et al. 2008). Classification methods and assessment of vegetation cover levels have been used to identify gully erosion areas by Torkashvand and Shadparvar (2011) from Landsat ETM data. Martinez-Casasnovas and Zaragoza (1996) proposed a two-phase method that combines classification (Landsat TM bands 3, 5, 7, and NDVI) and assessment of vegetation cover levels only for the class representing gully sidewalls.

2.4.3 Mapping of overall soil losses

There are various modeling approaches available for estimating soil losses resulting from different types of erosion, which can be phenomenological, empirical, or a combination of the two. The Universal Soil Loss Equation (USLE) is a commonly used model for computing soil loss per unit area over a given period of time. The USLE model considers several factors, including rainfall and runoff erosivity index, soil erodibility factor, slope length factor, slope steepness factor, surface cover and management factor, and practice factor. RS techniques play a significant role in obtaining data for calculating regional estimates of soil losses and mapping these losses over larger areas. Photogrammetry, radar interferometry, and LiDAR are some of the methods that can be used to provide the necessary topographic data required for the calculation of slope length and steepness parameters.

2.4.4 Mapping of Soil drying and crusting

Decreasing soil moisture (SM) can have a significant impact on agricultural production and soil crusting reduces water infiltration capacity (Wani et al., 2009) hence these two factors need to be assessed and monitored for improving production. There has been significant research focused on developing remote-sensing techniques for mapping soil moisture (SM) content (Wagner et al., 2007; Wang and Qu, 2009). The major approaches for detecting SM content include radar techniques, radiation balance and surface temperature calculations, reflectance in the visible, near-infrared, and shortwave-infrared regions, and integrative methods that utilize more than one spectral range. Soil crusts can be identified by significant colour changes, which can be parameterized by the soil's spectral reflectance. NIR analysis has facilitated the identification of a new normalized spectral area parameter, which has been found to correlate well with soil infiltration rates.

2.4.5 Monitoring soil quality deterioration

The task of mapping degraded soil properties is difficult, as these chemical and physical properties evolve mainly in the soil at depth, with limited expression of their variation on the soil surface. Consequently, the use of indirect methods in general and those based on plant properties as indicators of subsoil conditions in particular, is relatively common.

- **Soil salinity**

Salinization occurs when minerals and salts from irrigation water are not washed away by rain or irrigation, leading to the accumulation of Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^- ions. Remote sensing methods have gained attention in the last decade for mapping soil salinization and its regional effects. There are two ways of mapping soil salinity: surface salinization mapping and subsurface salinization mapping. Surface salinization mapping involves high-resolution aerial photographs and multispectral images such as IRS and Landsat. Hyperspectral sensors have also been used in this method. Subsurface salinization mapping can be performed using indirect methods that implement passive sensors, which utilize spectral information from the soil surface or plants, or active sensors such as electromagnetic induction meters. Soil salinity as estimated with multispectral and hyperspectral remote sensing is given in Fig. 2.5.

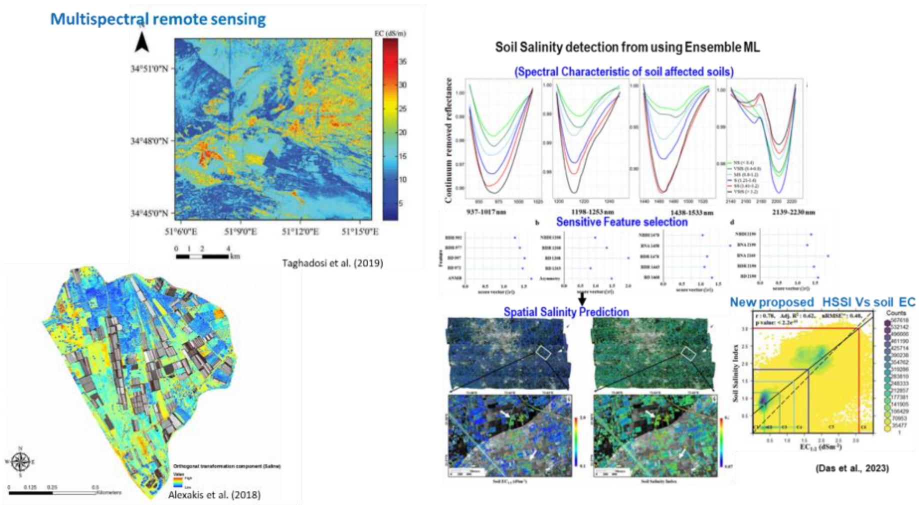

Fig. 2.5 Soil salinity as estimated with multispectral and hyperspectral remote sensing

- **Soil Organic Matter and Nutrients**

Soil organic matter (SOM) is a product of biological decomposition and has a major impact on agricultural production and climate change on a global scale and hence, SOM mapping is essential for evaluating land degradation and soil fertility. Nitrogen, potassium, and phosphorus (N, K, and P) are soil nutrients that are essential for field productivity. Monitoring the nutrients using remote sensing is difficult as they accumulate mainly in the subsurface soil layers. Techniques in this field were developed using two main approaches. The first approach involves studies that link spectral information from the soil surface to subsurface conditions. The second approach links plant properties to subsurface nutrient conditions, primarily assessing spectral indicators of nutrient content in leaves.

2.4.6 Assessing soil contamination

Soil contamination is a significant environmental concern, with vast soil areas functioning as sinks for both organic and inorganic contaminants released from the use of fossil energy and human activities. These materials include petroleum hydrocarbons, heavy metals such as Ni, Cr, Cu, Cd, Hg, Pb, Zn, and As, acid mine drainage, and pesticides. Reflectance properties of soils enable an assessment of the various contaminants within them. Hyperspectral technology has been used to assess soil contamination resulting from metal mining based on pyrite oxidation. Soil contamination by hydrocarbons can also be detected using remote sensing data. Studies have shown that heavy metals do not exhibit characteristic absorption features in the VIS-NIR-SWIR wavelength region. However, they can be detected indirectly due to their complex interaction with organic matter, or their association with moieties such as hydroxides, sulphides, carbonates, or oxides that are detectable. Alternatively, they can be detected through their adsorption to clays that absorb light in this wavelength range. An example of assessing heavy metal using remote sensing is given in Fig 2.6.

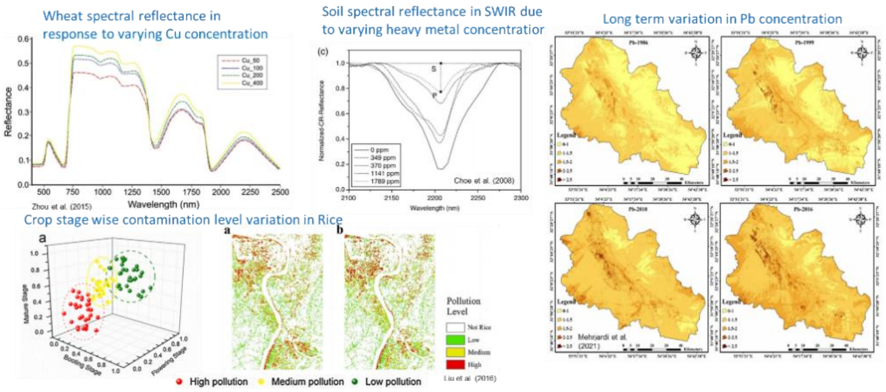

Fig. 2.6 Assessing soil contamination using remote sensing

2.4.7 Conclusion and Future thrust

Environmental monitoring of soil is a crucial aspect for sustainable land management. Remote sensing tools and techniques are gaining popularity for soil quality assessment due to their ability to provide valuable information about soil properties, which are difficult to measure in the field. Remote sensing can be used to monitor soil moisture content, texture, and nutrient status. Additionally, remote sensing can provide early detection of soil degradation, which is essential for preventing further damage and prioritizing remediation actions. Remote sensing involves the use of various sensors, such as multispectral and hyperspectral sensors, to collect data about the earth's surface. The data collected can be processed to create maps and models of soil properties and identify changes over time. The data can also be combined with other environmental data, such as weather and land use data, to gain a more comprehensive understanding of the soil's ecosystem.

The success of remote sensing efforts depends on whether they improve decisions of land managers. There are some challenges associated with remote sensing for soil quality assessment. One of the main challenges is the need for accurate ground-truthing data, such as field observations and laboratory analyses, to validate the digital soil maps. Additionally, some soil properties, such as organic matter content and metal contamination, are challenging to measure using remote sensing techniques. Further research is needed to improve the accuracy and reliability of remote sensing data for soil quality assessment.

2.4.8 Satellite Agro-meteorological and Value Added Agro-Advisory Services

Agrometeorological sciences holistically bridged the gap between meteorological, hydrological and biological sciences to address the dynamicity of soil plant atmosphere continuum in different temporal and spatial scale. The timely and accurate assessment of crop-weather interaction and its translation to operational farm management recommendations at various spatio-temporal scale is key to safeguard the farm resources and crop losses. At present scattered point scale agro-meteorological information of different crops at irregular temporal domain is used to monitor and issue agrometeorological advisories for a cluster of districts. Hence there is need to provide desired agrometeorological information at spatial and temporal scale through geospatial platform to capture variability within a block or district. The recent advances of RS in wide range of electromagnetic spectrum in optical, thermal and microwave regions in terms of spatial, temporal and radiometric resolution is the key to have better agrometeorological parameters for assessment of near real time crop condition and growth from low earth orbiting (LEO) and geostationary (GEO) satellites. The synoptic observations of agrometeorological variables from polar and geostationary platform is key for monitoring of agriculture at regional to national scale. This will help to plan appropriate agricultural operations to offset adverse and dynamic crop conditions. The agro-meteorological indicators on spatial scale at regular interval and accurate high-resolution weather forecasting at short, medium and extended ranges are essential components to generate value-added information on early warning and forewarning for farmers' advisories.

2.4.9 Core Agromet products from Indian geostationary satellite

- **Vegetation Index (VI)**

Vegetation index is a mathematical representation of spectral response of vegetation in different wavelength to know the vigour and health of vegetation. The "Normalized Difference Vegetation Index" (NDVI) is widely used for vegetation growth monitoring. NDVI is computed as per equation (1)

$$\mathrm{NDVI} = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \qquad (1)$$

- **Surface insolation**

The amount of solar radiation reaching at ground surface between 300 to 3000 nm is known as surface insolation or global insolation and is the driving input for two important eco-physiological plant processes such as evapotranspiration and photosynthesis. In the present scenario surface insolation is one of the most important renewable energy resources. The daily insolation data is also used for estimation of crop biomass and yield. In past, interpolated data from the limited ground station was used to generate the spatial insolation maps. The regular observations from the geostationary satellite (high temporal sampling frequency) pay a way to compute 30-minute dynamics of the surface insolation. Instantaneous surface insolation was generated using spectrally integrated radiative transfer scheme and three-layer cloudy-sky model with cloud-top albedo, temperature, atmospheric water vapour from visible, thermal IR and water vapour spectral bands and vertical profile of aerosol and ozone (Bhattacharya et al., 2013). Surface insolation is provided through INSAT 3D and 3DR from MOSDAC geo-portal.

2.5 Land surface temperature (LST)

The land surface temperature (LST) lead to characterizing the interaction between surface-atmosphere energy fluxes, thus having great usage in agrometeorology, hydrology and other environmental applications. A single (10.5-12.5 µm) and dual (10.2-11.3 µm and 11.5-12.5 µm) thermal spectral bands with Radiative Transfer (RT) model were used to retrieve LST from satellite. The basis of LST algorithm depends on transmissivity, upwelling and downwelling radiances of the atmosphere along with surface emissivity.

2.6 Rainfall

Around the globe the limited and unequal distribution of rain gauges and weather radars over land and scarcity of rainfall data over the oceans have significantly limit the use of these data sets in numerical prediction, hydrological and crop models. The meteorological satellites have shown their potential for improved identification and quantification of precipitation (rainfall). Current meteorological geostationary satellite provides visible (VIS) and infrared (IR) spectral data at high temporal resolution able to capture the growth and decay of precipitating clouds. Microwaves sensing have an ability to provide interaction of radiation with hydrometeors but at coarser resolution and limited swath from polar satellites such as Tropical Rainfall Measuring Mission (TRMM) (Kummerow et al., 1998). At present three algorithms are used to estimate rainfall from Indian geostationary satellite such as (i) GOES Precipitation Index (GPI) (ii) INSAT Multispectral Rainfall Algorithm (IMSRA) (iii) Hyrdo-estimator (HEM) (Varma, 2018).

2.7 Surface Soil Moisture (SSM) product

The regular operational surface Soil Wetness Index (SWI) and volumetric Soil Moisture (SM) products were developed using SMAP L-band time series radiometer data. An absolute soil moisture W(t) at particular time was derived from SMAP-L band brightness temperature (Tb), permanent wilting point (PWP) and field capacity (FC) of soil modelled using time series data (Pandey et al., 2021).

2.8 Geo-spatial value added Agromet products

- **Leaf area index (LAI)**

LAI is defined as the single sided area of green, functioning leaves per unit ground area. LAI can play a vital role for determining vegetation physiological state and health. Agricultural crop LAI from satellite can be retrieved using forward and inversion modeling of one dimensional (1-D) canopy radiative transfer (CRT) model *PROSAIL* and satellite reflectance data. *PROSAIL* has two components (i) *PROSPECT* (Jacquemoud & Baret, 1990) simulates reflectances at leaf level and (ii) *SAIL* address the directionality. The different statistical and machine learning inversion techniques are used to invert the satellite observed surface reflectance to get the unique crop LAI.

- **Evapotranspiration**

Potential Evapotranspiration

The potential or reference evapotranspiration (ET_0) represents the atmospheric water demand over vegetative surface. The rate of ET_0 is influenced by various meteorological parameters such as air temperature, wind speed, solar radiation and vapour pressure deficit. Due to its theoretical background potential evapotranspiration (PET), hereafter referred as grass reference evapotranspiration (ET_0), is expressed in terms of amount of water loss per unit time to atmosphere from non-limiting moist surface covered with a uniformly and actively growing short grass such as Alfalfa. The daily ET_0 in millimeter is computed using daily insolation from INSAT 3D and 3DR and three hourly weather forecast from WRF (Weather Research Forecast) model (Nigam and Bhattacharya, 2014). The FAO56 model is customized for INSAT and weather data to generate daily

ET_0. The generated ET_0 over Indian region shown in Fig 11.7 (Vyas et al., 2016). Presently the daily operational product of ET_0 is available from MOSDAC portal for user community.

Actual Evapotranspiration

Actual evapotranspiration (AET) can be estimated from latent heat fluxes (Eλ or LE) and latent heat (L) of evaporation. The satellite-based surface latent heat flux (Eλ) estimation is generally accounted from the residual of surface energy balance (Kustas et al., 1994). In the single source (soil-vegetation complex as single unit) and two source (soil-vegetation as two unit) surface energy balance approach is used to estimate AET. The actual evapotranspiration has been generated using (INSAT) data over Indian landmass using this approach (Bhattacharya and Nigam, 2015).

- **Surface Dryness Index (SDI)**

Surface Dryness Index (SDI) is used to quantify precipitation availability over atmospheric water demand. SDI represents adequacy of the precipitation to satisfy atmospheric vegetation water demand. Weekly SDI can be derived using the daily potential evapotranspiration (PET) from INSAT 3D and Hydro Estimator (HEM) rainfall products.

Glimpses of some of the agromet and biophysical parameter are given in Fig 2.7.

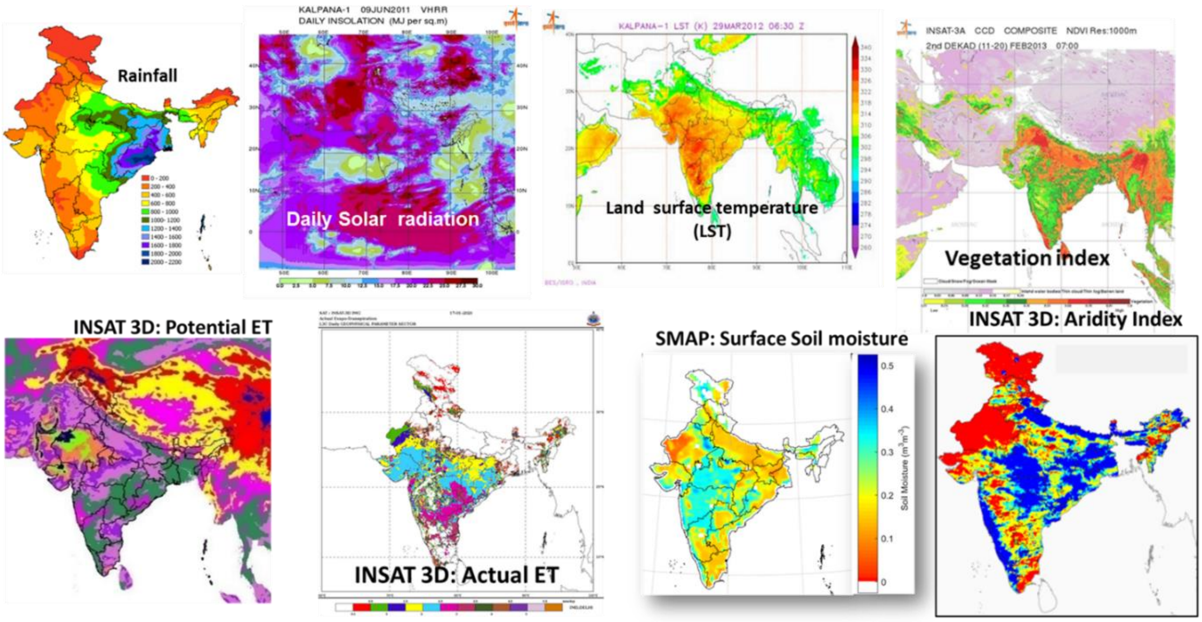

Fig. 2.7 Examples of Agro-met and biophysical parameters retrieved through Indian satellite data.

2.9 Application of agro-met products

- **Crop sowing date**

The crop sowing date acts as a key input to initialize the crop conditions within a dynamic crop growth model. This decides the growing window for a crop and set the boundary condition for crop yield modelling and other agronomic inputs such as irrigation. The time-series NDVI data is used to generate the crop sowing date with different approaches.

- **In season crop area progress**

In India different methodology has been evolved during the past two decades to monitor crop area and production using Indian polar satellite data. But as polar satellite has a limitation of temporal resolution and swath periodic monitoring of crops at regular interval is difficult at country level. It can be overcome by using geostationary satellite data. The data obtained from geostationary satellite can add to the advantage of viewing the constant area with changing solar zenith and azimuth angle. This will give a need to explore geostationary satellite data to monitor progress of crops at regular interval for Indian condition.

- **Agromet Advisories for the farmers**

The current advisory framework under Gramin Krishi Mausam Seva (GKMS) of India Meteorological Department (IMD) lacks in, near real time assessment of crop and soil conditions to improve the quality and coverage of advisories. The spectral observations from polar and geostationary satellites provide agromet products for synoptic, real-time and continuous monitoring of crops. In order to strengthen the existing advisories under GKMS, the usage of daily agro-met products from satellite in six AFMUs (Agro-Met Field Units) (382 blocks of 60 districts) is initiated by Space Applications Centre, ISRO and IMD. Several agromet products such as NDVI, PET, SDI, Minimum and Maximum LST and SSM aggregated for block and district agricultural regions are provided to all six AFMUs in user friendly format through a dedicated web link from VEDAS (Visualisation of Earth Observation Data and Archival System) (https://vedas.sac.gov.in) geoportal (Nigam et al., 2023). Time series and near real-time agromet products during agricultural seasons are being used to interpret crop sowing prospect, crop condition, irrigation requirement, crop stress etc. at block and district scales.

2.10 Conclusion

This chapter concludes that geospatial technology plays a pivotal role in revolutionizing agriculture and soil management practices. Its applications, such as precision agriculture, crop monitoring, soil mapping, land use planning, yield prediction, and decision support systems, provide valuable tools and information for farmers to make informed decisions and implement sustainable practices. Geospatial technology enables precision agriculture by allowing farmers to analyze spatial data and optimize resource management, leading to improved resource efficiency, reduced environmental impacts, and increased crop yields. It facilitates continuous crop monitoring and management, aiding in the identification of crop health issues, stress factors, and nutrient deficiencies, enabling timely interventions to optimize crop performance. By utilizing geospatial technology for soil mapping and analysis, farmers can characterize soil properties, assess land suitability, and implement site-specific management practices. This approach supports effective soil conservation, nutrient optimization, and erosion prevention, contributing to improved soil health and long-term sustainability. Geospatial technology also plays a critical role in land use planning and management, integrating data on land cover, topography, soil characteristics, and climate patterns. This enables farmers to make informed decisions regarding crop selection, land allocation, and zoning, leading to optimized land utilization, reduced land degradation, and the promotion of sustainable agricultural practices.

Furthermore, geospatial technology aids in yield prediction and forecasting, facilitating production planning and risk management for farmers. By integrating historical data, weather information, and crop growth models, farmers can estimate future yields and make proactive decisions to adjust planting strategies, optimize harvest schedules, and identify market opportunities. The development of decision support systems in agriculture, incorporating geospatial technology, enhances overall farm management. These systems integrate various data sources, providing real-time information, recommendations, and alerts to optimize resource allocation, reduce production costs, and improve decision-making processes. Overall, geospatial technology empowers farmers with valuable spatial information and tools, enabling them to optimize resource utilization, improve crop productivity, reduce environmental impacts, and foster sustainable agricultural practices. By integrating geospatial technology with traditional farming practices, we can pave the way for a more efficient, productive, and environmentally conscious agricultural sector.

2.11 Future scope and challenges

The retrieved meteorological and value-added agrometeorological products and indicators from satellite appears as a valuable tool for crop growth and condition assessment in near real time. This will help to planner to make decision on regional to national scale. There is a need to provide location-specific advisory by providing finer-resolution medium range weather forecast and satellite agrometeorological products for timely evaluation of the real ground situation for a given location. The initiation of usage of satellite agrometeorological products showed the pathway to assess the ground situation in faster manner to incorporate into the agromet advisory bulletin. The awareness and acceptance of the satellite derived agromet products among agrometeorological community can be a new beginning for the generation of location-specific advisories for the farmers. The future ISRO and global collaborative space missions such as GISAT (Geostationary Imaging Satellite), INSAT 4th generation, NISAR (NASA ISRO Synthetic Aperture Radar), Indo-French TRISHNA (Thermal InfraRed Imaging Satellite for High-resolution Natural Resource Assessment) etc. will not only provide better spatial and temporal resolutions but will further enhance the accuracies of agromet products. Among aforementioned missions, NISAR will provide all sky monitoring of ecosystem through L and S-band SAR (Synthetic Aperture Radar) observations while TRISHNA mission will address irrigation management at farm scale through high-repeat advanced multi-band thermal infrared remote sensing observations. The future advancement in space technology will help in improving the quality of current agrotechnological products and advisory services to provide better farm-scale solutions to farmers.

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Chapter 3

URBAN AND REGIONAL PLANNING

3.1 Introduction

3.1.1 Urbanisation as a global phenomenon

The population of the world has rapidly urbanised and industrialised in the 20th and 21st centuries. In 2005, over 74% of the population in developed countries lived in urban areas, compared to 43% in developing countries. According to Ritchie and Roser (2018), the percentage of people living in cities worldwide has climbed from just 13% in 1900 to 29% in 1950 and has reached >55% (>4 billion) by 2020. About 3.5 billion people already reside in urban regions, and since the world is continue to urbanise; 62% of the 8 billion people on the planet, or roughly 5 billion people, are anticipated to occupy urban surfaces by 2030. By 2030, developing countries will have 56% of their people living in urban areas. The urban planners and governments in emerging countries will face significant challenges as a result of the magnitude of urbanisation.

3.1.2 Urbanisation scenario in India

India is not an exception to the urbanisation propensity; in fact, Indian cities are among the fastest developing in terms of both population and geographic area. People continue to migrate from rural to towns and cities, unabatedly. Due to India's fast urbanisation, there were 159 million (23%) urban residents in 1981, 217 million (26%) in 1991, 286 million (28%) in 2001, and 377 million (31.16%) in 2011 (Chimankar, D.A., 2016). As a result, whereas India's population has increased threefold since independence, urban populations have increased fivefold. The total number of urban settlements have increased from 4029 (1981) to 4689 (1991), 5161 (2001) to 7935 (2011) (Mishra and Mishra, 2021). The 7935 towns and cities house 377 million of the urban population (Table 3.1) as per Census (2011). In 2006, the country's average population density per square kilometre was 370, while the urban population density per square kilometre was 1260, covering an area of 26 million hectares, or 0.6% of the country's geographic area. By 2030, there will likely be 600 million more people living in urban areas across the country (UN, 2018; Arkatkar, 2018; Kumar et al., 2021).

Table 13.1 Growth in Number of Urban Settlements: 1901-2011

Census Year	Urban Population (in millions)	Percentage of Urban to total population	Number of urban settlements/ Agglomerations
1901	26	11.00	1,827
1951	62	17.29	2,845
2001	285	27.78	5,161
2011	377	31.16	7,935

Source: *https://censusindia.gov.in/census.website/*

3.1.3 Definition of urban settlements

As per Census of India, the definition of urban areas (*https://www.mha.gov.in/MHA1/Par2017/pdfs/par2013-pdfs/ls-070513/6458.pdf*) are as follows -

a. **Statutory Towns**: These towns are notified by the relevant State/Union Territory Government and have local governing bodies like Municipal Corporations, Municipalities, Municipal Committees, Cantonment Boards, or Notified Town Area Committees, etc. irrespective of their demographic makeup.

b. **Census Towns:** These communities meet the following requirements: (i) have a population of at least 5,000; (ii) have a male working population that is mostly employed in non-agricultural pursuits; and (iii) have a population density of at least 400 people per hectare.

c. **Urban Agglomerations (UAs):** These urban settlements are continuous urban spreads made up of one or more towns and any outgrowths that are located next to them. According to the definition of an urban agglomeration, it must have at least one statutory town and a combined population of 20,000 people.

d. **Out Growths (OGs):** These are the areas surrounding a main city or town that typically extend outside the city borders and include well-known locations like a railway colony, university campus, port area, etc.

The Census of India classifies towns based on their population size as per six-fold classification scheme: i) Class I: 1,00,000 and above; ii) Class II: 50,000 to 99,999; iii) Class III: 20,000 to 49,999; iv) Class IV: 10,000 to 19,999; v) Class V: 5,000 to 9,999 and vi) Class VI: Less than 5,000 persons (Bhagat, 2004). Table 3.2 shows how Indian towns were categorised for the census years 2001 and 2011 using the six-fold classification indicated above.

Table 3.2 Classification of towns in India (2001 and 2011)

Class of Town	India (total number of towns)	
	Census 2001	Census 2011
Class I	433	568
Class II	493	474
Class III	1383	1373
Class IV	1561	1683
Class V	1040	1749
Class VI	224	424

(Source: Census of India, 2011)

3.1.4 Levels and scales of Planning

Perspective Plan is a long-term (20–25 years) document that provides state government with the objectives, policies, strategies, and general programmes of the urban local authority regarding the spatio-economic development of the settlement under its jurisdiction. It is supported by the necessary maps and diagrams.

Master Plan/Development Plan, which is developed within the parameters of the approved perspective plan, is a medium-term (generally ten or five-year) plan that offers comprehensive proposals for the socio-economic and spatial development of the urban centre and specifies how the local authority and other agencies are to use land resources and carry out development therein.

Annual Plan is conceived within the framework of a Development Plan, and it describes the new and ongoing projects that the local authority intends to carry out during the specific fiscal year and for which the necessary financial resources will be raised from plan funds and other sources.

Projects/schemes are detailed working layouts with all necessary supporting infrastructure, as well as project reports containing information on the cost of development, sources of funding, and recovery instruments for their execution by a public or private agency. They are conceived within the framework of an approved development plan. Table 3.3 shows the mapping scales for various plans.

Table 3.3 Mapping Scales for Various Plans

S. No.	Type of Map/ Planning Exercise	Size of Planning Area		Data source
		Metropolitan Level	**Small and Medium**	**Satellite Data**
01.	Map of Regional Setting	1:250,000 1:1,000,000	1:100,000 – 1:250,000	Satellite Data, Collateral Maps
02.	Perspective Plan	1:100,000 1:250,000	1: 50,000 1: 100,000	Satellite Data, Census Data & Collateral Maps
03.	Master Plan	1: 25,000 1: 50,000	1: 10,000 1: 25,000	Satellite Data, Census Data, Collateral Maps & Ground truth
04.	Plan of Project / Scheme	1: 1,000 1: 5,000	1: 500 1: 2,500	Satellite Data, Aerial Data, Census Data, Collateral Maps, Ground truth & GPD Data

Source: Urban Development Plans Formulation & Implementation (UDPFI) Guide lines, MUD, GoI 1996

3.1.5 Challenges in Physical Planning

Physical planners require data and knowledge to create development plans. Data sources should be derived from constantly updated maps in order for these development plans to be truly successful and meaningful. However, creating such maps with appropriate scales and periodicity is a gigantic task. The difficulty of maintaining these maps up-to-date is further exacerbated by the fact that urbanisation is occurring quickly in the majority of emerging countries.

3.1.6 Potential of Geospatial technology in Urban and Regional Planning

In order to analyse the multi-faceted features of the urban environment, geospatial technology - a system integrating Remote Sensing (RS), Geographic Information Systems (GIS), and Global Navigation Satellite Systems (GNSS) is quite useful. The applications of remote sensing data include: mapping and interpretation of details presented in maps, and field-based implementation. It is crucial to understand the features and capabilities of these remote sensing data products that are available to different users, particularly to urban and regional planners. The benefit of using remote sensing data is that it gives us access to dependable data at regular intervals, expanse of built-up and location data, information on land use/ land cover (LULC), and a platform for monitoring and executing plans. The benefits of GIS include: i) data is maintained in physical, compact data files; ii) large amounts of data can be maintained and extracted quickly; iii) various computerised software modules/tools allow for a variety of manipulations, including map measurement, map overlay, transformation, and geographic design; and iv) graphic and non-graphic information can be combined and manipulated simultaneously in a related way.

3.2 Geospatial Applications in Urban and Regional Planning

3.2.1 Pattern of human settlements

Since remote sensing images provide a current and comprehensive perspective of settlements across the variety of landscapes, geospatial technologies are crucial for studying the settlement pattern. Spatial autocorrelation, the Ripley's K function (Hohl et al., 2017), the high/low clustering method, and others GIS-based approaches have all been used to examine the geographical pattern of settlements (Linard et al., 2012; Zhang et al., 2014; Maithani et al., 2019). Due to its simplicity and convenience of usage, the Nearest Neighbour (NN) distance technique is frequently utilised (Kint et al., 2004; Yang and Lee, 2007). The average NN distance, an index based on the average distance from each feature to its NN feature, is estimated to look into the layout and distance of the sample points. This index shows whether the settlement points are distributed randomly throughout the study area or if they are spatially concentrated. If the average NN ratio is smaller than 1, clustering is present in the pattern. The trend is towards dispersion if the average NN ratio is greater than 1. Based on NN analysis, the urban settlement patterns in the North-West Himalaya (NWH) were examined for the three constituent states of Himachal Pradesh (HP), Jammu & Kashmir (J&K) (including UT-Ladakh), and Uttarakhand (UK). High-resolution images were used to pinpoint the locations of the urban settlements based on the 2001 census. The NN ratio was then estimated using the resulting vector data as an input in a GIS environment (Table 3.4). The investigation revealed that HP state's urban settlements were distributed randomly, in contrast to J&K and UK states' clustered distribution. Despite the fact that all three states have hilly terrain, where urban settlement locations are heavily influenced by topography, access to water sources, and the availability of agricultural land, HP did not show clustering due to the high level of infrastructure facilities present throughout the state.

Table 3.4 NN ratio of towns in NWH states

State	No. of points	Observed mean distance	Expected mean distance	Nearest Neighbour Ratio	Z- Score	Pattern
H.P.	54	14282.50	13640.53	1.047	0.66	Random
J&K*	51	23321.54	23171.74	0.606	-2.088	Clustered
U.K.	62	11264.17	14174.96	0.794	-3.093	Clustered

*Including UT-Ladakh

3.2.2 Study of urban sprawl and land use/land cover

Satellite-based remote sensing systems are best suited for monitoring and updating, particularly for regional planning and analysis, because of their unique capacity to provide repetitive coverage for any place on the surface of the Earth. Therefore, to study the feasibility of such data products for urban expansion and land use, an Urban Sprawl Mission to study the urban sprawl and urban land use for 12 cities having a population of more than one million (1981 census) was carried out. The mission project was taken up in 1986 and completed in 1988/89. Mainly, Landsat Thematic Mapper/ Multispectral Scanner (TM/ MSS) data were used to study the urban sprawl and Landsat TM data for the preparation of land use map of 1988. For this study, land use classification was prepared in consultation with Town and Country Planning Organisation (TCPO), Delhi and other Town and Country Planning Organisations/ Departments in other States and the results of the studies were made available to the concerned development authorities. Jaipur Development Authority (JDA) made use of this study to revise the Master Plan of Jaipur City.

In a different study, data from Indian Remote Sensing (IRS, LISS-II, 36.5 m and LISS-III, 23.5 m) and Landsat TM (79 m) were utilised to examine the urban growth in the city of Dehradun during a period of five years (1987, 1992, 1998, 2003, and 2008). Six LULC classes: urban built-up, forest, agriculture, water body, scrub land, and tea garden were chosen as target classes using the Maximum Likelihood Classifier (MLC) following the temporal data georeferencing and co-registration (Fig 3.1). In order to create the urban growth map, the urban area for each time period was extracted, and an 8-directional cardinal scheme (i.e., north, north-east, east, south-east, south, south-west, west, and north-west) with a 1 km incremental buffer from the growth centroid of the Dehradun clock tower was assessed. When compared to growth rates observed during earlier time periods, Dehradun witnessed exceptionally high growth rates of around 32% and 49% in the years 1998-2003 and 2003-2008, respectively (Gupta, 2013).

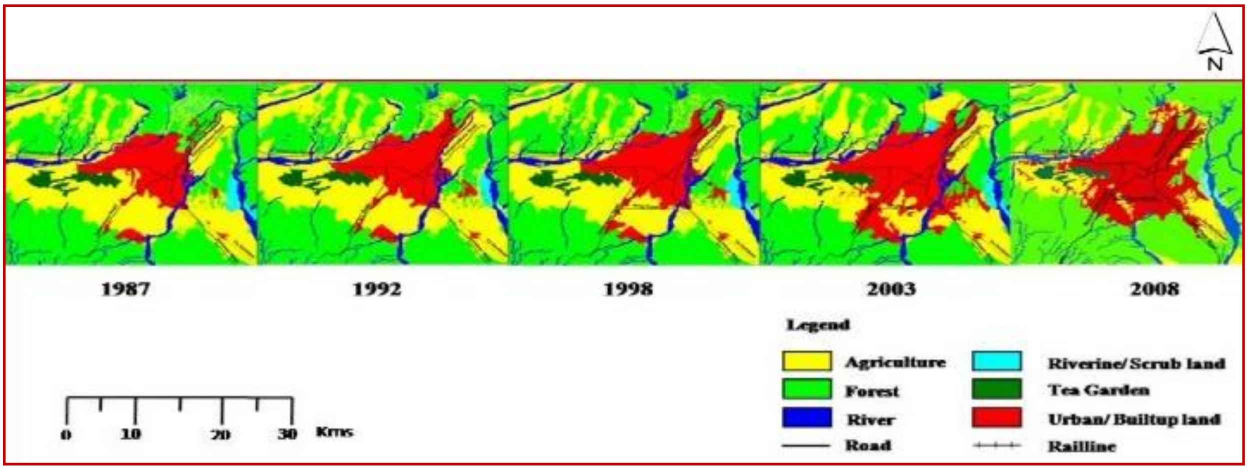

Fig. 13.1 LULC maps of Dehradun Urban area over a period of two decades (Gupta, 2013)

Monitoring urban growth using night-time data

Built-up areas can be evaluated by utilising operational line-scan system (OLS) nighttime light datasets from the Defence Meteorological Satellite Programme (DMSP). In order to estimate the percentage of built-up area on a per-pixel basis for a study area in the Indo-Gangetic Plains, a novel method was developed using two coarse spatial resolution remote sensing datasets i.e., Defense Meteorological Program (DMSP) Operational Line-Scan System (OLS) and Terra Moderate Resolution Imaging Spectro-radiometer (MODIS) Normalised Difference Vegetation Index (NDVI) data. It was investigated whether the Human Settlement Index (HSI) might be used to track the expansion of built-up regions in the Indo-Gangetic plains between 2001 and 2007. The OLS oscillating scan radiometer is a component of the DMSP satellites and operates in two spectral bands: thermal infrared band (TIR), which ranges from 10.5 to 13.4 µm, and visible near infrared band (VNIR), which ranges from 0.4 to 1.10 µm. The OLS covers the entire Earth every day due to its 2.7 km spatial resolution, 6 bits radiometric resolution, and 3000 km swath. The HSI, OLS, and NDVI datasets were analysed for correlation.

The total number of growth cells falling within each state and union territory were first counted in order to examine the expansion of the built-up area on a state-by-state basis. These cells were then divided into the three different HSI growth classes. The proportion of Class 1 growth cells was highest in the states of Delhi and West Bengal, while it was lowest in Chandigarh. Bihar has the highest proportion of Class 3 growth cells, followed by Uttar Pradesh. Punjab has the lowest proportion of Class 3 development cells (Fig. 3.2).

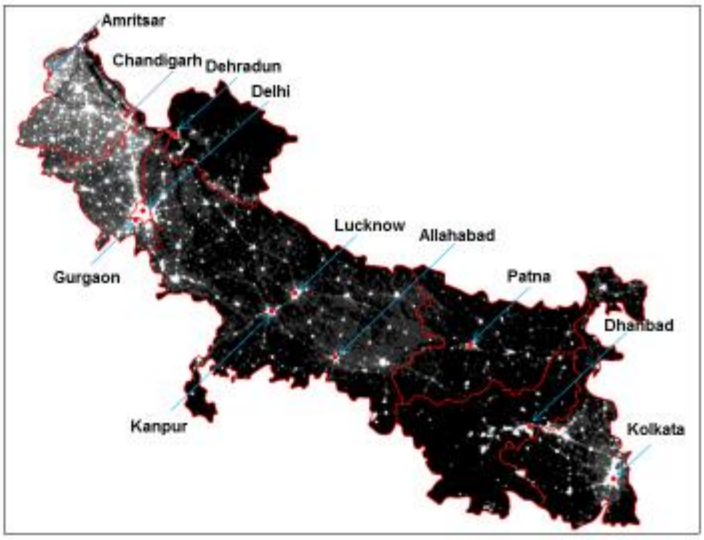

Fig. 3.2 Night-time OLS stable lights yearly composite for year 2001 (Roy Chowdhury et al., 2012)

3.2.3 Urban growth modelling

Contiguous agricultural and forest lands are being irreversibly converted into built-up areas in developing countries like India due to uncontrolled growth. Monitoring the expansion of built-up areas on a regional and global level has therefore become a desirable task for city managers. Urban planners are currently searching for methods and tools to model and forecast the pattern of urban expansion based on indicators or drivers of urban growth as well as policies.

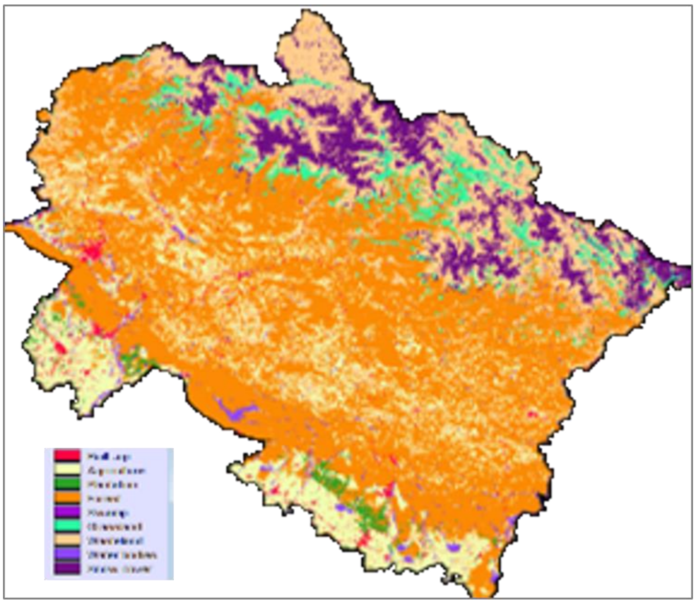

Fig. 3. 3 Simulated land cover map for 2020 (Source: Singh, 2016)

In a study over Uttarakhand, the state's land cover change was examined, and the land cover trajectory was extrapolated using a spatial predictive model based on cellular automata (CA). In this investigation, CA-Markov chain analysis was used. A stochastic process known as a Markov chain model the future state of a system based on the current state without much knowledge of the past. By creating a transition probability matrix based on land cover maps from two separate time periods, Markov Chain analysis describes the likelihood of land cover changes. CA is used into the approach to give the model a spatial component. The *Bhuvan* website allowed users to obtain land cover maps for the years 2006, 2010, and 2015 for the state of Uttarakhand. For analysis purposes, these maps were divided into nine classes: built-up, agricultural, woodland, grassland, plantation, snow cover, wasteland, and water bodies. Based on the land cover map of period T1 (2006-2010), the Markov transitional probability matrix was developed. By adjusting the neighbourhood size and model iterations, the CA-Markov was calibrated for period T1. Following model validation for the period T2 (2006–2010), the model was run to simulate the land cover for the year 2020 (Fig 3.3).

3.2.4 Master/ Development Plans preparation: creation of urban land use

A spatial database at a scale of 1:10,000 for Silvassa town was created using high resolution Cartosat-1 (PAN) ortho-corrected data for the year 2007 and GIS techniques. The Valsad District, Gujarat and Thane District, Maharashtra border the 490 sq. km. study region on all sides. Cartosat-2 data at a scale of 1:5,000 was also used to update the database details. In 2008, several thematic details were collected and ground checked, including the road network, settlement nodes, built-up area footprints, water bodies, surface drainage and canals, and other land use details up to level-III. Silvassa town's urban land use is depicted in Fig 3.4. The GIS database assisted in the preparation of the Development Plan by assessing the database for transportation, environmental sensitivity, settlement zoning, and for policy regulations on the intended land uses.

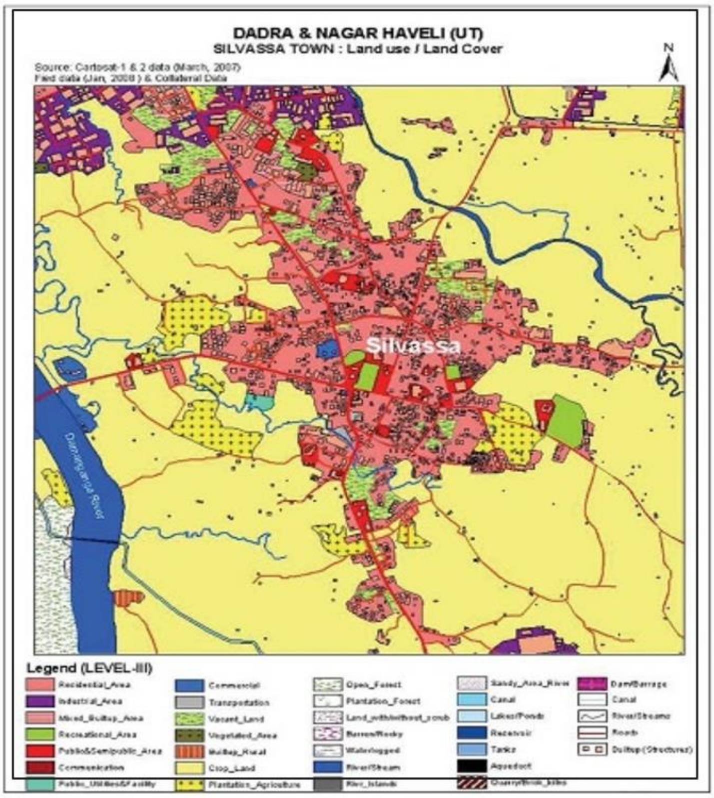

Fig. 3.4 Urban LULC Map of Silvassa (Source: https://www.nrsc.gov.in/sites/default/files/pdf/ebooks/Chap_5_Urban.pdf)

3.2.5 Bhuvan-NUIS: Web-based application for Master Plan preparation

This application is an extension for National Urban Information System (NUIS) scheme to enable preparation of Urban plans in Geospatial domain developed using Open-Source GIS technology. Towards effective utilisation of the NUIS towns' geospatial database, a comprehensive Web based

Geospatial solution "*Bhuvan*-NUIS" was developed for providing facilities to States to share the existing 152 NUIS towns GIS database, their updation, and creation of new spatial and attribute data as required for Master Plan preparation. The application was developed in two components viz., web portal and QGIS plugin. The web portal provides the hierarchical based workflow for the data management which includes citizen view, town specific view, state specific view and country specific view. The second module is *Bhuvan* NUIS Plug-in in QGIS software which provides Gateway for Client to Bhuvan server communication. *Bhuvan*-NUIS provided single window working platform for data, tools for formulation of Master plan and enables Urban Geospatial Governance. Some key achievements of the program are: i) About 2,500 town planners have been trained on Geospatial technologies, and ii) The Master Plan formulation by the respective Urban Local Bodies was initiated through two-week hands-on training to the town planners for 3 states in the country. NUIS-*Bhuvan* is a part of Urban & Regional Development Plan Formulation and Implementation Guidelines (URDPFI, 2014) prepared by Ministry of Housing & Urban Affairs (MoHUA) of Govt. of India.

AMRUT: Formulation of GIS based Master Plan

Government of India has introduced the national mission, namely Atal Mission for Rejuvenation and Urban Transformation (AMRUT) in 2015. Its thrust areas included water supply, sewage and septage management, storm water drainage to prevent flooding, non-motorised urban transportation, and green space/parks. One of the key reform under AMRUT mission is "Formulation of GIS-based Master Plan" which is aimed at Class-I cities (population greater than 100,000), state or UT capitals, heritage cities, coastal towns, and cities from hill states, islands, and tourist hotspots. As per the process flow, the National Remote Sensing Centre (NRSC) of Indian Space Research Organisation (ISRO), Govt. of India has created urban geospatial database at a scale of 1: 4,000 for AMRUT cities in collaboration with TCPO, MoHUA, GoI; State Governments/ULBs and with the assistance of the private geospatial industry. The database consisted of both spatial and non-spatial attributes. The benefits of large scale (1:4,000) urban Geospatial database are: i) All Urban Local Bodies share a uniform and Standard GIS Database, ii) Infrastructure Planning, iii) Utility planning, iv) Enable geospatial governance, iv) Future site planning & design, v) Up-to-date comprehensive database & multiple spatial analysis, vi) Eco-sensitive areas management, vii) Encroachment monitoring, and viii) Green area development.

3.2.6 Quantifying urban landscapes-green space assessment

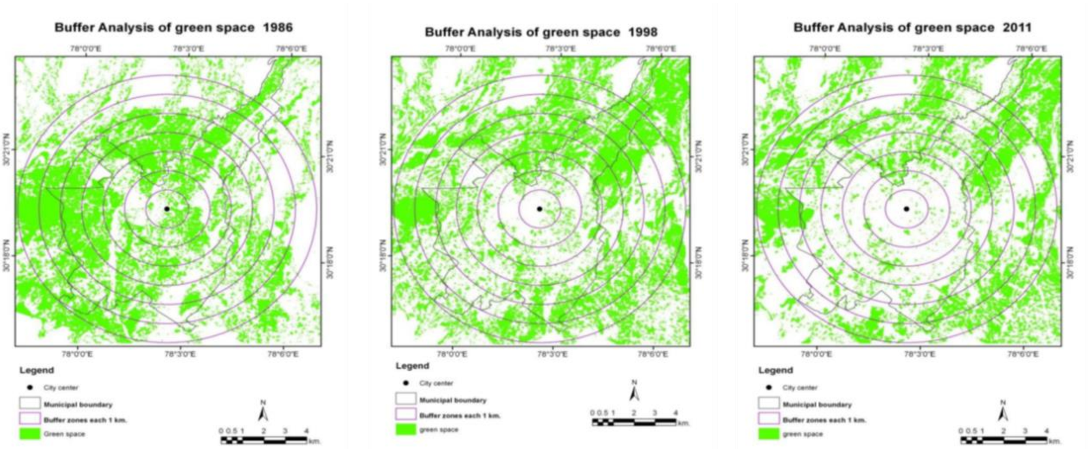

Fig. 3.5 Distribution of Green Spaces within 7 Buffer Zones of 1 km from City Centre for the Year 1986, 1998 and 2011 (Source: Jain et al., 2013)

Landscape diversity is a hallmark of urban settings. The phenomena of de-densification within cities irreparably harms the sustainability rate of urban setup due to rising in-migration to the city and restrictions or limitations for the city expansion. Using IRS-1C/1D LISS-III and Landsat-TM images of Dehradun city, the landscape pattern was investigated using spatial metrics, such as percentage of landscape (PLAND), mean patch size (MPS), and number of patches (NP) metrics (Jain et al., 2013). Using the supervised classification technique, the five LULC classes namely, built-up, forest, green space, open space, and river were identified. According to the statistics obtained, the year 1998 had significant fragmentation. Between 1986 and 2011, both built-up areas and green spaces showed a pattern of compactness. PLAND also demonstrated a loss of open space. PLAND and MPS values also showed a decline in open space. Despite the fact that the PLAND of forests rose between 1986 and 2011, the low MPS and high NP throughout same time showed that the forest cover is fragmented. In order to assess the urban environmental quality, seven 1 km-long buffers around the city's clock tower were examined (Fig 3.5). Within the 1 km zone, there has been a sharp decline of green space, from 34.62% to 7.78% from 1986 to 1998, and subsequently to 2.81% in 2011. In buffer zones, it can also be shown that the percentage of green space grows starting at 6 kilometres from the city centre (Jain et al., 2013).

3.2.7 Land suitability for solid waste management

Solid waste management entails organising the production, collection, transportation, and disposal of solid waste in a way that is environmentally friendly while adhering to ideals of economy, beauty, energy efficiency, and conservation. The majority of the land inside urban boundaries is set aside for one of the land uses specified in master plans. The issue emerges when the inappropriate locations transform into hazardous zones or display signs of their abuse. These differences may pose serious problems in the future, and the intensity can only be scientifically explained.

Using the Analytical Hierarchy Process (AHP), a study has been conducted to (Fig. 3.6): (i) identify landfill sites in the Dehradun Urban Area (DUA), (ii) demonstrate the use of remote sensing and geographic information systems (GIS) technology in the creation, management, and analysis of databases, and (iii) study the use of AHP in site suitability process modelling and demonstrate the pair-wise comparison procedure to capture relative and consistent judgements of two factors at one time (Singh, 2002).

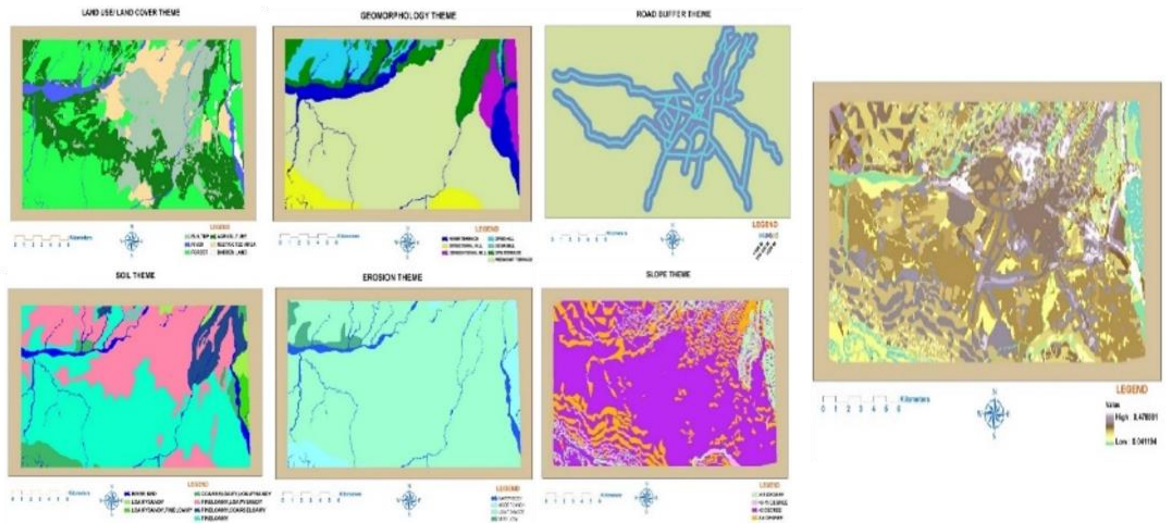

Fig. 3.6 Ranking of solid waste disposal sites based on AHP (Source: Singh, 2002

3.2.8 Slums identification

In Dehradun city, around 80% of the informal settlements are located around Rispana and Bindal Rao drainage systems, and also along railway lines. These are the high-density developments that co-exist with marginal areas, hill slopes, drainage network, etc. The condition of houses near to the river is more dilapidated in comparison of the houses away from the river bed. The proximity of these settlements to the riverbed makes them susceptible to flash floods. Slum areas are dynamic and experience significant changes in the built environment throughout time. The majority of these squatter communities are located close to high- and middle-income residential regions or small commercial areas where these people work in various occupations. Consequently, it is possible to separate slums from satellite images.

3.2.9 Urban heritage- preserving the built

The preservation of cultural heritage is vital for a country's identity, besides its sustainable management is also required to advance the country's economic development. Geospatial technology developments offer potential datasets and analysis tools for examining the current situation for thorough documentation and evaluation of heritage sites. With the aid of high-resolution satellite data, GPS, and an exhaustive field survey, a GIS database for forty Indian National Trust for Art and Cultural Heritage (INTACH) designated heritage structures was created for this project. For each building, the data included location, age, physical condition, height, construction material, and ownership status as pull factors, and distance from a lake, highway connectivity, and infrastructure accessibility as push factors.

Towards the examination of these parameters, a GIS index system was employed, and two indices i.e., the Redevelopment Potential Index (RI) and the Urgency Index (UI) were used (Ko, 2008). Using Saaty's pairwise comparison method, all the parameters were evaluated using the AHP. St. John Wilderness Church was chosen for additional research utilising advanced sensors like the Terrestrial Laser Scanner (TLS) because its UI value was the highest. It took 15 scans in all to determine the point cloud's high density and complete coverage of the building. Figs 3.7 and 3.8 depict the location of scans conducted around the church and the resulting point cloud of the church following geo-registration, respectively. Applications of the resulting 3D model include structural evaluation of buildings, spotting foundation and exterior cladding fractures, roof problems, and degraded mortar.

3.2.10 Seismic hazard assessment

Seismic or earthquake activity refers to the shaking of the Earth's surface caused by the sudden release of energy in the Earth's crust. It is a natural phenomenon resulting from the movement and interaction of tectonic plates. Earthquakes can vary in magnitude, ranging from minor tremors that are barely noticeable to devastating quakes that can cause widespread destruction and loss of life. Characteristics of earthquakes include their magnitude, which measures the energy released during the event, and their intensity, which describes the effects of the earthquake at specific locations. Earthquakes can also be categorized based on their focal depth (shallow, intermediate, or deep) and the type of fault movement (e.g., strike-slip, thrust, or normal). Space technology plays a crucial role in enhancing the study of seismic activity and earthquakes in several ways such as earthquake monitoring through remote sensing instruments which can monitor changes in the Earth's surface and detect movements and deformations that could indicate potential seismic activity. This data helps scientists in understanding earthquake precursors and forecasting seismic events.

Geospatial technology can be used to assess the seismic risk and vulnerability assessment. A study was conducted for Dehradun city, Uttarakhand using the United Nations' Risk Assessment Tools for Diagnosis of Urban Areas Against Seismic Disasters (RADIUS) in a GIS environment. At the start, an earthquake scenario for the study area was presumed (Richter Magnitude = 6.8, Depth of earthquake = 21 km, and Epicentral distance = 13 km). The Peak Ground Acceleration (PGA) values were generated from this scenario earthquake model. The hazard map was prepared from the above analysis as represented by various Modified Mercalli Intensity (MMI) values and possible damages to various structures and lifeline facilities were estimated.

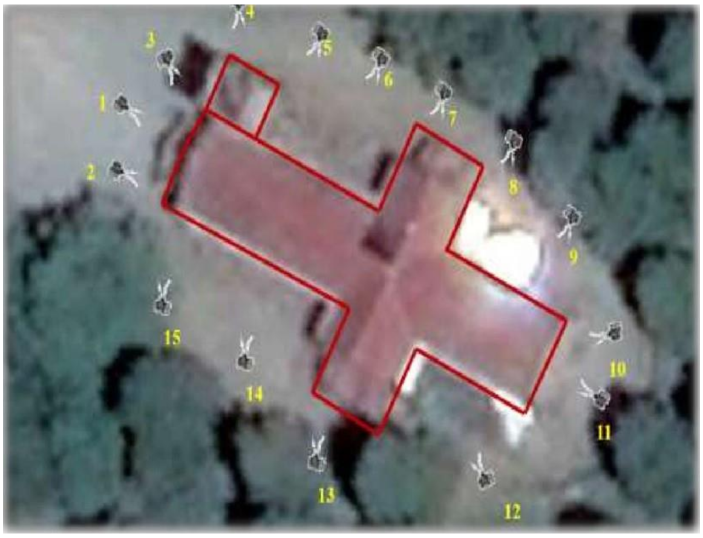

Fig. 3.7 Locations for 3D laser scanning

Fig. 3.8 Resultant point cloud of church after geo-registration

The majority of the building stock in the old city areas including Khurbura, Lakhi Bagh, and Jhandawala was found to be old and out-of-date, making them particularly vulnerable to damage. The slum communities near the Bindal and Rispana rivers were found to be most impacted as the majority of the building were informal or of low quality. The areas around Rajpur Road, Ballupur, and Vijay Park that have recently been developed will be least affected because of new construction in these areas in accordance with engineering codes. Fig 3.9 displays the overall number of damaged structures (in percentage terms) by ward. These findings may be quite significant since they will help planning organisations better comprehend the effects of earthquakes, should one occur near some urban areas (Maithani and Sokhi, 2004).

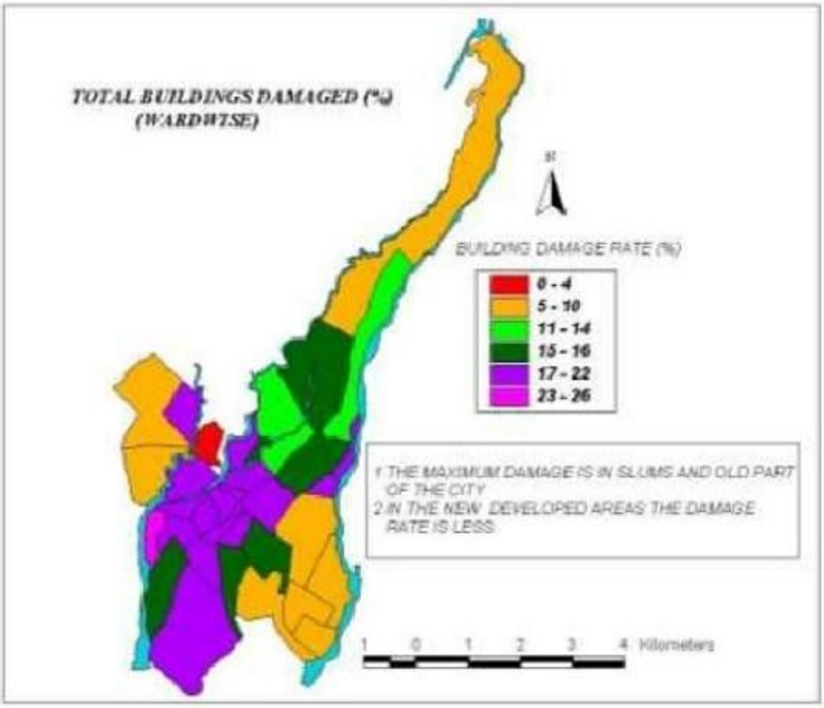

Fig. 3.9 Total buildings damaged (in percentage) ward wise (Source: Maithani and Sokhi, 2004)

3.2.11 Tourism potential estimation

Tourism is a significant source of income for many countries in the world. It has an impact on the economies of both the source and the host countries, and in some situations, it is crucial. The maximum number of tourists who can visit a place without destroying its physical, economic, or sociocultural environment or creating an unacceptable decline in the level of visitor happiness is known as the tourism carrying capacity.

The carrying capacity of Nainital town for tourism has been evaluated using remote sensing data and auxiliary data (Kumar et al., 2019). The recent spike in travel to Nainital has resulted in inadequate lodging and infrastructure for visitors, which could be detrimental to the expansion of the tourism business in the area. The number of domestic and international visitors during peak season, the residential population, and the typical number of days that visitors stay in Nainital city were used to estimate the carrying capacity for tourism (UDPFI, 1996). In the current study, high resolution satellite data, a Cartosat DEM with a 30 m resolution, ward maps, land use maps, topographical maps, and the Nainital Guide map were all employed. Secondary data that focused on the perception and opinion of travellers, those working in the tourism industry, and specialists were also taken into consideration. To plan the route for tourism locations such as heritage monuments, lake sites, and adventure tour paths around Nainital town, network analysis was done. Planners can utilise the suggested methods to upgrade infrastructure on schedule. During the busiest times of the year, it has been seen that the number of visitors exceeds the capacity of the infrastructure and facilities used by tourists (Table 3.5).

Table 3.5: Available carrying capacity in Nainital City

District	Tourist Town	Destinations Covered	Carrying Capacity	Existing Load	Available Capacity
Nainital	Nainital	Naini lake, Raj Bhawan, High Court, etc.	67252	78452	-11,199

3.2.12 Solar energy potential estimation

Opportunities to access India's immense energy resources are provided by the country's high rainfall, abundant solar insolation, and large wind-capturing regions. Solar rooftops are a growing source of renewable energy that can be deployed to emphasize the smart city concept. Building footprints and a high-resolution Digital Surface Model (DSM) are two essential inputs in this analysis. For the study region of Gandhinagar, DSM was produced using high resolution Worldview-2 data utilising the digital photogrammetric tool of a GIS software. The two parameters that determine DSM quality are the matching approach and the stereo image orientation quality. In urban regions and open areas, the measured accuracy revealed mean errors of 0.424 m and 0.35 m, respectively. Using the Object Based Image Analysis (OBIA) technique of image segmentation and image classification, which has a 92% accuracy, building footprints were retrieved from the fused (PAN+MSS) image. Based on a method from the hemispherical viewshed algorithm (Rich 1990; Rich et al., 1994) and further improved by Fu and Rich (2000, 2002), total, direct, and diffuse insolation were estimated for built-up areas. The findings revealed that there was enough of insolation over built-up areas from April to October (Fig 3.10).

Fig. 3.10 Global Radiation in Wh/m^2

3.2.13 Air pollution in urban areas

Anthropogenic activities cause air pollution, which is a serious issue. For eight Indian cities with populations of five million or more (Delhi, Ahmedabad, Kolkata, Mumbai, Hyderabad, Chennai, Bengaluru, and Pune), a study was conducted that focused on analysing the gaseous pollution scenarios before and during lockdown using satellite (Sentinel-5P datasets) and ground-based measurements (Central Pollution Control Board's Air Quality Index). Pre-lockdown period (11 March – 23 March 2020), Lockdown-1 period (LD 1) (24 March – 7 April 2020), and Lockdown-2 period (LD 2) (8 April – 21 April 2020) scenarios were all considered in the investigation. The major reduction in values as seen through Sentinel data can be seen in Delhi, where maximum and average values decreased by 70%. This is followed by maximum NO_2 values in Bengaluru (63%), Mumbai (57%), Ahmedabad (56%), Hyderabad (49%), Pune (37%), Kolkata (34%), and Chennai (33%). The two-week mean value of NO_2 spatial analysis showed a decrease in the values when compared with the status in 2019 (first lockdown period) and when analysed w.r.t. pre-lockdown scenario (46% reduction in LD 1), which then rose nominally in the LD-2 period (5-10%) for the eight cities with populations of five million people or more alone. Additionally, it was found that regions with high long-term NO_2 exposure were associated with 53% of Corona positive cases and 61% of fatality cases in just the eight largest cities in the nation (Fig 3.11) (Siddiqui et al., 2020).

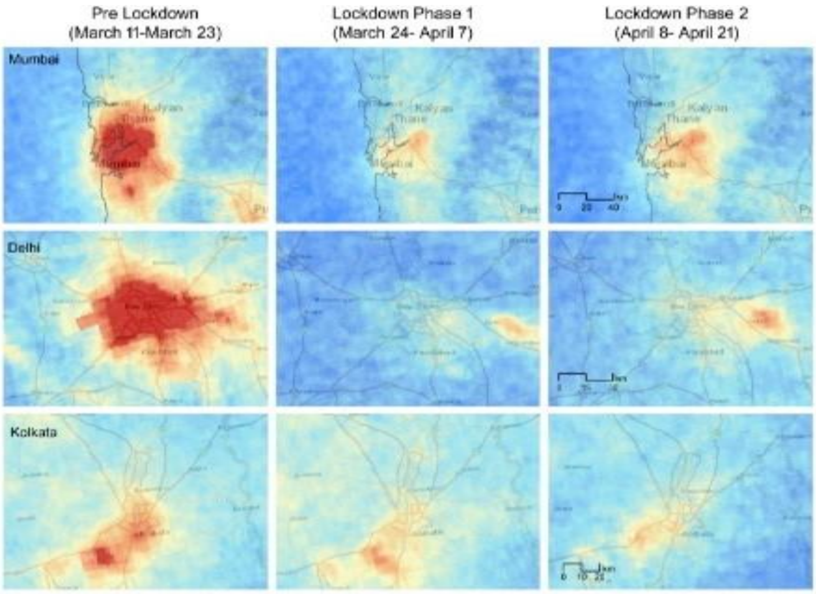

Fig. 3.11 NO2 levels in Indian cities during Pre-lockdown and during lockdown (1 and 2) (Siddiqui et al., 2020)

3.2.14 Urban Heat Island (UHI)

Thermal remote sensing is an effective method for examining the factors that influence shifting land use patterns and, in turn, the urban heat island (UHI) effect. The thermal infrared data can be used to examine metropolitan areas' UHI and manage their open spaces appropriately.

A study conducted on the urban agglomeration of Dehradun revealed that the average LST has increased by 14.8% between 2000 and 2010 and by 11.8% between 2010 and 2019. It was estimated that urban densification, urban geometry (reduced sky view factor, urban canyons), and near ground sources of anthropogenic heat (traffic, commercial activities, and air conditioners) were the main causes of the increase in LST values. While cold spots correspond to locations with natural and semi-natural vegetation, LST hot spots were discovered in areas near dry water bodies, urban built-up areas, certain cultivated and controlled areas, and bare soil. While the proportion of all other land cover fell, the percentage of urban built-up areas inside hotspots climbed from 6.8% in year 2000 to 27.86% in year 2019, and the percentage of suburban built-up areas also increased from 1.36% to

20.08% in year 2019 (Fig 3.12). Urban bodies can create suitable LST mitigation measures using the suggested methodology (Nautiyal et al., 2021).

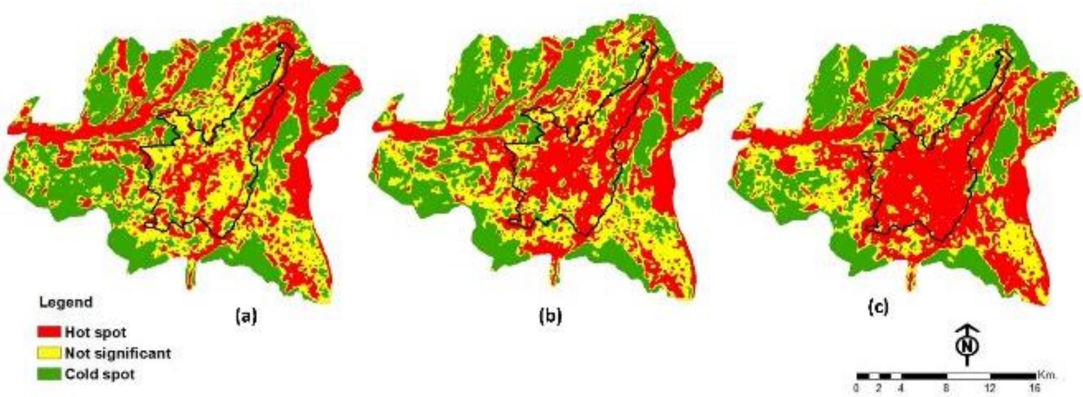

Fig. 3.12 Spatial distribution of hotspots in Dehradun urban agglomeration on (a) 19 February, 2000, (b) 29 January, 2010, (c) 23 February, 2019 (Source: Nautiyal et al., 2021)

3.2.15 Characterisation of urban materials

An interesting topic of research nowadays is the identification of materials in an urban environment utilising hyperspectral remote sensing techniques. In terms of urban heat islands (UHIs) and urban pollution islands (UPIs), the characterization of materials in an urban setting is crucial in determining the environmental regime. From the reflectance image taken by the Airborne Visible InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG) over a section of Ahmedabad city on February 11, 2016, the research seeks to locate the pure endmembers. The various materials used in the scenario are represented by the pure endmembers. To improve the interactive extraction of materials that are present, the endmembers are extracted on a spatially and spectrally reduced dimension of data. On the data, an improved matched filtering (MF) technique known as MTMF was used.

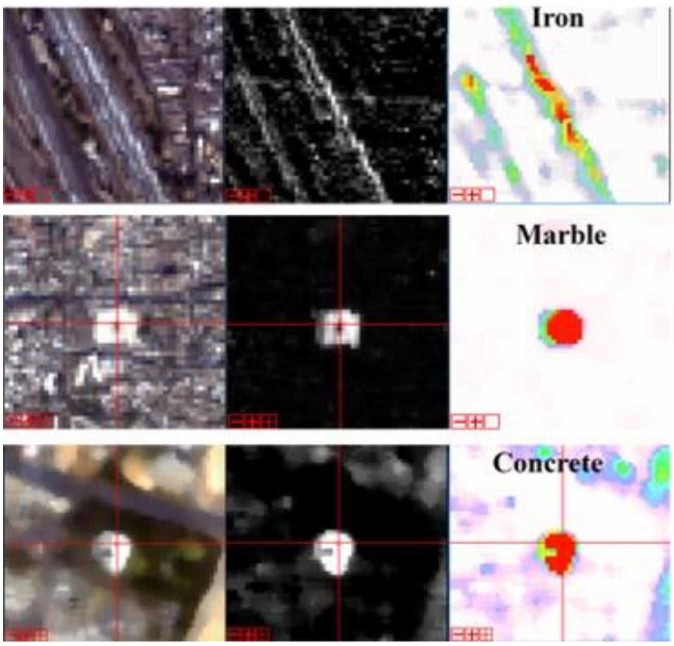

Fig. 3.13 Identification of urban materials using MTMF technique for Ahmedabad (Siddiqui et al., 2022)

On the data, an improved matched filtering (MF) technique called MTMF was used to estimate abundance images, which denote the existence of a particular chemical composition in a given pixel. The technique used made it possible to obtain endmember abundance images while describing the presence of particular urban materials as concrete, asphalt, tin, and china mosaic tiles, among others (Fig 3.13) (Malleswara et al., 2022; Siddiqui et al., 2022; Singh et al., 2019).

3.2.16 Urban features extraction using UAV datasets

Urban planning, governance, environmental analysis, agricultural research, etc. are just a few of the remote sensing applications where imaging systems based on Unmanned Aerial Vehicles (UAVs) have been shown to be useful. UAVs offer a number of advantages over conventional remote sensing platforms, including enhanced speed, safety, and flexibility while collecting data at a lower cost. In addition, UAVs may fly rather close to the target, producing photographs with incredibly high quality. A DJI Phantom-4 pro UAV with a non-metric camera and visible colour bands (red, green, and blue) was utilised in a study at Roorkee, Uttarakhand to collect the UAV datasets. A set of 102 photos with a ground sampling distance of 1.79 cm from the ground while flying at a height of 150 m were collected (Jain, 2019). The orthomosaic image with the DSM was created after processing the UAV images that had been collected. An integrated dataset made up of orthomosaic images is then segmented using the Multi Resolution Segmentation (MRS) approach. After the image has been segmented with MRS, the resultant image objects were categorised using OBIA. Rulesets were developed using object measurements prior to classifying image objects. Scale, form, and size are discovered to be the best segmentation characteristics for extracting urban zones. A UAV and OBIA approach can be used to update maps quickly and effectively, especially in metropolitan areas where conditions change often.

3.2.17 Urban flood risk modelling

Rapid urbanisation promotes urban floods and water logging by causing habitations to encroach on low-lying, natural regions, flood plains, and frequently drainage routes. Additionally, as cities get more populated, impermeable surfaces expand. This causes runoff to significantly increase and eventually overwhelm storm water drainage systems, exceeding their design capacity. With reference to the hydro-dynamic setup of the cities of Bhubaneswar (Bhattacharjee et al., 2021) and Dehradun, as well as their levels of urbanisation, studies have been done to assess the danger associated with water-logging conditions in urban regions. Utilising the elevation, slope, LULC, rainfall conditions, and the city's built storm water drainage infrastructure, the Storm Water Management Model (SWMM) was used to estimate the runoff depth, extent, peak flow, and intensity of floods.

LULC map of the study area was created using the IRS LISS-IV (MS) and Cartosat-2 (PAN) integrated product. To assess the drainage system's capacity for various return periods of rainfall, the design infrastructure for the storm water drainage (SWD) channels has been gathered. An extremely severe rainfall instance of 122 millimetres in 24 hours was estimated to result in average water accumulation of between 0.3 and 0.6 metres, with some regions even reaching 1.5 metres of depth in 24 hours. The intensity of risk increases as against different return periods of heavy rainfall events due to rise in the level of water accumulation (Fig 3.14). The study demonstrates the utility of geospatial techniques in understanding the risk of urban flooding caused due to high rainfall events and consequently helpful to urban planners towards managing the storm water drainage (SWD) systems.

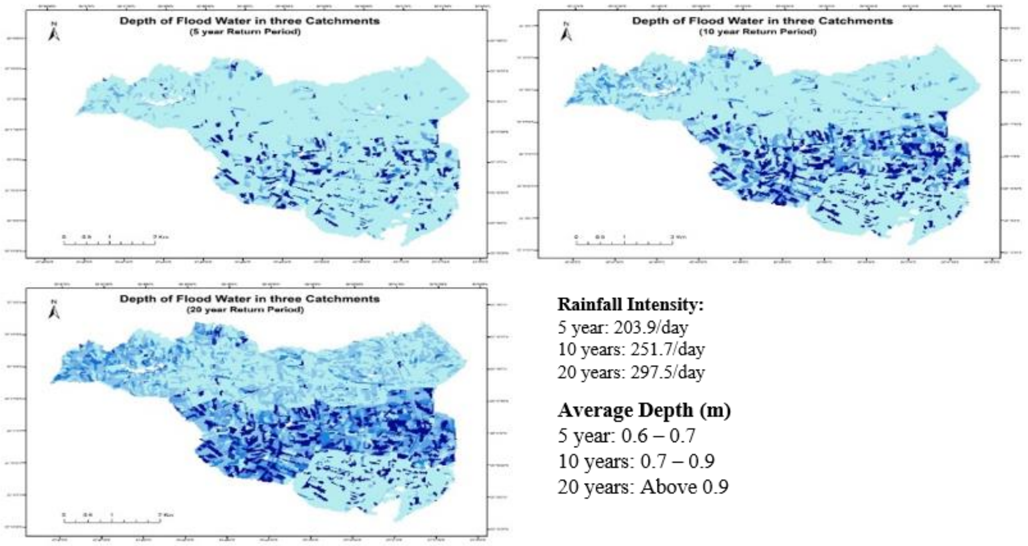

Fig. 3.14 Urban flood risk analysis (Source: Bhattacharjee et al., 2020)

3.2.18 Urban water distribution modelling using geospatial techniques

Water Utilities form the core part of any urban infrastructure. However, in developing countries, the existing Water Distribution System (WDS) has many deficiencies such as smaller pipe diameter for water distribution mains, lack of storage tanks, and uneven distribution of water supply. To overcome all these deficiencies, the urban development authorities can use hydraulic modelling tools like Environmental Protection Agency Network (EPANET) along with geospatial data as inputs for efficient planning and on ground implementation of WDS in the cities. The spatial database of the Water Distribution System (WDS) for the city of Dehradun has been created in the current study using a Geographic Information System (GIS) environment, drawing data inputs from various sources including satellite images, scanned maps, Computer Aided Design (CAD) files, Global Positioning System (GPS), Ground Penetrating Radar (GPR), and water utility surveys. The existing as well as future water demand for the city has been estimated using various methods of population projections considering the growth potential of different wards in the city. Further, water supply-demand gap analysis has been done using this geospatial database. Using EPANET 2.0, the existing WDS of Dehradun has been analysed to check for its reliability in current and future scenarios.

The existing 564 km distribution network was mapped, and it showed that PVC and asbestos cement pipes made up more than three-fourths of the system. Following validation using Ground Penetrating Radar (GPR) and database updates for pipe diameter, an accuracy of 93% was attained. The population Figs for 2041 have been projected using comparative method of population projection incorporating future growth potential of the city by land suitability analysis using Analytical Hierarchy Process (AHP). Decadal growth rates for decades 2011-2021, 2021-2031 and 2031-2041 were obtained as 36.39%, 30.83% and 26.72%, respectively and projected population as 10,26,200 (year 2041) for sixty municipal wards of Dehradun city. Despite having a surplus of water, Dehradun has water scarcity, primarily because of the inadequate state of the WDS that is now in place, according to supply-demand gap study. There is a bad practise of pumping water directly from tube wells into the network, storage tanks are needed at least at 29 points in the network, and 27% of the current pipes are smaller than the lowest permitted criteria. EPANET 2.0's extended period simulation of the network for a full day allowed for the identification of crisis locations with extremely low or negative water pressures (Fig 3.15).

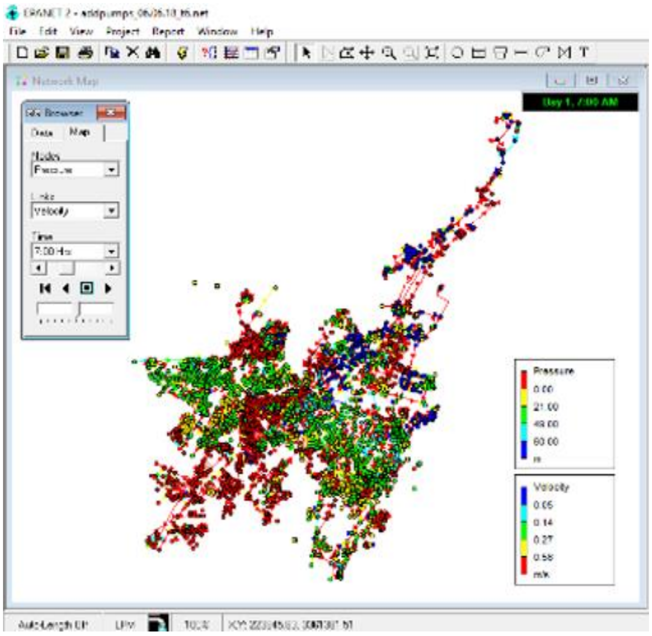

Fig. 3.15 EPANET Simulation results (Jaiswal et al., 2021)

The total absolute water supply after consideration for losses is 188 MLD and demand is 117 MLD in 2016. Through model simulation, it is observed that total supply-demand gap will become negative in the year 2041, if current scenario continues and adequate steps are not taken to conserve water and whole city will face huge water crisis. The upgraded WDS of Rajender Nagar area of the city was also checked for its current and future feasibility in EPANET and it was found to be adequate for meeting the future water demands. The model outputs showed that no problem of negative pressures exist even in the morning peak hours when total demand reached up to 25,000 LPM. Least pressure existing anywhere in the network was obtained as 13.85 m. Thus, it can be concluded that a GIS based water utility mapping and asset management is the need of the hour for our civic authorities to efficiently manage and conserve water as precious resource for future (Shrivastava et al., 2018; Jaiswal et al., 2021).

3.2.19 Urban canopy parameters computation using 3D databases in GIS

Urban Canopy Parameters (UCPs) significantly impact the UHI formation and natural ventilation in urban areas. A software has been developed for the computation of key aerodynamic UCPs such as Frontal area index, Sky View Factor and Height-to-Width Ratio (Jhaldiyal et al., 2018). Out of five cities selected in varied climate zones of India, 2D and 3D Urban Canopy parameters were computed for three cities: Delhi and Chandigarh (Composite climate), Bhubaneshwar (Warm and Humid) for urban climate studies. The retrieved vegetation and building heights from high resolution optical stereo data are shown in the Fig 3.16. The class-wise error analysis of building heights reveals RMSE values of <1 m in all classes.

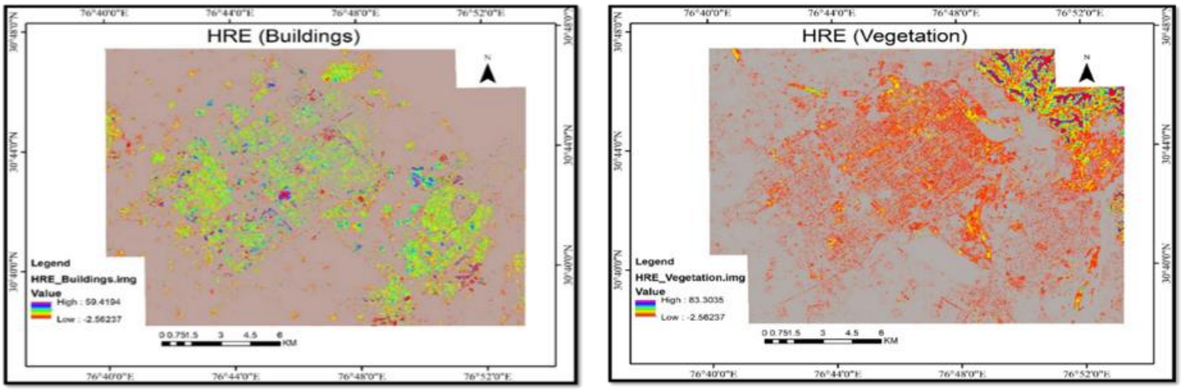

Fig. 3.16 Vegetation and building canopy in Chandigarh (Source: Jhaldiyal et al., 2018

3.2.20 Polarimetric SAR data for urban LULC

Information on urban LULC is crucial for land use planning, legislation, and effective utilisation. Urban classes generally have a tendency to blend with a number of non-urban classes, which prevents their automated classification. Data from polarimetric SAR reduces the mixing of urban and nonurban classes. Built up and non-built up are automatically distinguished using speckle divergence of single Pol HH data speckle divergence. The transmission parameters of the SAR system are influenced by the electromagnetic waves (EM) wave's significant polarisation property. Polarisation, which can be horizontal, vertical, or at any angle, refers to the orientation of the electric field plane with respect to the plane that is orthogonal to its plane of propagation. On polarised data, various decomposition techniques are used for various urban types. To enhance urban LULC categorization, a novel complementary information strategy has been presented by Tripathi et al. (2023).

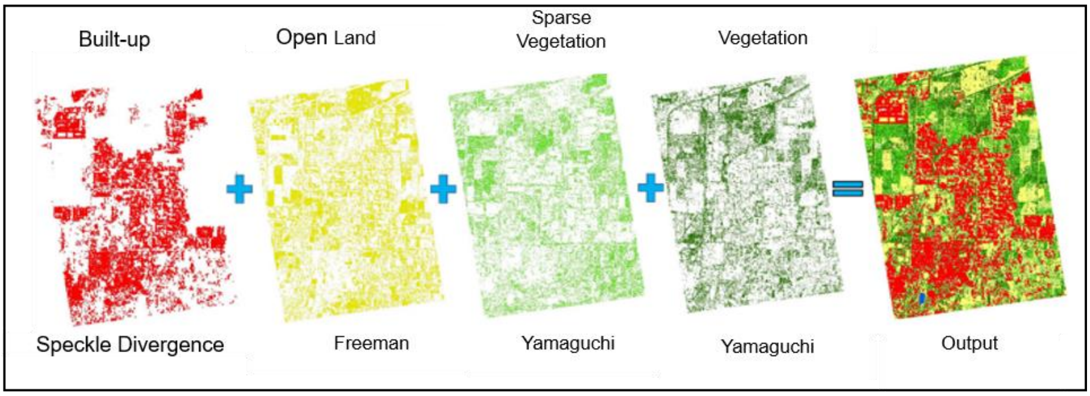

Fig. 3.17 Urban LULC using Microwave data (Source: Tripathi et al., 2023)

Overall accuracy of this complimentary information approach showed better accuracy as compared to traditional methods. There is about 3% overall accuracy improvement as compared to other classified traditional methods. Overall accuracy of the classified image through complimentary information is 83.33% and kappa statistics is 0.80 (Fig 3.17).

3.3 Conclusion

Remote sensing and GIS are becoming essential tools for planners due to their distinct advantages in terms of timeliness, repetivity, real-time data reception and transmission, and computer compatibility. Thus, in the current context of rapid urbanisation and urban growth, the methods suggested above can offer solutions to urban, rural, and regional planners in meeting many of the mapping and other physical data requirements, and with support from GIS and GPS systems, the data analysis can be carried out for urban and environmental planning.

Urban, rural, and regional planners must be as soon as possible provided with these cutting-edge tools and information system technologies for mapping and analysis if they are to effectively address the global phenomenon of urbanisation, particularly in the Indian context. We cannot afford to delay the use of such systems or methodologies any longer. The methods and techniques mentioned above can therefore help urban/rural and regional planners in meeting the majority of the mapping and other physical data needs in the current situations of rapid urbanisation and fast rural to urban immigration leading to spontaneous settlements, and as such are indispensable and imperative.

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Chapter 4

FOREST RESOURCE APPLICATIONS

4.1 Introduction

Forests are the natural resource, which provides mankind with numerous benefits both in goods and services. Managing this important resource base both spatially as well as temporally dynamic, can be a daunting task without the utilization of proper spatial tools. Space technology has an immense influence on the decision-making processes especially in areas like forest resource management. Remote sensing as a tool has facilitated a systematic and hierarchical approach of forest resources assessment and its monitoring using sensors of different spatial and spectral capabilities, the characterization, quantification, and monitoring including specific efforts toward understanding the structure, composition, and function of different natural habitats/ecosystems. Studies have provided key inputs for the regulation of the impact of developmental activities and to sustain the delivery of natural ecosystem goods and services. Forest resource assessment in India is being carried out at different levels e.g., bi-annual forest cover mapping using satellite remote sensed data.

With the availability of basic spatial coarse-scale databases of forest type and forest inventory etc., for important ecosystems, efforts have been made for understanding the ecosystem's structure and processes. The spatial information generated using remote sensing data is used in conjunction with ground-based information in the geospatial domain. Subsequently, values have been added in terms of spatially explicit quantification for growing stock and biodiversity assessment. Process understanding related to landscape change and simulation, carbon sequestration, hydrology, generic ecosystem patterns, species niche models, and regional climate models has also been addressed. The web-enabled information systems with significant impact factors are also useful to efficiently process, query and disseminate the data.

Optimal sampling designs for forest timber volume estimation; Automated forest cover retrieval and change assessment; Species exploration and niche modelling; Biodiversity monitoring and change modelling; Vegetation stress analysis; Forest ecosystem responses to climate change and anthropogenic impacts; Ecological Foot Printing analysis for sustainable development and Forest vulnerability and change assessment are the thrust areas identified for the retrieval of forest parameters using high resolution and hyperspectral data. But gaps in the information still exist in areas like forest fragmentation causes, invasion of exotics, rapid fire alarm system, shifting cultivation assessment, and biodiversity assessment. This can be achieved through the development of advanced sensors with combined capability of higher spatial and temporal resolution as well as enhanced spectral capabilities. Ground-based information database is also lacking in the Indian sub-continent region and this needs to be looked into urgently for a spatial understanding of the ecosystem processes and their subsequent upscaling for regional-level management.

4.2 Global and National Issues, Scenarios, and Developments

4.2.1 Global Scenario

Retrieving information about forest resources is a process for obtaining information on the quality and quantity of forest resources and forms the foundation of forest planning and forest policy. While early concepts of sustainable forest management and forest inventory focused on timber production, modern forest inventory concepts support a holistic view of forest ecosystems addressing not only timber production but also the multiple functions of the forest as well as the need to understand the functioning mechanisms of forest ecosystems.

Forest resources assessment facilitates a multifaceted analysis and study of forests is not only an important source of subsistence, employment, revenue, earnings, and raw materials to a number of industries but also critical for their vital role in ecological balance, environmental stability, biodiversity conservation, food security, and sustainable development of countries and the entire biosphere. Forests have to be managed judiciously not only for environmental protection and other services but also for various products and industrial raw materials. In some parts of the world biological resources are being depleted faster than they can regenerate. Following the 1992 United Nations Conference on Environment and Development (UNCED) conference in Rio de Janeiro, considerable progress has been made in the area of sustainable forest management (Table 4.1). For example, the International Tropical Timber Organization (ITTO) and the Forest Stewardship Council (FSC) developed criteria and indicators for sustainable forest management and certification. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) describes measures to mitigate greenhouse gasses effects and addresses in Article 3.3 in particular the impact of deforestation and afforestation on global climate change. The Convention of Biological Diversity (CBD) which was ratified in 1994 deals with the protection and maintenance of biodiversity.

Table 4.1 Increase in information needs about forest lands in the USA (Source: Franklin, 2001)

Timber	Multiple resources Timber	Biomass Multiple resources Timber	Global warming Biomass Multiple resources Timbers	Ecosystems Biodiversity NWGS Global warming Biomass Multiple Resources Timber	Non-forest lands habitats, old growth and primary forests Ecosystems biodiversity NWGS Global warming Biomass Multiple resources Timber
1950s	1960s	1970s	1980s	1990s	2000+

The information requirements from forest owners, policy planners, the scientific community, and society, in general, concerning forest resources have been growing steadily since the 1950s when the main focus was on information about timber supply. The multiple functions of forests biomass, global warming, biodiversity, and non-wood goods and services have since gained prominence.

The thematic scope of forest inventories can vary considerably. UNCED criteria and indicators for sustainable forest management have been formulated through several international, national, and nongovernmental processes. These include the Pan-European (or Helsinki) process (for European forests), the Montreal Process (for temperate and boreal forests), the Tarapoto Proposal of Criteria and Indicators for Sustainability of the Amazon Forest the United Nations Environment Program (UNEP) Food and Agriculture Organisation (FAO) Expert Meeting on Criteria and Indicators for Sustainable Forest Management in Dry-Zone Africa, or the Lepaterique Process of Central America. The ITTO, the Tarapoto Process (TARA), the Centre for International Forestry Research (CIFOR), the African Timber Organization (ATO), and the Central American Commission for Environment and Development (CCAD) developed systems of criteria and indicators for sustainable forest management which cover administrative, economic, legal, social, technical and scientific issues which affect natural forests and plantations. The criteria define the essential factors of forest management against which forest sustainability may be assessed. Each criterion relates to a key management factor which may be described by one or more qualitative, quantitative, or descriptive indicators. Through measurement and monitoring of selected indicators, the effects of forest management action, or inaction, can be assessed and evaluated and action adjusted to ensure that forest management objectives are more likely to be achieved. Table 4.2 summarizes the criteria and indicators identified by the processes and initiatives and should facilitate the definition of inventory objectives.

Table 4.2 Criteria and indicators for sustainable management.

Extent of forest resources and global carbon cycles
Area of forest cover
Wood-growing stock
Successional stage
Age structure
Rate of conversion of forest to other use.
Forest ecosystem health and vitality external influences
Deposition of air pollutants
Damage by wind erosion
Forest vitality indicators
Incidence of defoliators
Reproductive health
Forest influence indicators

Insect / disease damage
Fire and storm damage
Wild – animal damage
Anthropogenic influence indicators
Competition from introduction of non-native plants
Nutrient balance and acidity
Trends in crop yields
Biological diversity in forest ecosystem
Ecosystem indicators
Distribution of forest ecosystems
Extent of protected areas
Habitat suitability
Forest fragmentation
Area cleared annually of endemic species
Area and percentage of forest lands with fundamental ecological changes
Forest fire control and prevention measures
Species indicators
Number of forest- dependent species
Number of forest-dependent species at risk
Reliance on natural regeneration
Resources exploitation systems used
Measures for in situ conservation of species at risk
Genetic indicators
Number of forest-dependent species with reduced range

Productive functions of forests
Percentage of forests/other wooded lands managed according to management plans
Growing stock
Wood production
Production of non-wood forest products
Annual balance between growth and removal of wood products
Level of diversification of sustainable forest production
Degree of utilization of environmentally friendly technologies

4.2.2 National Scenario

The Indian sub-continent is known for its diverse bioclimatic regions supporting one of the richest flora and fauna in the world. The continent is a confluence point of three major terrestrial biogeographical realms (viz., the Indo-Malayan, the Eurasian, and the Afro-tropical) and the Antarctic realm and is ranked as one of the mega-biodiversity countries in the world. India has a forest cover of 713,789 km^2, covering 21.71% of the total geographic area of the country (FSI, 2021). Forests are widely distributed in the country across different bioclimatic and topographic zones. Indian forests offer valuable ecosystem services such as carbon sinks, soil erosion control, flood mitigation, and various goods. Much of the demand for timber, fuel wood, and fodder is met through these forests. The need for understanding and assessment of this multiplicity of biodiversity in terms of ecosystem services and goods is important to design appropriate conservation strategies. The standing stock volumes and the volume of wood removed indicate the condition of the forests and the economic and social utility of forest resources to national economies and local communities. This information contributes to monitoring the use of forest resources by comparing actual removal with the sustainable potential.

Besides, there has been growing recognition of the role of Non-Wood Forest Products (NWFPs) as an integral part of sustainable forest management in developed and developing countries. A wide variety of products are collected from forests, woodlands, and trees outside forests – a major portion of which are consumed by households or sold locally, while some find export markets. Understanding the potential contribution of NWFPs to sustainable rural development, especially in poverty alleviation and food security, requires good statistical data, which in most cases are gathered sporadically and are often unreliable.

Traditional rural populations, particularly the tribes/ aboriginal people depend heavily on a very large spectrum of bioresources associated with forest landscapes. The disproportionate demand and destructive methods of extraction have put unreasonable pressure on our wild Phyto resources. Due to this, a pressing need is felt to have a reliable database of Phyto resources such that a sustainable strategy can be formulated. Anthropogenic pressures are taking a heavy toll on the country's forests. Disturbances, such as forest fire, shifting cultivation, grazing, mining activities, and construction of dams, agricultural conversions, and urbanization are the prominent ones. In view of the above, the precise estimates of bioresources, their availability, location, and extent, extraction and renewal systems are very important.

4.3 Remote sensing applications in forestry

Forestry or vegetation science is one of the established and well-flourished branches of science and we have at least one century-old tradition of forestry management records. Similarly, in the last decade, several ecology and forest schools have contributed significantly to the development of basic concepts on the structure and function of ecosystems. However, these so-called conventional methods standalone had several limitations. One of them was that they were not spatially explicit as well as there was a lot of difficulty in revising those observations as well as there was no surrogate available to model them for different scenarios or different niche conditions. Here came the advantages of remote sensing technology. With the mapping and stratification through remote sensing, the area coverage could be very large with even low-intensity sampling by taking advantage of stratification. The temporal revisit of the satellites has made it possible to assess and analyse changed scenarios with better accuracy and precision. Satellite data is collected using remote sensing sensors deployed on satellites orbiting the Earth. These sensors include optical, microwave, and LiDAR sensors. Optical sensors capture data in the visible, near-infrared, and shortwave infrared portions of the electromagnetic spectrum, providing information about the Earth's surface, vegetation, and atmosphere. Microwave sensors operate in the microwave spectrum, penetrating cloud cover and capturing data on precipitation, soil moisture, and sea ice. LiDAR sensors use laser pulses to measure distance and provide high-resolution elevation and terrain data. These sensors contribute to our understanding of the Earth's environment, with resolutions ranging from sub-meter level for optical sensors to tens to hundreds of meters for microwave sensors and a few centimeters to meters for LiDAR sensors.

Additional applications include forest land appraisal, timber harvest planning, monitoring, logging and reforestation, planning and assessing plant vigor and health in forest nurseries, mapping “Forest fuels” to access fire potential, planning fire suppression activities, assessing potential slope features and soil erosion, planning forest roads, inventorying forest recreation resources, assessing wildlife habitat, and monitoring vegetation regrowth. The terrestrial vegetation systems like forests, grasslands, scrub, and agriculture provide unique reflectance properties of electromagnetic radiation received enabling to characterize using satellite remote sensing. In view of the very large extent and heterogeneity of the country, modern tools like satellite remote sensing technology which can help in deriving synoptic and periodic information on bioresources from forests, grasslands, and scrub is considered as one of the potential complementary tools for conventional ground assessment.

Acquisition of images of earth from space has opened new frontiers in mapping. The multi-spectral satellite images provide definitions of vegetation patches, which are related to phenological types, gregarious formations and communities occurring in unique environmental setup. The temporal images help in monitoring all back processes a landscape has experienced (Delcourt and Delcourt, 1988). Improvements in spatial resolution have enabled the availability of data in varying scales (Fig. 4.1).

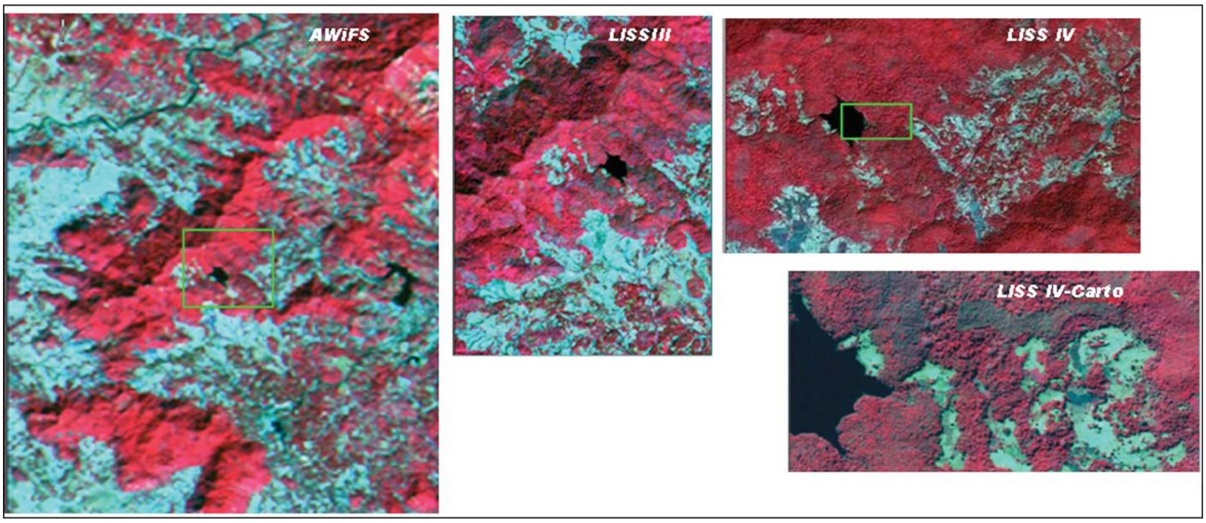

Fig. 4.1 Scale diversity of remote sensing data

The role of multi-spectral, multi-resolution sensors in quantifying the various forestry components as well as their sensitivity is described in Tables 4.3-4.5.

Table 4.3 Role of multispectral RS derived parameters for various forestry components (H-high; M-medium; L-low) (Murthy & Jha, 2010)

S. No	Parameter	Pigmentation	Canopy structure and gaps	Composition	Temperature canopy water regimes
1	Phenology	H	M	H	M
2	Crown Closure	L	H	L	L
3	Vegetation Types	M	H	H	M
4	Species	M	H	H	H
5	LAI	H	H	M	
6	Biomass	H	H	H	M
7	Biochemistry	H	L	H	L
8	Transpiration	L	M	H	H

Table 4.4 Sensitivity of RS wavelength bands in the quantification of forestry structural and functional parameters (Murthy & Jha, 2010)

Band	Wavelength (nm)	Description	Where it can be used	Index
Blue	**435-500**			
	415	Chlorophyll degradation, detects early stress	Drought, pathogen attack	NPQI
	420	Plant stress status	Drought, pathogen attack	PI1
	430	Carotinoid/chlorophyll-a content	Senescence, phenology	SRPI
	435	Chlorophyll degradation, detects early stress	Drought, pathogen attack	NPQI
	440	Vegetation health index, chlorophyll fluorescence ratios	Drought, pathogen attack	PI3, PI4
	500	Index of vegetation cover	Primary productivity	SGR
Green	**520-565**			
	531	Xanthophyll light response ~	plant pathogen attack,	PRI
		photosynthetic efficiency, Sensitive to carotenoid/chlorophyll ratio	Senescence	
Red	**565-740**			
	570	Xanthophyll light response ~	plant pathogen attack,	PRI
		photosynthetic efficiency, Sensitive to carotenoid/chlorophyll ratio	Senescence	
	599	Index of vegetation cover	Primary productivity	SGR
	600	Anthocyanins / Chlorophyll		RGR
	665	Index of green vegetation cover	Precision farming, soil organic content	SR, NDVI
	680	Carotinoid/chlorophyll-a content	plant pathogen attack,	SRPI

Band	Wavelength (nm)	Description	Where it can be used	Index
			senescence	
	690	Vegetation health index, chlorophyll fluoresence ratios	Drought, pathogen attack	PI3
	695	Plant stress status		PI1, PI2
	699	Anthocyanins / Chlorophyll		RGR
	705	Leaf chlorophyll content	Detects trace quantities of vegetation cover in arid and semi-arid regions	mNDVI
	740	Vegetation health index, chlorophyll fluorescence ratios	Drought, pathogen attack	PI4
NIR	**750-1000**			
	750	Leaf chlorophyll content	Detects trace quantities of vegetation cover in arid and semi-arid regions	mNDVI
	760	Plant stress status	Drought, pathogen attack	PI2
	800	Carotinoid/chlorophyll-a concentration		SIPI
	840	Discriminates soil and	Precision farming,	NDI, SACRI
		dry matter	soil organic content	
	845	Index of green vegetation cover		SR, NDVI
	860	Leaf water content	Drought, precision farming	NDWI
	900	Leaf water content	Drought, precision farming	WBI
	970	Leaf water content	Drought, precision farming	WBI
SWIR	**1000-3000**			

Band	Wavelength (nm)	Description	Where it can be used	Index
	1240	Leaf water content	Drought, precision farming	NDWI
	1510	Foliar Nitrogen content	Impact of nitrogen loading	NDNI
	1650	Discriminates soil and	Precision farming,	NDI, SACRI
		dry matter	soil organic content	
	1680	Foliar Nitrogen content, Foliar lignin content	Impact of nitrogen loading	NDNI, NDLI
	1754	Foliar lignin content	Non-leaf based biomass	NDLI
	2020	Cellulose & lignin absorption	Precision farming,	CAI
		features, discriminates plant litter from soils.	soil organic content	
	2100	Cellulose & lignin absorption	Precision farming,	CAI
		features, discriminates plant litter from soils.	soil organic content	
	2220	Cellulose & lignin absorption	Precision farming,	CAI
		features, discriminates plant litter from soils.	soil organic content	

Table 4.5 Role of sensors of different spatial resolutions in studying the major forestry components

S. No	Sensors	Greenness	Structure	Composition
1	Coarse (~1 km and more)	H	M	L
2	High (~20-250 m)	H	H	M
3	Very High (~10 m and less)	H	H	H

4.3.1 Retrieval of forest parameters and integrated analysis

Fig. 4.2 explains the conjunctive use of ground data, Remote Sensing, GIS, and GPS in forestry applications. The integrated use of these technologies helps in describing the four major components – the greenness, crown closure, mixed vegetation types, and the species assemblages, both qualitatively and quantitatively. The availability of a large possibility of spatial, temporal, and radiometric resolutions has made it possible to address the described components almost directly. However, ground-measured parameters such as the climatic, topographic, and socioeconomic need to be collected from the ground and integrated with remotely sensed data with the help of various GIS analyses, various forestry products required for the forest managers, researchers and academia can be obtained as shown in Fig. 4.2.

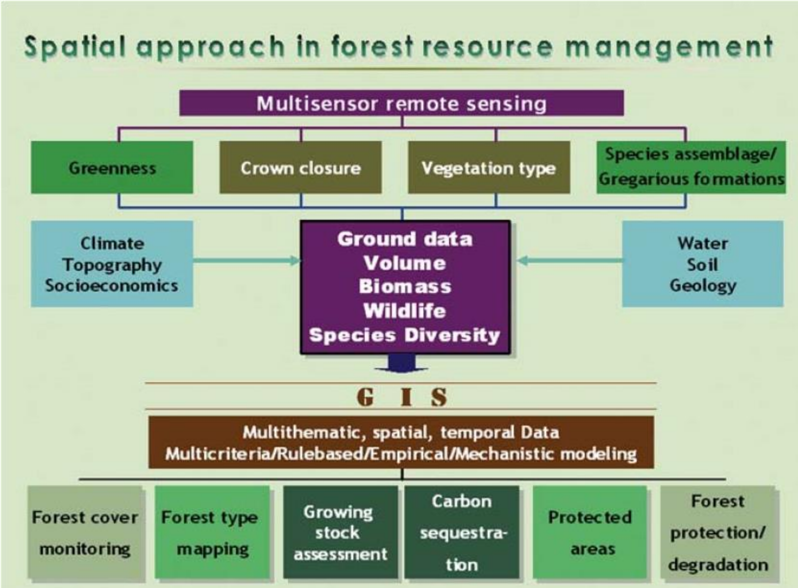

Fig. 4.2 Spatial Resource in Forest Resource Management sensed data into the GIS.

1. Greenness

The seasonality of vegetation also called phenology is one of the key elements of vegetation study. The understanding of greenness amount and its cycle along different season and its spatial distribution is crucial to any climate change study as it is directly linked to the role of vegetation in carbon and water cycle. The leafy biomass controls these two cycles and can be monitored comprehensively through the daily, weekly or seasonally orbiting remotely sensed data. The time series data of spectral vegetation index provide a powerful tool to learn from past events, monitor current conditions and prepare for future change. Comparison of current vegetation data records with historic long-term averages have been used to support ecosystem monitoring, and help evaluate the impact of rising global temperature and CO_2 levels and provide evidence of the impact of the 1989 and 1998 El Niño events around the world.

Global, regional and local natural resource survey and assessment strategies are increasingly incorporating remotely sensed imagery to monitor current and historical vegetation dynamics and often rely on the combined use of multisensory vegetation data. A rising number of national, regional and local users and applications are employing geospatial tools that incorporate time series of spectral vegetation index data and other reference data such as roads, rivers and soil information for spatially and temporally explicit natural resource and agricultural monitoring. Although a variety of satellite sensor options are now available, practical considerations (i.e., data and processing costs, free distribution, the inherent trade-off between spatial and temporal resolution, and the influence of cloud cover) favour platforms that provide frequent images that are systematically processed into products useful for the assessment of vegetation. Two sensors among those that currently meet these criteria are the NOAA Advanced Very High-Resolution Radiometer and NASA's Moderate Resolution Imaging Spectroradiometer. Since SPOT VEGETATION and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) NDVI data are not freely distributed, these data are not included in the analysis. Among other products, both AVHRR and MODIS reflectance data are transformed into the Normalized Difference Vegetation Index, the most widely used vegetation index.

2. Forest type Mapping

i. Digital method:

Multi-spectral images are primarily subjected to digital image classification using both supervised and unsupervised approaches depending upon the land-cover class response in spectral sensing. Supervised classification presumes the occurrence of a Digital Number (DN) value to a particular category. The image processing module is provided with sample areas of distinctive spectral zones over which computation is extrapolated over the whole image. The unsupervised approach generates spectrally explicit classes without consideration for thematic distinction which is subjected to a posteriori grouping. Statistical comparison of each given pixel(s) with overall image statistics in iterative mode helps to cluster spectral associations in an unsupervised technique.

Land cover and vegetation classes of a typical area meant for forest management would usually be patterned with forested, agricultural, and man-made features. Supervised classification is operated upon forested as well as agricultural tracts. Forests stand out uniquely due to the spectral distinction due to grades of foliage prevalence. Agricultural tracts consisting of cropped and fallow areas respond spectrally due to their separate class of near-infrared/red reflectance relations. Bamboo-dominated regions represent another spectral distinction. Other obviously distinguishable categories like water, barren areas, sand could also be recognized spectrally. Specimen spectral signatures are generated using Area Of Interest (AOI) facility in 'Signature editor' in Image processing S/W. The facility captures complete variation in a given irregular patch of pixels in terms of basic statistical parameters for each band viz., near infrared, red etc., which form the centre for segregation of classes. Spectral homogeneity, corresponding generally to a homogenous theme stratum on ground, can be attained either using qualitative visual interpretation or region growing algorithms available. Region growing algorithms search all around the designated pixel for specified DN value range and envelop selected ones for signature collection.

Signature sets thus generated are purified iteratively, based on the contingency matrix depicting commission and omission, as well as using feature space based spectral ellipses of respective spectral classes. Supervised classification algorithm based on maximum likelihood algorithm is operated upon the image using these purified signature sets. The output classes are compared for theme-wise and subjected to class merging, if there is high similarity between classes. Classified image was standardised for required number of land-cover classes and subjected to image smoothing using majority 3X3 filter to dampen spurious noise. These filters consider the modal value of nine pixels and resample the area for proper re-alignment. The area statistics are generated.

ii. Visual method:

The image characteristics of shape, size, pattern, shadow, tone and texture are used by interpreters in tree species identification. For example, individual tree species have their own characteristic crown shape and size. Some species have rounded crowns, some have cone-shaped, and some have star-shaped crowns. Variations of these basic crown shapes also occur. In dense stands, the arrangement of tree crowns produces a pattern that is distinct for many species. When trees are isolated, shadows often provide a profile image of trees that is useful in species identification. In pure stands (plantation), the canopy is regular in pattern and tree height is even or changes gradually with the quality of a site.

Phenological correlations are useful in tree species identification. Changes in the appearance of trees in different seasons of the year sometimes enable discrimination of species that are indistinguishable on a single date. The most obvious example is the separation of deciduous and evergreen trees that is easily made on images acquired when the deciduous foliage has fallen. Visual image interpretation is used extensively for growing stock estimation, biomass and carbon stock estimation. The Primary objective of such operations is to determine the volume of timber that might be harvested from an individual or more stand of trees. To be successful in image-based timber cruising, biomass and carbon stock studies, one requires the skill of an integrated interpretation of both aerial or satellite and ground data. Image measurements on individual trees or stands are statically related to ground measurements of tree volume, biomass and carbon mass in selected plots. The results are then extrapolated to large areas.

The parameters of interest in forestry derived from image analysis most often are

(1) tree height or stand height,

(2) tree-crown diameter,

(3) density of stocking, and

(4) stand area, etc.

3. Preparation of Forest Crown Density Maps

Forest crown density is used as one of the critical parameters in forest cover assessment, growing stock estimations and monitoring in India. Satellite remote sensing-based crown density mapping started during 1984 and technology is made as operational activity at national level. Since then, Forest Survey of India has carried out nine national biennial surveys using remote sensing. Since 1995 IRS LISS II and LISS III sensors satellite data with 36.25 and 23.5 m resolution respectively are used for the purpose. With the increasing spatial resolution of the sensors and the advancement in satellite data processing, the crown density mapping has progressed from two crown density classes viz., 10-40% and >40% to three crown density classes 10-40%, 40-70%, >70%. Based on the latest report of 2021, national forest cover is estimated as 713,789 km^2 covering 21.71% of the total geographical area of the country. This database also stands as one of the important inputs for national forest growing stock assessments.

Detailed forest crown density mapping with crown density interval of 20% is also prepared using IRS PAN, IRS LISS IV sensors' data at 1: 25,000 scale for forest division and micro level planning. These databases are used for monitoring and evaluation of afforestation, reforestation activities and as stratification input for developing optimal sampling designs for growing stock assessments. Based on the forest crown density levels, rehabilitation and selection working circle are demarcated to facilitate conservation and harvest plans respectively. With the availability of CARTOSAT, IKONOS and QUICKBIRD series of satellite data, detailed forest crown-based information viz. crown diameter, number of crowns, degree of overlap etc., are amenable for mapping. These data bases are prepared for microlevel monitoring and forest condition assessment. Based on the interpretation key developed as shown in (Fig. 4.3), the respective satellite data is interpreted for forest crown density delineation on screen-based standardisation and correlation from field experience along with ancillary information available. High-resolution satellite images are essential in generating precise forest crown density maps. These images are acquired from satellites equipped with advanced sensors capable of capturing fine details of the Earth's surface. Through a series of preprocessing steps, including image correction and enhancement, the satellite data is prepared for analysis. Using classification techniques, forested areas are identified, and tree crown segmentation is performed to isolate individual tree canopies. By analyzing the size, shape, and arrangement of these segmented crowns, metrics such as crown cover and canopy closure are derived to estimate the forest crown density. These maps provide valuable insights for forest management, ecological research, and monitoring changes in forested areas.

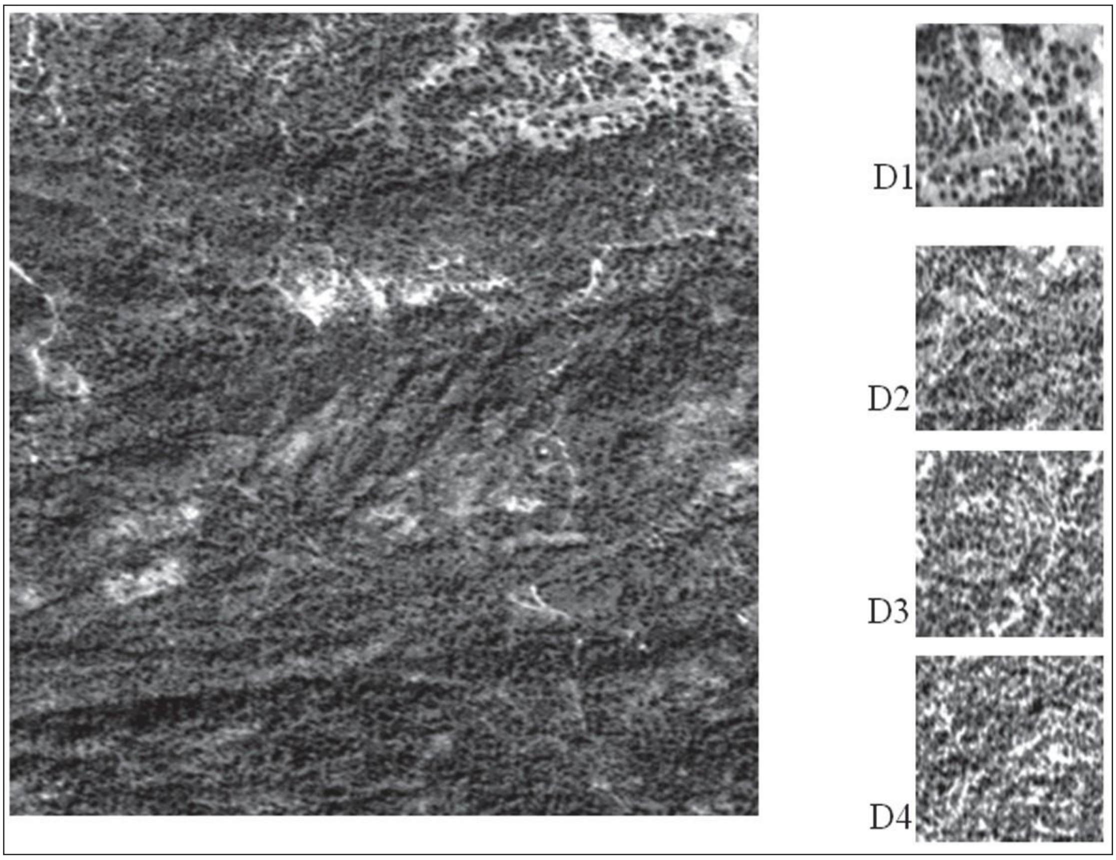

Fig. 4.3 IRS Pan data for forest crown density mapping

Chandrashekhar *et al.* (2005) demonstrated the test-assessment and practicability of forest canopy density mapping using satellite remote sensing data and biophysical spectral response modeling. Forest canopy density stratification through object-oriented image analysis and conventional method of visual interpretation also have been compared with the Forest Canopy Density (FCD) Mapper semi expert system (Nandy et al., 2003). Similarly, Roy et al. (1996) conducted a study in which a three-way crown density model was developed for the classification of forest crown density classes which utilizes the vegetation index, bare soil index and canopy shadow index.

4. Forest Quantification - Inventory Approaches

The precise estimation of forest ecosystem parameters depends on the efficiency of three stages of quantification process viz. design stage, estimation stage and inference stage. The design stage means selecting the design by which the data is gathered, the estimating stage selecting and using the estimators for the parameters of interest i.e., population means and totals, and the inference stage analyses the accuracy of these estimators i.e., calculation of standard errors and confidence levels. Sampling methods, plot size and shape, and sample size determination are crucial elements in data collection for research purposes. Random sampling involves selecting individuals or elements randomly from the target population, while stratified sampling divides the population into homogeneous groups for sampling. Cluster sampling involves selecting clusters of individuals, and systematic sampling selects elements at fixed intervals. Plot size and shape vary based on research objectives, ranging from small units to large areas. Sample size determination considers factors like desired precision, population variability, sampling method, and research goals. Proper consideration of these factors ensures the collected data is representative and reliable for drawing meaningful conclusions.

Geoinformatics based approaches involving remote sensing, GIS, GPS and information science enhances the development of reliable, time and cost-effective approaches. In forested ecosystems selected features are typically identified by their location. Consequently, any quantitative assessment needs spatial perspective: sampling in space. There are two scientifically robust approaches for sampling and extrapolating from a sample to an entire population i.e., design and model-based methods. The key difference between the design and model-based approaches lies in the source of randomness they utilize. Both these approaches are effectively used in the development of different quantitative database on growing stock, biomass and species diversity in the country.

5. Forest Quantification – Biomass, LAI

One of the important ways of enhancing the efficiency of estimation is to bring out reliable stratification of the complex population and optimally sample subpopulations. The satellite remote sensing provides precise stratification in terms of forest crown density, vegetation types, communities and species formations which can form the basis for reducing the strata variance and make precise estimates. This assumes larger relevance in the context of high degree of variability of spatial distribution of vegetation types in India. Forest quantification involves the measurement and estimation of key parameters such as biomass and leaf area index (LAI) in forest ecosystems. Biomass refers to the amount of living organic matter in a forest, including trees, shrubs, and understory vegetation. Accurate estimation of biomass is essential for assessing carbon stocks, understanding ecosystem dynamics, and monitoring forest health. Various methods are used for biomass estimation, including destructive sampling, allometric equations, and remote sensing techniques that utilize satellite data and LiDAR technology. LAI is a measure of the amount of foliage present in a forest canopy. It represents the leaf area per unit ground area and is an important indicator of forest productivity and ecosystem functioning. LAI estimation is crucial for understanding photosynthetic activity, light interception, and energy exchange within forest canopies. It can be measured using ground-based techniques such as hemispherical photography or through remote sensing methods that utilize satellite imagery and optical sensors. Forest quantification of biomass and LAI provides valuable insights into carbon sequestration, forest growth, and ecosystem dynamics. This information is critical for informed decision-making in forestry management, climate change mitigation, and conservation efforts. The spatial explicitness in the estimates was brought out at desired scale and accuracy through geostatistical tools and GIS based spatial balancing methods. However, the resolution of spatial explicitness depends on the details of stratification and intensity of ground sampling required for scale and type of assessments.

Studies showed strong possibility of using spectral response-based models for biomass estimation. However, it is noteworthy that remote sensing-based aboveground biomass (AGB) estimation is a complex procedure in which many factors such as atmospheric conditions, mixed pixels, data saturation, complex biophysical environments, insufficient sample data, extracted remote sensing variables, and the selected algorithms, may interactively affect AGB estimation. The increase in reflectance of the NIR provides a remarkable capability for distinguishing vegetation from almost any other surface material, especially soil and water. Thus, this contrast is the basis for the application of vegetation indices in the estimation of vegetation parameters. Studies have established relationships between the LAI of the canopy and vegetation indices from the signal reflected from the top of the canopy in the NIR and Red regions of the spectrum.

4.4 Multi-sensor, multi-resolution remote sensing in forestry

4.4.1 Coarse-resolution remote sensing

Over the past few years, global datasets from coarse spatial resolution sensors have become more and more readily available (Townsend et al., 1994; Arino & Melinotte, 1995). Use of satellite image data for mapping and monitoring (Table 4.6) global land-cover, biomass burning, estimating geophysical and biophysical characteristics of terrain features, or monitoring continental-scale climate shift, is a primary input for biodiversity assessment. The rapid revisit time of AVHRR helps better understanding of land cover, burnt area, etc., at both global and regional levels (Stone et al., 1994, Loveland & Belward, 1997; Eva & Lambin, 1998). The global vegetation type maps, analyses of land-cover changes and burnt areas in conjunction with trends in human disturbance, are effectively used to generate coarse-scale biodiversity maps and identification of biodiversity hotspots. In addition, the Moderate Resolution Imaging Spectroradiometer (MODIS) is designed to provide consistent spatial and temporal comparisons of global vegetation conditions that can be used to monitor photosynthetic activity, which facilitate understanding the biodiversity function.

Table 4.6 Satellite Remote Sensing sensors and potential in biodiversity assessment (Murthy et al., 2003)

Scale	Data sources	Forest attributes	Spatial resolution	Temporal frequency	Mapping scale	Monitoring cost
Global	NOAA-AVHRR MODIS WIFS	Phenology types Forest / Non Forest Net Primary Productivity Deforestation Biomass burning	180 - 1 Km^2	Daily	>1:5000,000	Low
Regional	IRS LISS	Forest / Habitat types Secondary types	5 - 90 m	5 - 25 days	>1:50,000	Low to high
	IRS PAN	Disturbance - logging/roads/fire /encoarchments Plantations Ecotones				
	Landsat Spot JERS-1 ASTER	Wetlands Gregarious formations Target species with gregarious distribution				
Local	IKONOS Aerial photography Aerial multispectral scanner LIDAR CASI	Target species with gregarious distribution Species assemblages / Communities Regeneration Forest disturbance Agriculture Logging / roads Canopy gaps Plantations Harvest rates Level of degradation	< 5 m	User defined	>1:10,000	High

4.4.2 Medium-resolution remote sensing

Rapid change in land-use in tropical areas and the need to map changes in land use over large areas effectively, calls for application of medium-resolution satellite sensors. At the national or local level, IRS, Landsat or SPOT imagery can provide finer-scale information on forest type distribution and agricultural expansion. Radar systems, such as JERS and Radarsat, are not affected by clouds, and are useful for determining the extent of forest and non-forest landscapes where topographic relief is not substantial (<200m). Medium-resolution remote sensing is instrumental in forestry applications, providing valuable information on a regional and landscape scale. Sensors like Landsat and Sentinel-2 capture multispectral imagery, enabling forest cover mapping, change detection, and assessment of forest health indicators. Medium-resolution data also supports forest inventory and biomass estimation, fire monitoring, and habitat mapping for biodiversity assessments. Its balance between detail and wide-area coverage makes it a valuable tool in forestry, often complemented by high-resolution imagery and ground-based measurements for more accurate and comprehensive analysis. Vegetation type and land use of entire India was mapped on a 1:50,000 scale by using IRS LISS data (IIRS, 2012). Datasets from IRS 1C/1D LISS-III have been used effectively in mapping the pure plant colonies of *Hippophae rhamnoides* in the Spiti region of India with prior knowledge of their occurrence and vegetation types of the area by using remote sensing (Roy *et al.* 2001). IRS 1C/1D LISS-III FCC has been used for stratification of *Ephedra gerardiana* in complex terrain conditions of Lahul and Spiti district (Porwal *et al.,* 2003). LANDSAT TM was used for estimation of species richness, indicating biodiversity hotspots in riparian and ecotonal areas (Gould 2000).

4.4.3 High-resolution remote sensing

Applications of high or very-high-resolution remote sensing techniques to the conservation of biodiversity, assessment of protected areas, and species protection, show that fine-grain remote sensing is underused in conservation of forest ecosystems. High-resolution remote sensing plays a crucial role in forestry by providing detailed information about forest ecosystems at a fine spatial scale. High-resolution satellite sensors, such as WorldView, GeoEye, or Pleiades, capture imagery with exceptional detail, allowing for precise analysis of individual trees, canopy structure, and forest disturbances. These sensors enable accurate forest mapping, including delineation of forest boundaries, identification of tree species, and detection of forest health indicators such as insect outbreaks or disease spread. High-resolution remote sensing also supports forest inventory and monitoring activities by providing data for estimating tree height, crown diameter, and aboveground biomass. Additionally, it aids in assessing the impact of logging, measuring forest regrowth, and supporting ecological research on biodiversity and habitat mapping. With its fine spatial resolution, high-resolution remote sensing is an invaluable tool for detailed forest characterization and management. Very high-resolution data are useful for determining the actual activities on the ground that have led to forest clearing. Although such data can detect very small clearings, the scientific community as yet has very little experience with these data. In addition, laser scanner data in combination with very-high-resolution satellite images, e.g., Worldview, IKONOS, QuickBird, Cartosat 2S and 3 can be applied to the assessment of tree-wise timber volume calculations, and the detection of even single trees, especially for forest inventory tasks. The synergy of these different data sources can guarantee foresters a high level of information extraction for these applications.

4.4.4 Temporal monitoring

The amount of change that is occurring in tropical parts of the World has been of considerable interest in the past ten years. Remote sensing offers perhaps the only practical method of analysing large areas over time. Green & Sussmann (1990) used a combination of aerial photography, forest maps, and satellite images to estimate deforestation rates in Madagascar from 1950 to 1985, spanning a total of 35 years. With the advent of availability of satellite remote-sensing data, several countries have recently launched temporal monitoring of forest cover, which facilitates analysing biodiversity losses. However, these studies do not provide information on vegetation type transition and losses, which is primarily necessary for understanding shifts and losses in biodiversity. A few examples of the studies conducted in southern Western Ghats of India and Vindhyans of central India and North-East India have provided details about vegetation type transitions. These transitions, when coupled with ground-based species databases, help in analysing and quantifying biodiversity losses. Prediction of the spatial distribution and relative abundance of wildlife on the basis of multitemporal satellite data and simulation models is also a recent development; Coops & Catling (2002) extensively reviewed such approaches.

4.4.5 Hyperspectral remote Sensing

Hyperspectral remote sensing is used for detection and identification of minerals, terrestrial vegetation, and man-made materials and backgrounds. The ability of imaging sensor to acquire the reflectance spectrum of pixel in significant detail leads to substantial difference in the reflectance values of pixel belonging to disparate material of earth surface. Actual detection of materials is dependent on the spectral coverage, spectral resolution, and signal-to-noise ratio of the spectrometer, the abundance of the material and the strength of absorption features for that material in the wavelength region measured. There are many applications which can take advantage of hyperspectral remote sensing.

- Atmosphere: water vapor, cloud properties, aerosols
- Ecology: chlorophyll, leaf water, cellulose, pigments, lignin

- Earth Science: mineral and soil types
- Coastal Waters: chlorophyll, phytoplankton, dissolved organic materials, suspended sediments
- Snow/Ice: snow cover fraction, grainsize, melting
- Biomass Burning: subpixel temperatures, smoke
- Commercial: mineral exploration, agriculture and forest production

Hyperspectral sensors are able to discriminate, identify and determine many characteristics about earth's features. Hyperspectral image analysis requires more attention to issues of atmospheric correction and relies more on physical and biophysical models than statistical techniques. Physical modeling and Empirical modeling are the approaches that can be employed to relate digital remote sensing data to biophysical variables.

4.4.6 Microwave and LIDAR sensing of forests

Recent advances in instrumentation and techniques are producing estimates of biomass with unprecedented accuracies in even the most densely forested ecosystems. Traditionally, these attributes have been measured in the field using handheld equipment. Field methods are accurate but are time-consuming and therefore limited to either mapping at fine scales or relatively sparse sampling at the landscape scale. Multi-spectral and hyperspectral remote sensing have been used to map some aspects of structure at moderate resolution and broad scales. However, passive optical sensors have difficulty penetrating beyond upper forest layers and are better suited for mapping horizontal components, such as land cover type. Synthetic aperture radar (SAR) and interferometric synthetic aperture radars (InSARs) can provide measures of vertical structure at landscape scales at varying degrees of accuracy. Scientists used a ratio of P- and C-bands and the HV polarization (PHV/CHV) as well as L to C ratios (LHV/CHV) to predict biomass in boreal forests. Researchers found a direct correlation between biomass and X and L-band with HV polarization (LHV/CHV) backscatter, again in a boreal forest. Many other studies reported accurate results for biomass retrieval are in plantations or in very simple (in terms of either physiognomy or floristics or both) forest types. SAR and InSAR appear to be suited for structurally homogeneous, simple forest types at the present time, although advances in technology should improve estimates in other ecosystem types.

Light detecting and ranging (LiDAR) provide highly accurate measurements of forest structure. Due to the high cost of flight time, the need to limit scanning to near nadir in order to prevent ranging errors, and the presence of coverage gaps due to aircraft pitch and roll, many LiDAR studies provide samples at the stand level or image small areas, most missions do not provide the same wall-to-wall coverage at the same scale as a Landsat TM scene or SAR image. In India, this technique could be utilized to address various aspects of forest ecosystem management, not possible earlier with the data available from aerial photographs, optical and radar satellites or even by ground measurements (Behera and Roy, 2002). Numerous researchers, have shown that LiDAR or RaDAR measurements can be used to estimate forest biomass. It can also be determined which of the LiDAR height and RaDAR height and cross-sectional returns most accurately predict total above ground forest biomass in arid, relatively heterogeneous ponderosa pine stands.

4.4.7 Geomatics and Forestry

Geoinformatics (geographic information science, geomatics) aims at the development and application of methods for solving specific problems - with special emphasis on the geographical position of objects. The future research direction and opportunities will be significantly affected both by the availability and utilization of Information Technology. As the complexities of processes are only recently being recognized through the application of new technologies, it is evident that an enormous gain in understanding can be realized only if multidisciplinary data are evaluated numerically, and integrated geospatially through the utilization of Information Technology. Ever-growing understanding and acceptance that the Earth functions as a complex system composed of myriad interrelated mechanisms have made scientists realize that existing information systems and techniques used are inadequate. Currently, the uncoordinated distribution of available data sets, a lack of documentation about them, and the lack of easy-to-use access tools and computer codes are major obstacles for scientists and educators alike. These obstacles have hindered scientists and educators in the access and full use of available data and information, and hence have limited scientific productivity and the quality of education. Recent technological advances, however, provide practical means to overcome such problems. Advances in computer design, software, disk storage systems as well as the growth of the World Wide Web (www) now permit for the first time the management of gigabytes to terabytes of data for distribution to scientists, educators, students, and the general public.

Remote Sensing and GIS are disciplines that are strongly data driven, and researchers and government agencies often develop large data basis. The complexity of the fundamental scientific questions being addressed requires integrative and innovative approaches employing these data bases if we are to find solutions. Although a number of databases exist, the ultimate goal is to create a fully integrated data system populated with high quality, freely available data, as well as, a robust set of software to analyse and interpret the data. This system would feature rich and comprehensive databases and convenient access. These capabilities are needed to attack a variety of basic and applied Earth Science problems. The present day problems are inherently four-dimensional (x,y,z,t) in nature involving variation with time. Thus, their solution requires data analysis that is far more complex than provided by traditional Geographic Information Systems (GIS). The extent, complexity, and sometimes primitive form of existing data sets and databases, as well as the need for the optimization of the collection of new data, dictate that only a large, cooperative, well-coordinated, and sustained effort will allow the community to attain its scientific goals. With a strong emphasis on ease of access and use, the resulting data system would be a very powerful scientific tool to reveal new relationships in space and time, and would be an important resource for students, teachers, the public at large, governmental agencies and industry. Fundamental new discoveries will require the availability of databases that encompass a variety of temporal and spatial scales. Because of the need to integrate heterogeneous data sets and tools to analyse them, Geoinformatics provides the focus for community participation in a national experiment to enhance and retain the pre-eminent role in the world.

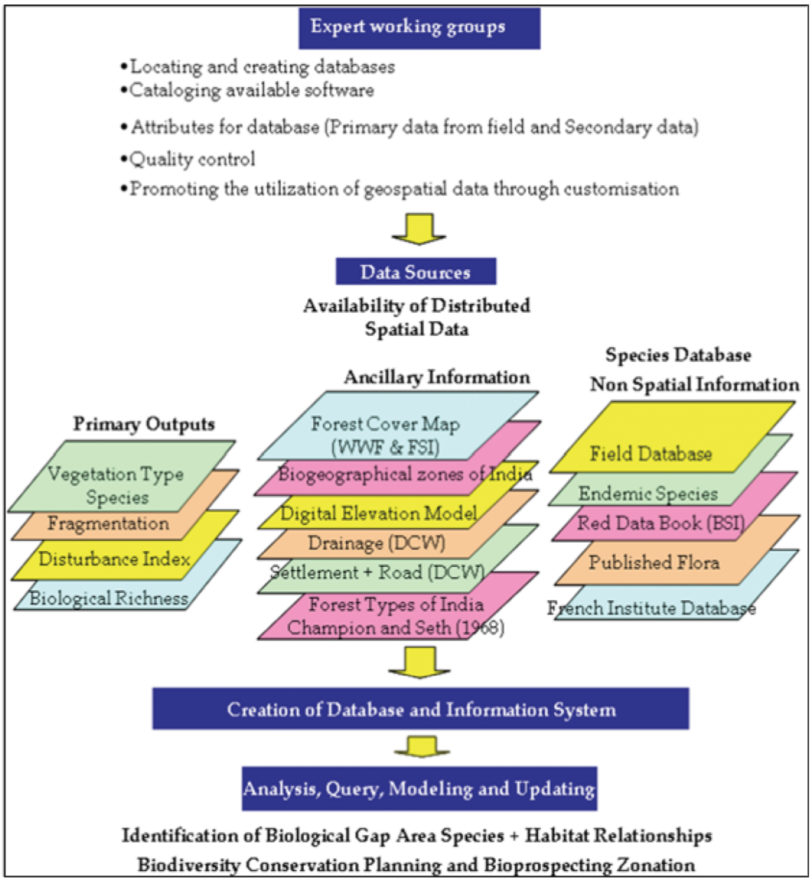

Fig. 4.4 Steps in geoinformatics for creating biodiversity information system

Human interventions largely control the distribution of vegetation and biodiversity. The developments in computer based Geographic Information System (GIS) enables the integration of spatial and nonspatial information for defining the habitats and improving vegetation type descriptions in space and time. A review on GIS and database for vegetation mapping and monitoring is given by Skole *et al. (*1993). It is also possible to evolve geospatial models using multi criterion to present disturbance regimes and landscape diversity. Landscape ecology has evolved as an operational tool with the availability of geospatial modeling techniques. Tomlin (1990), Mc Guire *et al.* (1988), Antencci *et al.* (1991) and Miller (1994) provide number of examples of application relevant to biodiversity. The power of having all information and knowledge along with access, modeling, and visualization tools at the fingertips of a user has great potential in advancing science, accelerating the discovery process, and enhancing the quality of science and education.

The holistic understanding of the complex mechanisms that control biodiversity, as well as their spatial and temporal dynamics, requires synergetic adoption of measurement approaches, sampling designs and technologies. The data requirements include data of both spatial and non-spatial nature and also of various time scales. In view of this, the combination of satellite remote sensing, Global Positioning System (GPS), and integrative tools (such as GIS and information systems) is an important complimentary system to ground-based studies. It has been well explained by Murthy *et al.* (2003) that these technologies together form the basis for geoinformatics. The various parameters required for biodiversity assessment and their amenability for measurements by different techniques is given in Table 4.7.

Table 4.7 Components of biodiversity assessment and measurement tools (Murthy *et al.*, 2003)

No	Parameters	Remote sensing	Ground Measurement / GPS	GIS Based (Derived/Integrated Spatial layer)
A	Human interventions	√	√	√
1	Logging	√	√	√
2	Grazing	√	√	√
3	Fire	√	√	√
4	NTFP resouces extraction	√	√	√
5	Trampling	√	√	√
6	Plantation	√	√	√
7	Agriculture	√	√	√
8	Encoarchment/ Clearances	√	√	√
9	Infrastructure	√	√	√
B	Natural Processes	√	√	
10	Climate	√	√	√
11	Erosion	√	√	√
12	Topography	√	√	√
13	Soil	√	√	√
C	Structure and Function		√	
14	Vertical structure	√	√	√
15	Size class distribution		√	
16	Relative abundance		√	
17	Gap frequency	√	√	√
18	Canopy openness	√	√	√
19	Standing and fallen dead wood		√	√
20	Trophic dynamics		√	√
21	Other structural elements		√	
D	Landscape level			
22	Vegetation type and extent	√		√
23	Landscape diversity	√		√
24	Species diversity	√	√	√
25	Number of patches per unit area	√		√
26	Neighbourhood	√		√
27	Patch shape	√		√
28	Core-edge ratio	√		√
E	Habitat level			
29	Species assemblages / Communities	√	√	√
30	Species diversity	√	√	√
31	Interior to exterior habitat	√	√	√
32	Regeneration	√	√	√
33	Habitat extinction	√	√	√
F	Species level			
34	Reproduction		√	
35	Dispersal		√	
36	Regeneration		√	
37	Migration		√	
38	Location extinction		√	

4.5 Major Application Projects

4.5.1 Different IRS satellite sensors and use for bioresources assessment

IRS P6 satellite provides unique opportunity of having different resolution sensors on the same platform. AWiFS (56 m), LISS III (23.5 m), LISS IV (5.6 m) provide the capability to study and assess different forest parameters at various spatial scales. Cartosat data help in detailed assessment of forest structure and species composition. A large range and scale of information can be acquired by making use of all these sensors. Coarse resolution sensors with high repetivity as the AWiFS are being used effectively for monitoring forest fires, rapid forest cover monitoring, vegetation phenology, carbon sequestration and forest productivity studies at global and regional scale. LISS III sensor having spatial resolution of 23.5 m has wide application for studying forest composition, gregarious formations, monitoring of forest stands and plantation activities. High resolution LISS IV and Cartosat sensors have applicability in studies pertaining to canopy density, canopy height and mapping of individual trees of economic importance as Teak and Sal and NTFP (Non-Timber Forest product) such as canes, gums, resins, fibre yielding forest species.

4.5.2 Forest Cover Assessment

At the backdrop of increased developmental activities, and demand for land and forest as bioresource, the Government of India took up the task of assessing forest cover in 1986. National Forest cover mapping was initiated by NRSA for the periods 1972-75 & 1981-83 using Landsat MSS data at 1:1 million scale. Forest cover mapping provides total forest area information in terms of crown density classes, an index of condition of forests. Forest crown density refers to the per cent area covered by tree crown per unit ground area. NRSA initial study has revealed significant loss of forests during 1972-83 and given alert signal to the country for conservation of forests. In addition, the study has also established the operational methodology for national cover mapping and technology was transferred to the Forest Survey of India (FSI). Since then, FSI has made seventeen biennial assessments. Forest cover was interpreted visually for the first seven cycles at 1:250,000 scale, and then digital approaches are followed for the subsequent cycles (1:50,000) for two crown density classes 10-40% and >40%. As spatial resolution improved classes > 70 %, 40 – 70%, 10-40 % and scrub have been delineated in addition to the tree cover outside the Reserve Forest areas. The present assessment (2021) reports 713,789 km^2 forest area which is 21.71% of the geographical area of the country (Fig. 4.5).

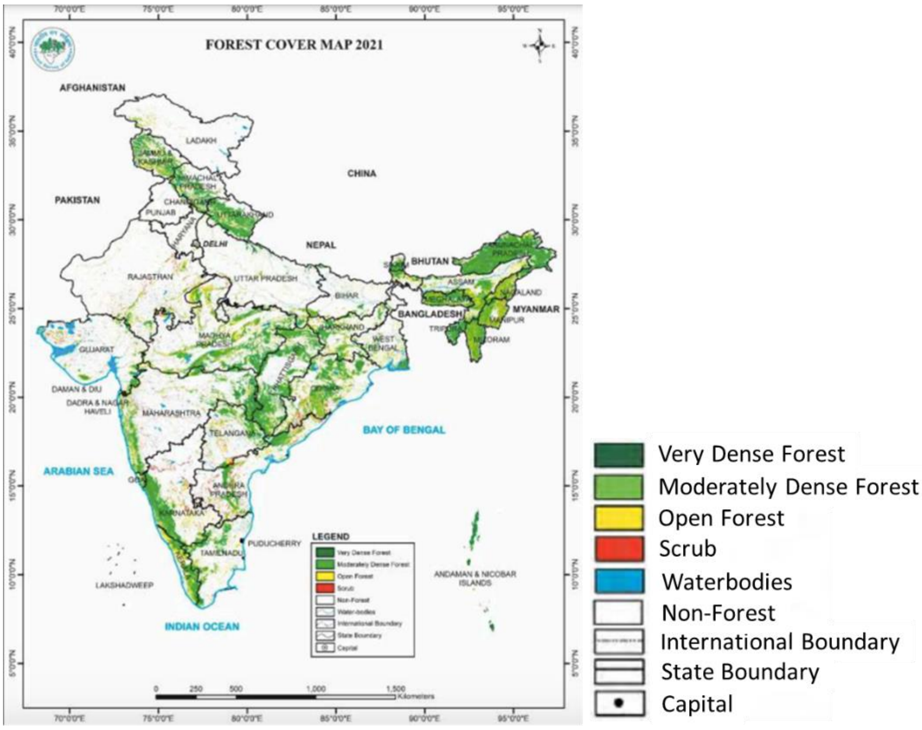

Fig. 4.5 Forest cover assessment of India (FSI, 2021)

4.5.3 Vegetation type mapping as potential base of bioresources

India has diverse climatic, geological, topographical and anthropogenic disturbance gradient. This has resulted in the formation of diverse vegetation communities e.g., major Eco-regions like Eastern and Western Himalayas, Shivaliks, Vindhyans, Eastern and Western Ghats and Coast constituting region specific vegetation type. Champion & Seth (1968) based on extensive ground surveys brought out forest type classification using forest structure, composition and environment (climate, topography). They identified 16 major type groups and 221 forest types. Champion & Seth (1968) classification scheme does not have spatial explicitness and with the increasing pressure on forests during the last three decades, changes at several places were noticed in forest composition. As part of joint initiative of Department of Space and Department of Biotechnology, 120 vegetation types covering mixed formations, gregarious formations, locale specific formations, grasslands, degradational stages, plantations, scrub and orchards were mapped for the entire country using IRS LISS-III data and available as digital database (Fig. 4.6). Recently, FSI has prepared a detailed forest type map for the entire country on 1:50,000 scale based on Champion & Seth's (1968) classification. Based on the phenological properties, the 16 major type groups of the country were mapped using multi temporal SPOT and IRS WiFS data.

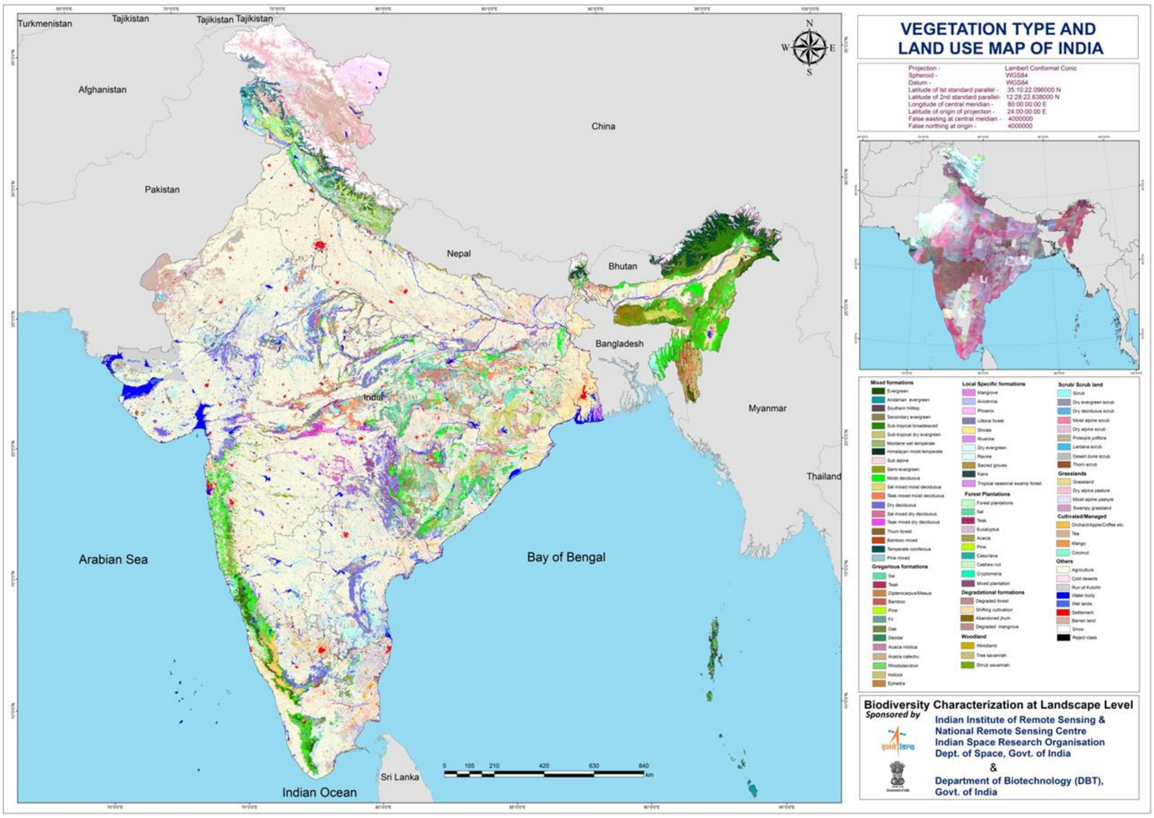

Fig. 4.6 Vegetation type/land use map of India (Roy et al., 2015)

4.5.4 Landscape level biodiversity assessment

On global to local scales, the only feasible way to monitor the Earth's surface to prioritize and assess the success of conservation efforts is through remote sensing. Currently a suite of remote sensing satellites, having various resolutions, are available to generate spatial information on vegetation and land-cover from global to local level. The remote-sensing-based information on vegetation and land cover provides a potential spatial framework and works as one of the vital input layers for the following:

- Vegetation, land cover losses and conversion
- Stratification base for optimal ground sampling and assessment of diversity
- Fragmentation and neighbourhood analysis
- Delineation of broader vegetation types and analysis of species assemblages along with ancillary data

- Identification of gregarious and ecological by important species
- Inputs for species habitat models
- Spatial delineation of biologically rich zones
- Developing conservation strategies

In a major initiative, the biological richness was characterised under the project 'Biodiversity Characterization at Landscape Level' (Fig. 4.7).

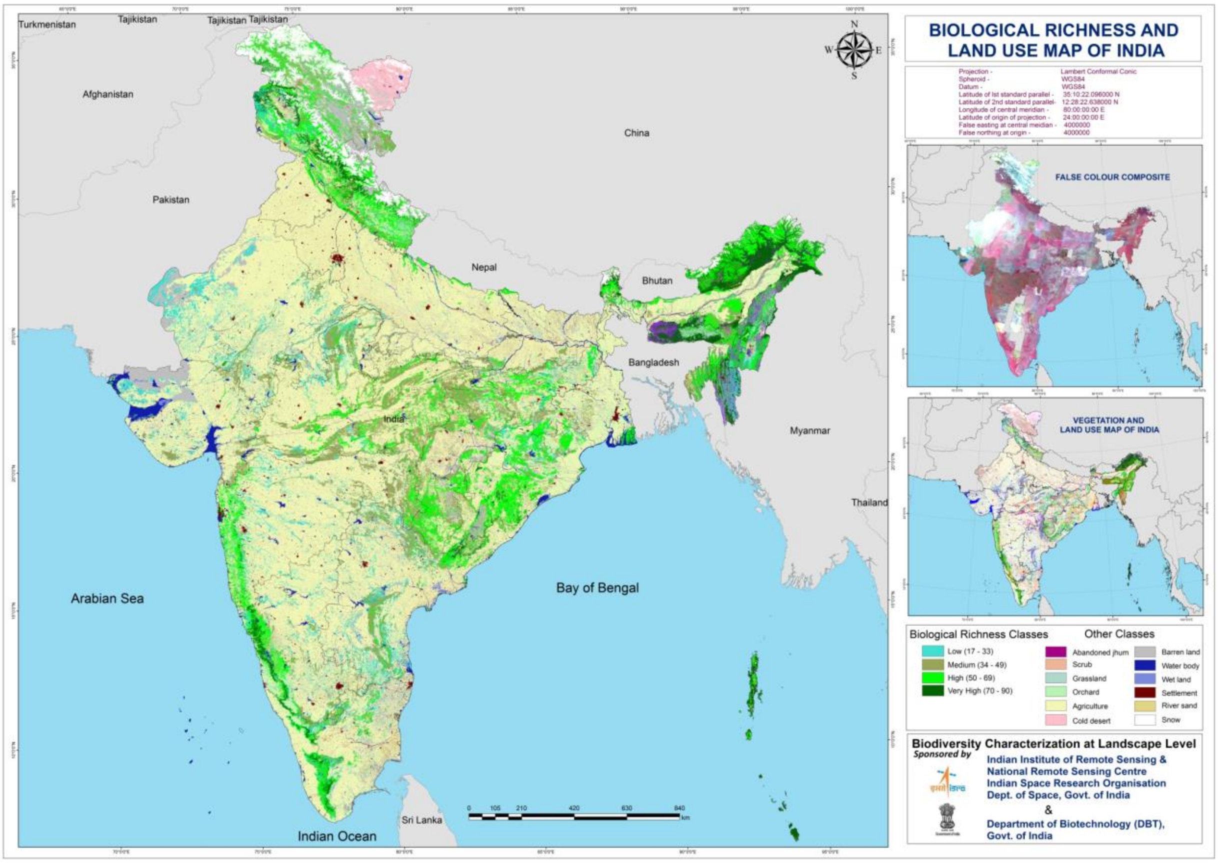

Fig. 4.7 Biological richness map of India.

4.5.5 Grassland Resources Assessment

Grasslands and savannas cover nearly one third of the earth surface, providing livelihoods for nearly 800 million people, along with forage for livestock, wildlife habitat, carbon and water storage. Conservation of grasslands/ savannas has become major concern due to their rapid degradation, in terms of reduction in productivity, invasion of weeds and land cover changes. In case of India, it is very critical that 80% of Indian grasslands/pasture are considered as very poor in their productive potential. As the milk production increased rapidly over the years, the pastures on the other hand, has not increased, instead they were getting reduced or degraded. This has created a wide gap between the availability of fodder and demand for it, which in turn will have wide ranging consequences on the balance of the ecosystem. Hence, it is very important to monitor and assess the state of grasslands and grazing resources. Considering the large area covered by the grasslands, it would be very difficult to assess them by ground-based methods. In this regard, Satellite Remote Sensing offers an effective tool to monitor and assess them periodically in time and cost-effective manner. In view of this, a study was carried out for mapping (1: 50,000 scale) of grasslands/ grazing resources using IRS LISS-III data for which 3 different bio-climatic regions namely, Western Himalayas (humid tropics), Gujarat (semi-arid) (Fig. 4.8) and Tamil Nadu (tropical) were chosen.

4.5.6 Species level mapping

The economically and medicinally important species like Teak, Sal, Dipterocarpus (Plywood) and medicinally important species like Hippophae, which grows in large extents as single species dominated formations can be identified and mapped using remote sensing sensors like IRS LISS-III. Sal forests serve as bioresource in terms of wood, fodder, NTFPs etc. and are mapped for the entire part of the country. The spatial information on the distribution of these species could be used as source to prepare scientific assessments on quantification, extraction and conservation systems. In addition, high resolution satellite data like IRS-LISS-IV and Cartosat could be used to map assemblage of species which can give the relative abundance of a species.

4.5.7 Biomass assessment as fodder, fuel and carbon stock

India has enormous biomass potential contained in different ecosystems. An accurate and precise measurement of carbon sequestered and released is very critical in terms of increasing population demand for biomass and to understand the role of carbon cycle on global climate change. Assessment of forest carbon is complex due to spatial variability and heterogeneity of vegetation, composition, underground growth, annual increment and extractions. As part of ISRO-GBP programme, National Carbon Project was initiated to address these issues. Forest carbon stock of the entire country was mapped as a part of this project. In addition, satellite remote sensing technique is used to estimate the fodder biomass, fuel wood availability enabling to understand the supply demand gaps and identify appropriate measures.

4.5.8 Community Forest management

Reliable accounting of forest resources and sustainable resources extraction has become critical and a new paradigm of “Forest Management” with rural participation has evolved. Several joint forest management and community forest management programmes are launched in different states. RS & GIS based approaches provide means to assess potential biomass, NTFP resources, perspective planning and monitoring. In this scenario the sustainable resources extraction has become critical. JFM activities are monitored and evaluated using Remote sensing data. Satellite remote sensing helps in site identification, resources assessment, monitoring and evaluation. Site identification includes delineation of degraded forests over suitable slopes/terrains and accessibility. Satellite remote sensing data also helps in monitoring and evaluation in terms of changes in greenness, crown closure improvements, mono species formations (Weeds/Bamboo/plantation) (Fig. 4.9).

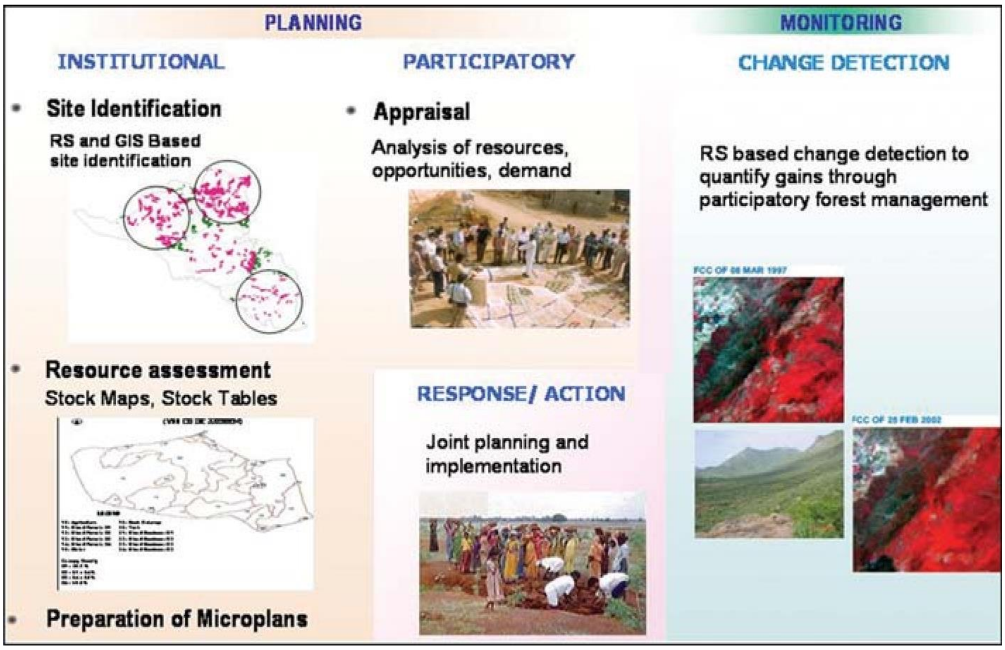

Fig. 4.9 Community Forest Management in India

4.5.9 Commercial Timber Resource Assessment

In India forest management plans need updation every 10 years. The management plan preparation requires detailed stock maps which show the type of standing forest crop and its timber volume. Ground based conventional methods take 4-5 years with ~5% ground sampling intensity. High resolution satellite data used for forest canopy and type stratification optimizes ground sampling intensity and proper distribution of sample points. Hence, using RS and GIS inputs work is accomplished in 2 years with 0.01-0.1% sampling. Several state forest departments are adopting these approaches. National Forest Working Plan code committee envisaged the use of RS & GIS in Forest Working Plan. A sample output provided in terms of stands tables (number of trees distributed across different species and diameter classes), stock tables (total timber volume across species and diameter classes) and stock map is shown in Fig. 13.10. These inputs are used by forest departments to make operational plans for suitable harvest and conservation scenarios.

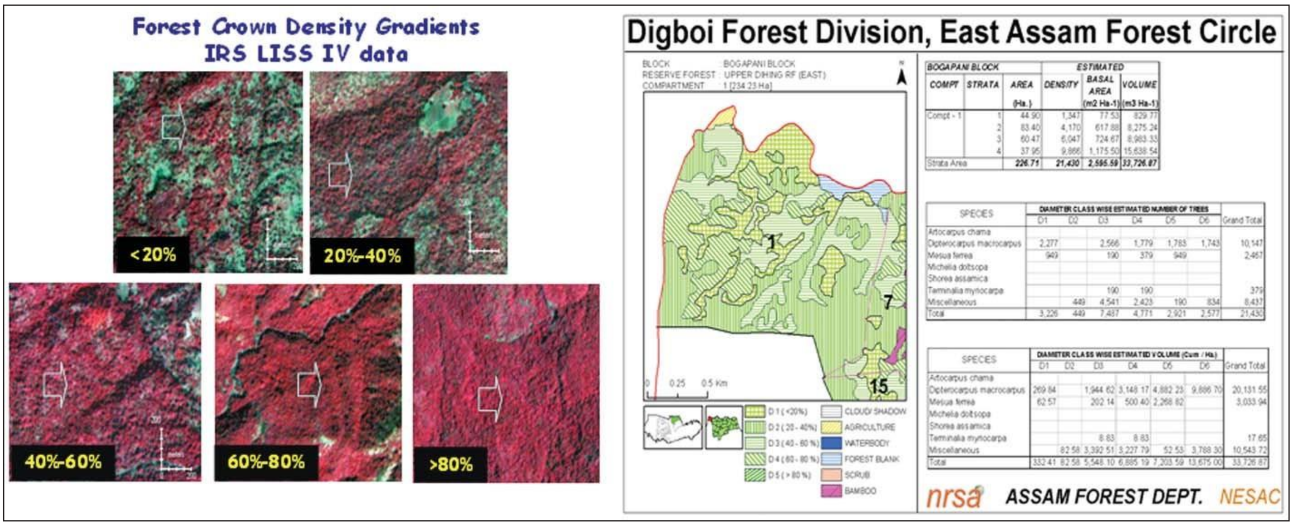

Fig. 4.10 Forest Working Plan Preparation

4.5.10 Protected Areas and Conservation

With increasing pressure on the primary forest ecosystems, the concept of “Protected Areas” has been introduced in the country under the Wildlife Protection Act (1972). Around 500 wildlife sanctuaries, 90 National Parks constituting 15.6 Mha of the forests exist. Remote sensing plays a vital role in wildlife habitat mapping and management monitoring by providing valuable information about the spatial distribution and characteristics of habitats. High-resolution satellite imagery and aerial photography are commonly used in these applications. Remote sensing data helps identify key habitat features such as vegetation cover, land use/land cover types, water bodies, and topography, which are critical for understanding wildlife requirements and preferences. By analyzing spectral signatures and texture analysis, remote sensing techniques can delineate different habitat types, assess habitat quality, and identify important corridors and connectivity between habitats. These maps can guide conservation efforts, inform land management decisions, and monitor changes in habitat conditions over time. Remote sensing also aids in wildlife population estimation, as it enables the identification and monitoring of important features such as breeding sites, nesting areas, or feeding grounds. Overall, remote sensing provides a cost-effective and efficient means to support wildlife habitat mapping and management monitoring, contributing to effective conservation and sustainable wildlife management practices. National mission to generate spatial databases on vegetation type (1:25,000) using IRS LISS IV data and large mammal density distribution launched for all protected areas under the aegis of Standing Committee on Bioresources. Satellite Remote sensing provides inputs in terms of vegetation type, habitat maps, water holes, management zonation prepared using rule-based criteria 3-D view of the Vegetation type map prepared using IRS LISS III data and management plan map indicating core, buffer, rehabilitation and tourism zones prepared using rule-based criteria for Kudremukh National Park in Karnataka are shown in Fig. 4.11.

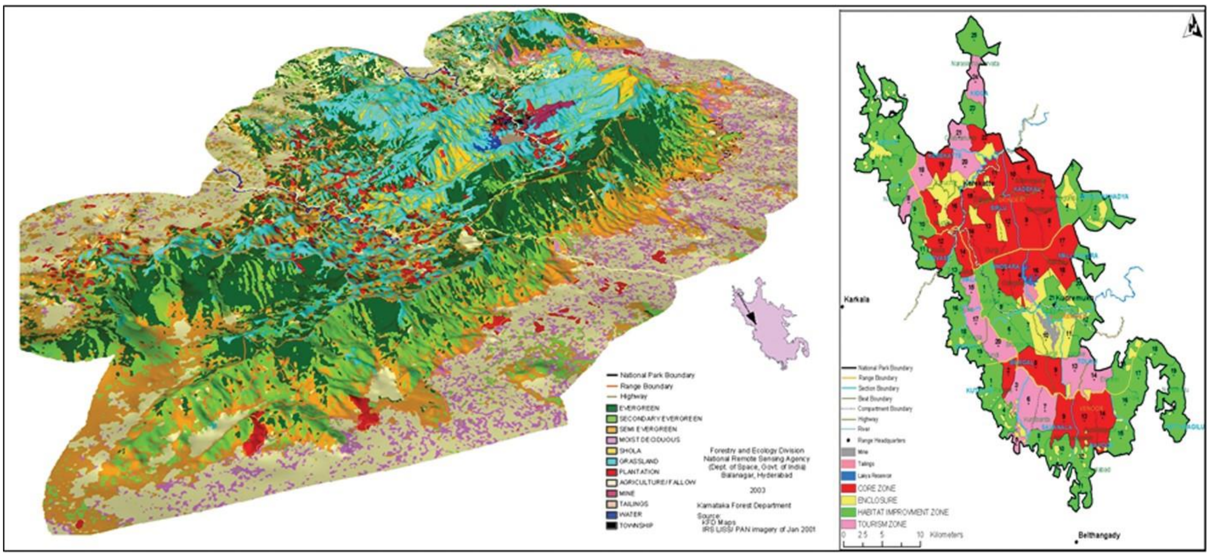

Fig. 4.11 Protected Area Management

4.5.11 Web-Enabled Information System

In order to disseminate databases to wider community, effective querying, relational analysis and decision making, web enabled information systems are developed to address biodiversity, Land Use and Land Cover (LULC) changes, Forest Fire related issues.

1. Indian Bioresource Information Network (IBIN)

Department of Biotechnology (DBT), Government of India, launched a national level programme to develop a digital database of the bioresource of the country. Indian Bioresource Information Network (IBIN) is uniquely placed as a single portal data provider on India's bioresource - plant, animal, marine, spatial data and microbial resources. For the first time ever, an electronic database has been developed using an indigenously developed software application for data access and query on spatial data, plant, animal, marine and microbial resources of the country. All the digital databases were developed with a common basic structure such that they could all be eventually compiled on to a single servicing platform. There arose a need to offer these non-spatial data (attribute data) sets on a wide network such that they become available to all the potential end users. India with unique floristic and faunal richness, their vastness, endemism, heterogeneity and also inaccessibility of large areas has necessitated creation of authentic baseline data on biodiversity. IBIN is being developed as a distributed national infrastructure, intended to serve relevant information on diverse range of issues of bioresources of the country to a range of end users. Its major goal is to network and promote an open ended, co-evolutionary growth among all the digital databases related to biological resources of the country and to add value to the databases by integration.

2. Global change studies – Need for LULC databases

Realising the importance of role of LULC in regulation of climate, productivity and biodiversity, the need for developing reliable LULC databases over India is considered as one of the critical task towards understanding climate and non-climate driven changes. In view of the several limitations of coarse scale available global LULC databases (Schmidt *et al.*, 2008), heterogeneous and fragmented landscapes of India, an effort has been made to develop LULC databases using multitemporal IRS AWiFS satellite data.

LULC Databases of India: LULC system in India exhibits high degree of spatial and temporal variability due to the influence of climate and local land use practices on agriculture, compositional and phenological variability of natural vegetated systems like forests, grasslands. In order to precisely capture these variabilities multi-temporal Resourcesat-1 Advanced Wide Field Sensor (AWiFS) data acquired during August- May of each crop calendar year (kharif, rabi, and zaid seasons) were used. LULC classification scheme (legend) amenable to digital classification was adopted in order to generate LULC maps rapidly. Hierarchical decision tree, maximum likelihood and interactive classification techniques were adopted for classification of the data.

3. Forest Fire Management

Fifty-five per cent of Indian Forests are prone to recurrent fires annually affecting ecological and economic damage. Conventional approach of the State Forest Dept. for fire protection through an elaborate network of fire lines, fire watch towers and manual fire control system has been far from adequate. The existing facility need to be augmented with effective and fast response tools like RS & GIS based fire detection, monitoring and damage assessment in conjunction with ground data. As part of Disaster Support Center of NRSC, services on Fire management are provided using multi-resolution, multi-temporal satellite data. Active forest fire locations for the entire country on daily basis to facilitate fire control operations using MODIS and DMSP data is provided as part of Indian

Forest Fire Response and Assessment System (INFFRAS) that is operationally started to provide these services through NRSC web site.

4.6 Gap Areas

Digital retrieval of forest parameters using high resolution and hyperspectral data, optimal sampling designs for forest volume estimation, automated forest cover retrieval and change assessment, species exploration and niche modeling, biodiversity monitoring and change modeling, vegetation stress analysis, disease detection, forest ecosystem responses to climate change and anthropogenic impacts, ecological foot printing analysis for sustainable development, forest vulnerability and change assessment are a few important R&D areas need to be addressed. IRS series of satellites which have been functioning as main work horse for the last two decades have limitation due to spatial, spectral and temporal resolutions, persistent cloud cover over certain areas and lack of atmospheric corrections to address natural resource monitoring, vegetation stress detection, biophysical and geophysical parameter retrievals. The fragmented forests and vegetation communities have been found to be a major limitation. Therefore, satellite sensors with high repeativity and high spatial resolution would strengthen these observational gaps. The land surface characteristics such as biomass, canopy moisture regimes, canopy roughness etc., are more sensitive in their reflection properties in the microwave regions. The inclusion of air and satellite borne microwave sensors in the IRS programme is very much required to fill this gap.

Non availability of thermal data also limits temperature estimation which is needed for ocean and land applications. On the other hand, to assess the vegetation stress, biogeochemistry, mineral regimes the existing spectral resolution in terms of number of spectral channels and channel width is inadequate. This calls for hyper spectral sensors providing spectral information at high spatial and spectral resolutions. In the context of infrastructure development, the existing satellite sensor resolutions need to be further enhanced to provide information on 1:1000 scale. These advanced land and ocean observation sensors would ameliorate the low availability of geophysical/biophysical products, viz., Land Surface Temperature, Insolation, Surface Radiation, Albedo, Precipitation, Vegetation Fraction, LAI, fAPAR, NPP.

4.7 Summary and Conclusions

In the last decade, there has been significant progress in the application of Remote Sensing GIS for forestry and ecological monitoring. The newer sensors, the hardware and software technologies have helped the scientists, and all concerned to understand the various paradigms of structure and processes of biosphere. However, in the light of newer challenges set by IPCC fourth assessment report, CBD, MDC goals, UNFCC and various other national and international conventions that have addressed the climate change and its constraints that is likely to impact the human as well as living system in general, still lot remains to be done such as availability of high repeat cycle, hyperspectral data of fine resolution etc. There is urgent need to progress on the establishment of proper linkages on the ecosystem models with RS monitoring data.

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Chapter 5

MARINE APPLICATIONS

In recent days' various space borne sensors have become the backbone of oceanographic research and applications. Operating in the Electromagnetic region (mainly optical to microwave), these sensors provide vital information of various physical and biological oceanographic parameters such as sea surface temperature, sea surface height, surface salinity, surface wave, winds, Sea Ice extent, thickness, concentration on a global scale, chlorophyll, and suspended sediment etc. In this chapter we will discuss Remote sensing techniques, measurement principles, retrieval of geophysical parameters and their applications ranging from near-real time operational use to addressing various science issues related to satellite oceanography, marine ecology and coastal processes.

5.1 Introduction

Oceanography, a multi-disciplinary science for studying the ocean, includes physical oceanography and marine bio-geochemistry. Covering about seventy percent of the Earth's surface, the oceans are central to the continued existence of life on our planet. We depend on ocean for food, water transportation, recreation, minerals and energy. Oceanic circulation plays a major role in the earth system by influencing weather and climate. Deeper ocean currents, commonly known as thermohaline currents have a large impact on climate change and global warming. Ocean processes span a horizontal length scale range from 1mm to 1000 km, and a time scale range from seconds to years. Hence it becomes essential to monitor oceans at various scales, ranging from diurnal to decadal (Fig. 5.1). In situ measurements by ships, buoys and floats, are highly accurate and one can measure ocean parameters at various depths, but it suffers from the limited coverage.

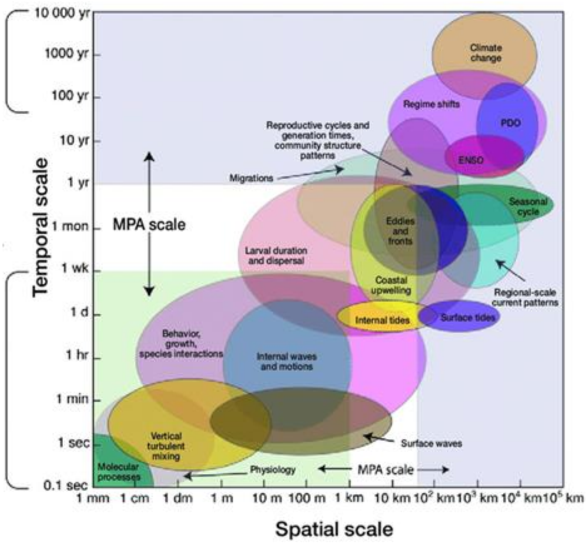
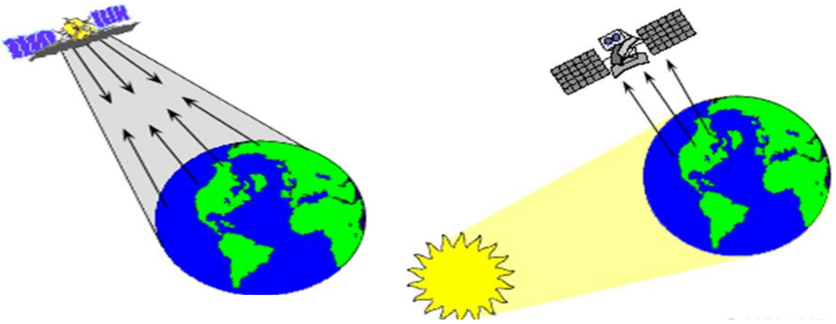


Fig. 5.1 Broad ranges of ocean processes and their space-time variability

Satellite measurements can give synoptic and geospatial view at a glance and repetitive measurements and is thus an attractive alternative. However, one has to be little cautious about the accuracy that essentially advocates for vicarious calibration and validation. Another limitation of satellite measurements is restriction with respect to surface measurements and data gaps between the orbits. Thus, numerical ocean waves and circulation models come into picture which can simulate the ocean over time by discretizing the space into small grids. But accuracy of these models is limited because of errors in initial conditions and unaccounted sub-grid scale processes. Nevertheless, by optimally combining in situ and satellite measurements into models one can get many details of the oceanographic processes. In this note we will briefly explain the available remote sensing technologies for ocean observations and numerical modeling of ocean with a little glimpse of available geospatial applications relevant to ocean.

Satellite observations are based on measurements of radiation either emitted from earth (passive sensing) or radiation returned as back-scatter from earth-atmosphere system (termed as "target" which includes geo-physical system components individually or collectively) when a satellite-based pulse source illuminates (active sensing) the target. The Fig. 5.2 shows the principle of active and passive remote sensing. The absorption by atmospheric gases and reflection / emission from earth's surface is the backbone of these remote sensing methods. As far as the Ocean is concerned, one can either use solar radiation reflected/scattered from it (this is mainly used for Ocean colour monitoring, which is then related to biological productivity, sediments etc.), or thermal infrared emitted from it (relates to SST), or microwave radiation emitted from it (relates to both temperature and roughness of the sea), or active microwave sensor (which can give more details of the sea roughness, leading to Sea Surface Wind Vector, Wave Spectra etc.). Another technique is called Altimetry which gives SSH, which is directly related to circulation. A brief active/passive sensor useful for ocean perspective is shown in Fig. 5.3. These observations from these sensors are assimilated in the numerical ocean models to give accurate ocean state prediction a few days in advance. Thus, both satellite observations as well as numerical models contribute towards the geo-spatial technologies for ocean applications. Thus, this note is further divided in to four short chapters. Chapter 5.2 and 5.3 will provide short note on active and passive satellite instruments and their relevance in ocean. Chapter 5.4 will emphasize on numerical models and the way they assimilate this information. Chapter 5.5 will talk about applications that they find in day-to-day life.



a) b)

Fig. 5.2 Principle of a) active and b) passive remote sensing

5.2 Active Satellite Sensors relevant to Ocean

Active satellite sensors measure the reflected or backscattered signal from the targets that are illuminated by radiations emitted by the sensor itself. These are basically radars with side looking or nadir looking capability. These sensors are sensitive to the surface roughness of the target. Also, they can measure range with high level of accuracy. From oceanography perspective, surface roughness is generated by winds or waves. Thus, these sensors are major players in measurement of wind and wave present in ocean surface. Range measuring capacity of these sensors also helps in measurement of sea surface height. Three major and most important active radars that measure ocean parameters at various resolution and accuracy are nadir looking Altimeters and slide looking radars like Synthetic Aperture Radars (SAR) and Scatterometers.

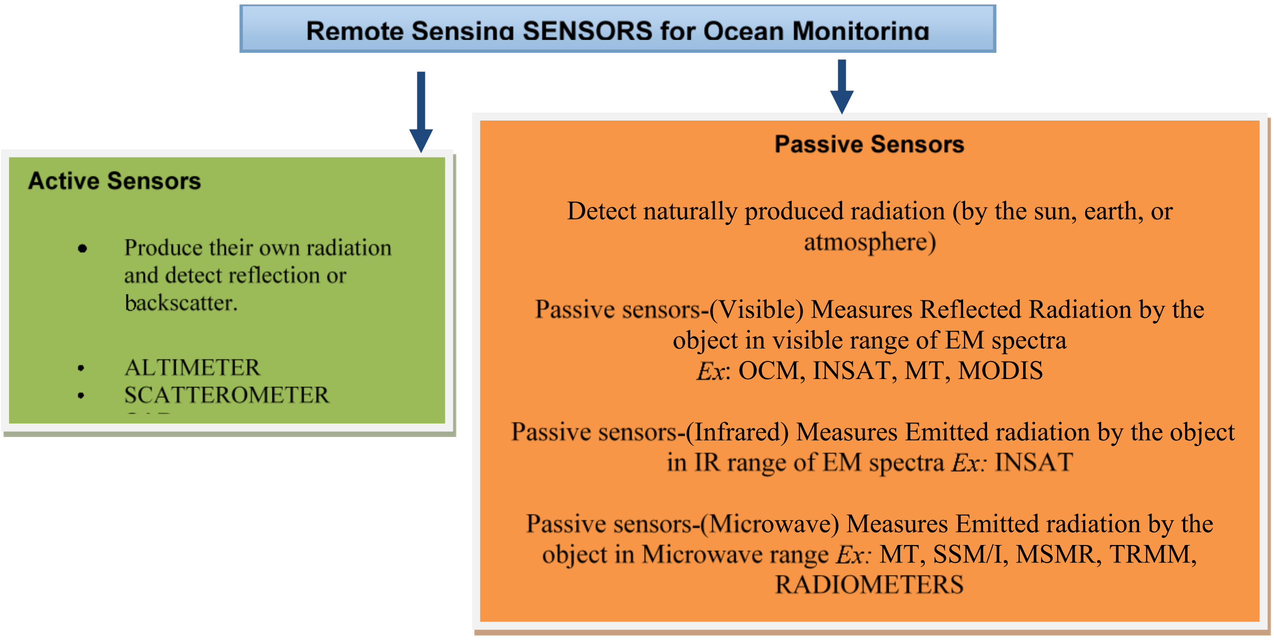


Fig. 5.3 The active and passive sensors relevant for marine applications

5.2.1 Satellite Altimetry: A versatile tool for ocean applications

Satellite altimeter is undoubtedly one of the most versatile space-borne instruments for measuring ocean variables. With the primary application of altimetry in understanding the ocean dynamics through making use of sea level information, it has come a long way where it is unthinkable of getting the estimate of global sea level rise without this instrument. Other ocean variables, significant wave height (SWH) and wind speed also retrieved from this instrument are contributing significantly in the operational oceanography.

Altimeter is a nadir-viewing radar that transmits short pulses, typically of a few nano seconds duration, and detects the return pulse along with the two-way travel time. The shape of the return pulse, known as 'waveform' represents the time evolution of the reflected pulse from within the footprint of the altimeter. As the name signifies, the primary goal of an altimeter mission is the measurement of the altitude of the sea surface from a reference ellipsoid. By measuring the two-way travel time of the radar pulse and knowing the speed of the electromagnetic wave, altimeter height above the sea surface called as 'range' is computed. Making use of precise orbit determination, height of the satellite above a reference ellipsoid is obtained. From these two measurements, one can then easily compute the sea surface height (SSH), height w.r.t reference ellipsoid by subtracting range from the orbit of the satellite. However, because of the slowing down of the radar pulse during its passage through ionosphere, and atmosphere, several corrections have to be applied. Apart from atmospheric corrections, one needs to correct for sea state bias and skewness effects. Apart from SSH, one can also compute another important characteristic of the sea surface, which is the significant wave height (SWH), related approximately inversely to the slope of the leading edge of the reflected pulse or the waveform. The third quantity of interest is ocean surface wind speed, which is empirically related to the maximum backscattered power. Over the ocean, observations are averaged over 1 s giving the along-track resolution of nearly 7 km (varies with ocean wave conditions) and cross-track 40 -300 km, depending upon the repeat cycle of the satellite. The principle of its measurement is shown in Fig. 5.4.

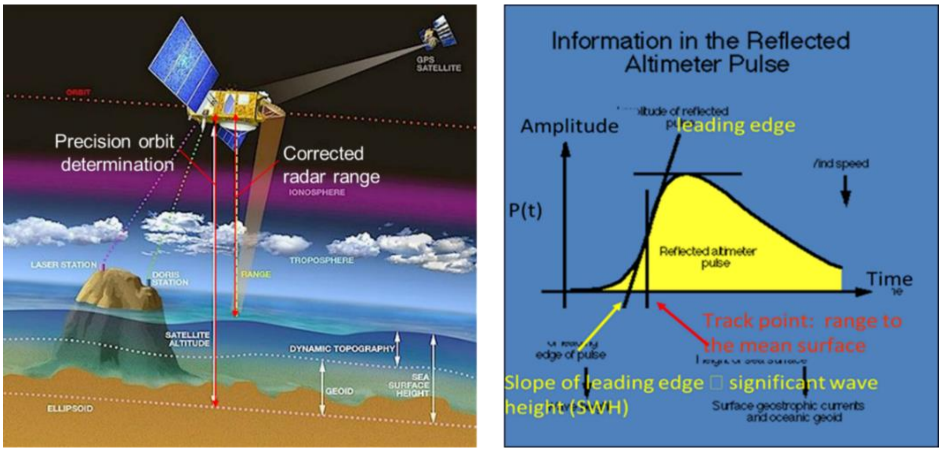


Fig. 5.4 Principle of altimeter measurement of SSHA and SWH

i. History of Satellite Altimetry

The first multi-purpose microwave instrument was on board SkyLab in 1974 and GEOS-3 in 1975. Seasat of NASA was launched in 1978. Launched in 1985, Geosat was used to monitor eddy variability and marine geoid. Sophisticated dual frequency altimeters (to take care of ionospheric effects) with onboard radiometer and improved orbit determination were ERS-1/2 (1991) launched by European Space Agency followed by U.S./French TOPEX/Poseidon (T/P), launched in 1992. Monitoring ocean circulation called for the strategic planning of a low-inclination mission carrying a high-accuracy altimeter on a non-sun-synchronous, repeat orbit for the determination of large-scale ocean currents, and complementary higher-inclination, sun-synchronous altimeter missions, which extends the temporal and spatial sampling to provide information on mesoscale eddies. This strategy was realized by NASA and CNES with the launch of Jason-1 in 2001 as a reference mission and Envisat launched in 2002 in a higher-inclination. And then followed Jason-2/3 and Geosat-follow-on missions. A paradigm shifts in altimetry measurements came with the launch of ISRO-CNES SARAL/AltiKa mission in the year 2013, which was a gap filler between Envisat and Sentinel-3 AltiKa was the first instrument to be operating at Ka-band (35-GHz) frequency with the bandwidth of 500 MHz, that enabled a vertical resolution of 0.3 m instead of 0.5 m in Jason Ku-band 3-dB footprint in the case of AltiKa is 8 km as against 20 km in Jason altimeter. Along with this, high pulse repetition (4000 per sec) results in better along-track sampling, enabling recovery of useful geophysical parameters near to the coast. Apart from it right now we have SWOT and CFOSAT SWIM missions in array of altimeters.

ii. Coastal Altimetry: A Challenging task

In open ocean satellite altimetry is a proven technology. Exploiting the high-rate altimeter data (20-Hz in the case of Jason-2 and 40-Hz for SARAL/Altika) for deriving coastal geophysical parameters is a challenging task. Coastal contamination in the footprint of the measurements requires dedicated classification, retracking strategy and special treatment of atmospheric and geophysical corrections.

In the coastal area, an altimetric waveform is corrupted because of the contamination caused by the presence of land in the footprint of the altimeter. For this reason, the waveforms measured in the coastal areas do not conform to the theoretical Brown model and special data processing efforts are needed for coastal waveform products. In fact, there are projects devoted specifically to analysis of coastal waveforms, namely PISTACH (Mercier et al., 1998) and COASTALT (Gommenginger et al., 2011). Launch of SARAL/AltiKa signifies a major leap in coastal altimetry owing to better signal to noise ratio, smaller footprint and high along-track sampling. In Fig. 5.5, we show the AltiKa and Jason-2 SWH measurements with distance from the coast near the Visakhapatnam region. Jason-2 gets contaminated beyond 8 km shoreward, the same in the case of AltiKa is up to shore.

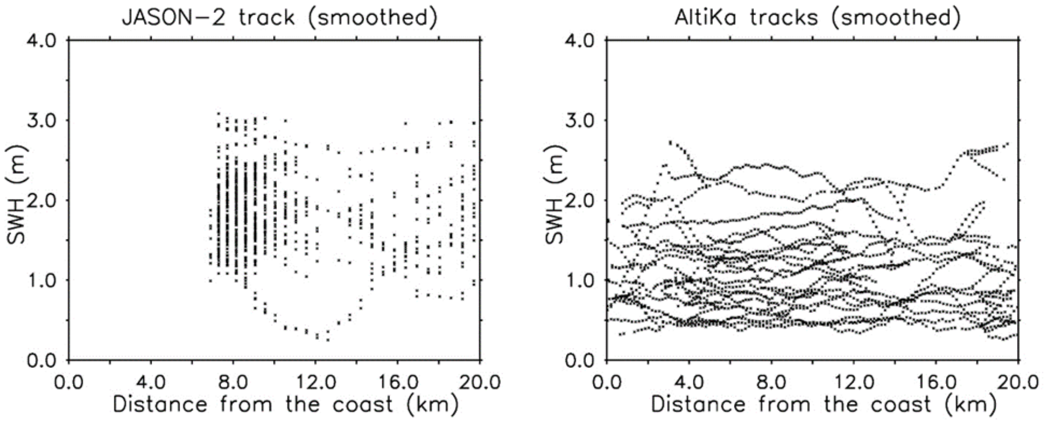


Fig. 5.5 Jason-2 vs. SARAL at coasts and Open Ocean

iii. Oceanographic Applications of Altimeter derived parameters

Altimetric measurements of sea level and significant wave height are the backbone of the operational oceanography (Fig. 5.6). Altimeter derived sea level and SWH are routinely assimilated in numerical models for generating ocean state forecasts. Forecasting the ocean state with 5-7 days lead time has immense applications in the marine fisheries, navigation, naval operations, oil-spill monitoring etc. As the sea level variations represent the integrated effect ocean heat, these data are now routinely used for hurricane forecasting. Altimeter derived sea level anomaly are widely being used by researchers to monitor the progress of El Nino, as these events affect the climate and have impact on economic conditions of nations. Altimetry data play important role in studies of ice-sheet mass balance. Sea level rise is one of the most severe manifestations of the present-day global warming. Since the availability of more precise altimetric data from 1992 onwards, global annual sea level rise of the order of nearly 3.1+/-0.4 mm/year has been estimated. In order to capture this kind of small change, altimetric system needs to have a mm level control on the system drift. This calls for the continuity of mission and homogenization and inter-calibration of different altimeters to minimize the bias.

5.2.2 Scatterometer: A dedicated payload for ocean wind measurement

Ocean surface vector wind, is major parameter for forecasting of weather and ocean state. It needs regular monitoring with good accuracy. Scatterometer measure ocean surface winds in all weather conditions by using microwave signals. It is measured over the global oceans with 1-2 days interval. In addition, scatterometer measures backscatter from polar and land ice regions. Surface winds generate of waves and basin scale ocean currents. Air-sea fluxes of heat, moisture and gases are modulated by the action of winds. In this way winds influence the regional as well as global climate.

i. History of Satellite Scatterometers

These space borne instruments have a long legacy due to continued effort from various international space agencies. Its journey began in 1978 with Seasat scatterometer by National Aeronautics and Space Administration (NASA). Further in 1996 Ku-band scaterometer- the NASA Scatterometer (NSCAT) onboard Advanced Earth Observing Satellite (ADEOS-1) was launched. Following the success of NSCAT, NASA also launched the SeaWinds scatterometer onboard Quick Scatterometer (QuikSCAT) in 1999. After end of mission life of QuikSCAT in 2009, NASA launched Rapid Scatterometer (RapidSCAT) on the International Space Station (ISS) in 2014. China also initiated scatterometer missions in 2011 with four scatterometers by the China National Space Administration (CNSA): HaiYang (HY)-2A, HY-2B, HY-2C, and HY-2D. Further, in 2018 China-France cooperation led successful launch of a rotating fan beam scatterometer onboard Chinese–French Oceanography Satellite (CFOSAT). European Space Agency (ESA) had a prolonged and continued effort in field of C-Band scatterometer. European Remote Sensing ERS-1 and ERS-2, officially known as Advanced Microwave Instrument (AMI) scatterometers were launched in 1991 and 1995 respectively. Three Advanced Scatterometer (ASCAT) instruments onboard Meteorological Operational-A (METOP-A), METOPB, and METOP-C were further launched by ESA during 2006, 2012 and 2018. India began its scatterometer program on September 8, 2009 with launch of the first scatterometer called Ocean SCATterometer (OSCAT) onboard Oceansat-2. SCATterometer SATellite -1 (SCATSAT-1) is second SCATTEROMETER mission by India Space Research Organization (ISRO).

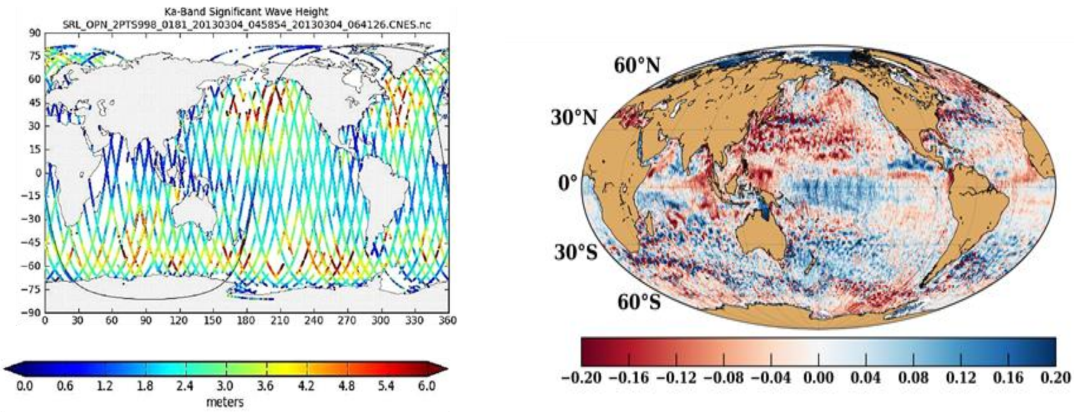


Fig. 5.6 Significant Wave Height and Sea Level Anomaly from Altimeter –SARAL / AltiKa

ii. Basic measurement techniques

A scatterometer is a side-looking radar system that transmits and receives microwave (electromagnetic, EM) pulses. When the EM radiation transmitted from a scatterometer impinges on ocean surface, most of the incident radiation gets scattered in different direction. Depending upon the roughness of the ocean surface, a portion of the incident radiation gets reflected towards the scatterometer antenna. This is called the phenomenon of backscattering. The backscattered power measured by the scatterometer is proportional to the surface roughness caused by oceanic winds. If the winds with higher magnitude blow over the ocean surface, the surface roughness will be more and thus a scatterometer will receive more backscattered power and vice versa. However, such proportionality is not uniform throughout the entire winds speed regimes. Fig. 5.7 shows the typical scanning geometry of scatterometer.

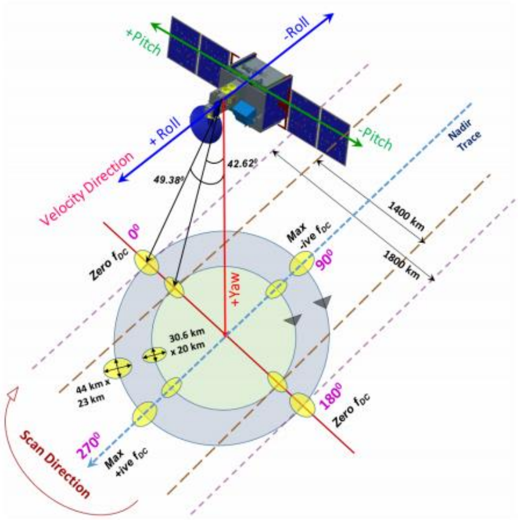


Fig. 5.7 Observation (conical scanning) geometry of EOS-06 scatterometer

iii. Retrieval of ocean surface winds from backscattering

The backscattered power intercepted by a scatterometer is measured in terms of backscattering coefficient or sigma-naught (σ^0). Backscattered power (σ^0) is proportional to the wind speed, but the problem comes when researchers try to retrieve winds from σ^0. This is simply because scatterometer measures only the σ^0 that has influence of the local winds, but not the actual winds. Thus, the retrieval of the winds from scatterometer measurements is basically an inverse problem where we have to find a suitable forward model for the σ^0 dependent on winds and then we have to invert that model to derive winds. Such a forward model is known as Geophysical Model Function (GMF) in scatterometer terminology. A GMF is developed by fitting collocated true winds (e.g., winds from in-situ observations like moored buoys, ships etc.) and measured σ^0 values. In most of the cases the GMFs are developed empirically and they depend on the wind speed, direction, scatterometer incidence and azimuth and polarization. Because of the wind direction dependence, a GMF exhibits bi-harmonic behaviour over the various direction zones. In practice, the GMF is generally developed post-facto using collocated wind observations mostly from NWP model and the scatterometer observations over a period of several months covering the full dynamic range of wind vector.

The exact behaviour of radar backscatter varies with scatterometer operating frequency, polarization and the incidence angle. However, the general trends of radar backscatter dependency on wind vector remains same, specifically the directional dependency of radar backscatter. It has been observed over decades using earlier satellite missions and also based on theoretical models that radar backscatter depends upon wind speed with a power law while it depends bi-harmonically on wind direction. This harmonic nature of radar backscatter on wind direction leads to multiple possibility of wind vectors yielding the same radar backscatter value and thus causes ambiguity in wind direction determination using a set of radar backscatter measurements. The radar backscatter decreases with incidence angle for given wind vector and polarization. Moreover, radar backscatter from ocean surface in vertical polarization is higher than that of horizontal polarization.

Assuming the other parameters remain constant and the dominant dependency of radar backscatter on ocean surface wind vector (speed and direction), extraction of wind speed and direction is carried out by comparing the measured radar backscatter with those simulated using suitable GMF for assumed wind speed and direction varied in its entire range valid for the GMF being used. This process yields multiple solutions of wind vector among which one solution corresponds to true wind vector while others are ambiguities. The wind speed values of these vector solutions have small differences while the direction values are quite different. These solutions are prioritized according to the deviation of measured radar backscatter from the simulated values with the vector solution having minimum deviation treated as highest priority solution. Under noise free conditions, the highest priority vector solution always identifies the correct (true) wind vector while under moderately noisy conditions, the highest priority solutions identify the correct wind vectors in about half of the data cases considered. Such performance of the algorithm is heavily dependent on the noise present in radar backscatter data. The characteristic of these prioritized solutions is such that the majority of correct wind vector cases can be identified between the first two highest priority solutions. Moreover, in most of the cases the directions of the first two highest priority solutions are mostly opposite to each other. Thus, when wind vectors are retrieved from scatterometer data over the swath, about half of the directions may be found in opposite direction to the overall wind directional flow in the data region. These directional ambiguities are filtered out by using another process known as directional ambiguity removal process.

iv. Ocean and ice applications of surface winds

Ocean general circulation models (OGCMs) are forced by air-sea fluxes at the ocean-atmosphere interface. These forcings consist of wind stress, heat fluxes, and freshwater fluxes (precipitation, river discharge, and glacier runoff). Out of these surface boundary forcings, wind stress plays the leading role. Hence, an accurate wind forcing is a prerequisite for obtaining realistic circulation features, whether dynamic or thermodynamic, simulated by an OGCM. Realistic OGCM simulation requires dense ocean observing network of surface forcings, which again, is non-existent, as of today. The problem is less severe as far as the surface wind stress is concerned, because of the presence of orbiting scatterometers. However, the surface wind vectors retrieved from a scatterometer are highly scattered in both space and time due to the limited beam-width of the scatterometer. (Fig 5.8) shows a typical descending pass for a day. Such scattered observations from scatterometers are analysed to produce synoptic gridded wind vectors (analysed wind vectors) regular in spatio-temporal coordinates. Hence the swath observations from a scatterometer are undergone through suitable statistical techniques to produce 6 hourly and daily analysed wind vectors and subsequently these vectors are used to provide forcing to the ocean circulation as well as ocean wave models. (Fig -5.9) shows the 6 hourly global gridded analysed wind for the same day. Hence the major application of scatterometer observation for oceanography is to provide forcing for the numerical ocean models. Scatterometer derived winds are also used to compute ocean surface currents along with Altimeter observations. The phenomena of land and sea breezes along the coasts can also be studied using scatterometer data. Apart from this, σ^0 are utilized to monitor the extent and variability of sea ice.

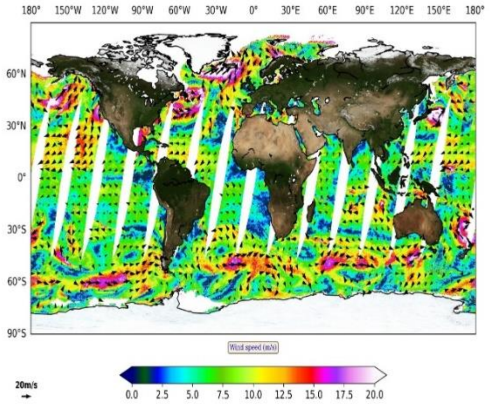


Fig. 15.8 Ocean surface vector winds as captured in the descending passes of EOS-06 scatterometer on 11 February 2023.

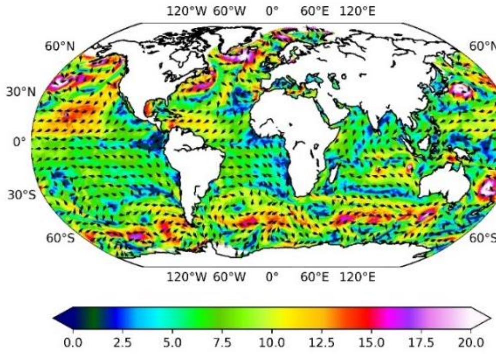


Fig. 15.9 6 hourly global ocean surface vector winds from EOS-06 scatterometer on 12 February 2023

v. New concept in scatterometry

It is now already established the importance of scatterometer in met-ocean studies and operational forecasting purposes. There are several new concepts in scatterometer are coming apart from the conventional conFigurations. A rotating fan beam scatterometer (RFSCAT) has been flown in the Chinese-French Oceanic Satellite (CFOSAT) to retain the benefits of both pencil-beam and fan-beam geometries. Also engineering efforts are being engaged to develop scatterometers processor that will be doing the retrieval on-board. Efforts are also envisaged to measure the ocean surface currents along with ocean surface winds from a single scatterometer.

5.2.3 Synthetic Aperture Radar based ocean observations at high resolution

i. Ocean surface winds and waves from SAR

As already mentioned, the backscattered power received by the SAR antenna mainly gives information about the surface roughness. Over the oceans, the surface roughness is governed by the surface winds and waves. For an oceanic scene captured by a SAR, higher wind and waves leads to higher surface roughness and thus higher backscattered power. In other words, the SAR data over the oceans contain the signatures of ocean surface winds and waves. Such a signature can be empirically represented by mathematical relationships in terms of Geophysical Model Function (GMF), which essentially relates the backscattered data with ocean winds/ waves and other sensor specific parameters (frequency, incidence angle, azimuth, polarization etc.). Thus, by carrying out the mathematical inversion of the GMF, information of the ocean surface winds/waves can be retrieved from the SAR data. Since only one observation per pixel is available from SAR, wind direction cannot be retrieved from the data. Fig. 5.10 shows the wind and wave parameters from EOS-04.

SAR derived winds and wave parameters are of extreme importance, as they contain very fine scale information, not available from other space-borne sensors. In addition, suitable choice of operating MW frequency makes the SAR data capable of retrieving winds in extreme weather conditions like tropical cyclones and hurricanes. Hence, SAR is the most suitable space-borne radar that can be used to measure the high-resolution winds/waves even over the cyclone eye. Such information is extremely useful in estimating the quadrant-wise wind distribution around the cyclone eye and this data can further lead to the improvement of the cyclone track prediction and forecasting of rapid intensification. Apart from these, there are a number of mesoscale and sub-mesoscale processes occurring at the air-sea interface, require the high-resolution information of the ocean winds. SAR derived winds have shown positive impacts when assimilated into numerical weather prediction model for hurricane track forecasting. Thus, SAR derived high resolution winds over the oceans are highly useful in large number of met-ocean processes.

ii. Future advancements in SAR for Marine Application

For the last four decades high resolution imageries over the ocean surfaces captured by various tandem SAR missions have been providing resourceful information to the research communities. At present scenario SAR is capable of working in mono-static mode, which suffers from receiving a major portion of the backscattered signals. To avoid this, the idea of bi-static SAR has already been conceptualized. Efforts are being dedicated presently over the globe to implement such systems practically. Also, the several SAR constellations are being planned. ISRO has already launched two of the SAR systems onboard RISAT-1 and EOS-4 for earth observation applications. Dual frequency SAR systems (e.g., NASA-ISRO SAR, NISAR) are getting ready for being launched in January 2024.

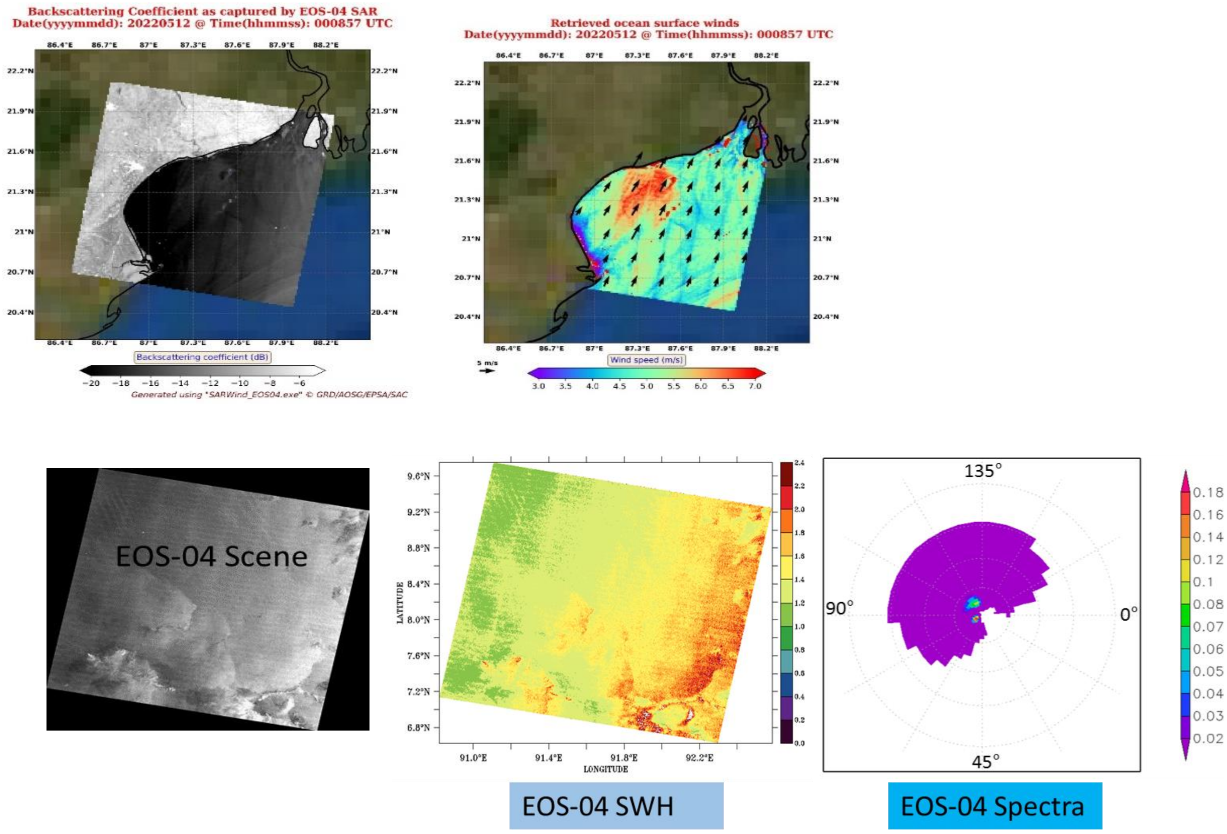


Fig. 5.10 Backscattering coefficients (left panel) from EOS-04 SAR and the retrieved ocean surface wind products (right panel) for 12th May 2022.

5.3 Passive Satellite Sensors for Ocean and marine observations

Passive satellite sensors sense the radiations coming from the earth. They do not have a source of light with them. This radiation emitted by earth's oceans are particularly received by the satellite radiometers and converted to meaningful ocean related information. This can be done at various part of electromagnetic spectra. In perspective of ocean, passive sensors that sense radiation at visible range and near infrared includes Ocean Colour Monitoring dedicated for marine biology studies. INSAT operates in Infrared range and is instrumental in Sea surface temperature measurement. Microwave range of passive sensors is extremely crucial for observing sea surface salinity like SMOS and Aquarius.

5.3.1 Ocean Colour Monitor: Looking at Marine Ecology

The colour of ocean is not just blue or green but it depends on the type of substances present in the ocean water. The main substances that present in ocean water are phytoplankton (tiny floating plants in ocean water), total suspended matter and dissolved/detrital matter and the optically active constituents present in these substances are chl-a pigment (phytoplankton), inorganic suspended particles (total suspended matter) and dissolved and particulate organic carbon (dissolved/detrital matter). These constituents/parameters play an important role in biological oceanographic studies of the ocean waters. These constituents can be detected from space through their distinct optical properties in the optical region of electromagnetic spectrum using Ocean Colour Monitors (OCM). Ocean Colour Monitors are passive radiometers, which detect reflected Sun light in the optical region of electromagnetic spectrum coming from the surface of ocean waters. This reflected light from the surface of water carries information about the water constituents and is used in estimating ocean colour geophysical parameters. Oceanography has attained a great importance from the point of view of ocean-productivity and bio-geo-chemical cycling, as also due to its impact on the oceanic CO2 and flux of carbon right from its surface to the depth of ocean colour data. Data with satellite remote-sensors provide temporally resolved synoptic views of ocean regions over a long period. These data can be applied to study spatial and temporal dynamics of ecologically and bio-geo-chemically important properties of the upper ocean, such as phytoplankton pigments, primary production patterns, suspended sediments, dissolved nutrients, and light attenuation properties. These applications signify the versatility of satellite remotely sensed data for addressing environmental issues in coastal regions.

i. History of OCM missions and its perspective

The ocean colour study was initiated using the Landsat satellite data in 1970s. Then exclusively the NIMBUS-Coastal Zone Colour Scanner (CZCS) mission started in 1978 and continued successfully until 1986. Later on, in 1990s ocean colour remote sensing started with improved sensor-based satellite missions like Indo-German Collaboration IRS-P3 MOS, NASA's Sea viewing Wide-Field of View (SeaWiFS), Japan's OCTS and Indian's Ocean Colour Monitor-1 (OCM-1 onboard Oceansat-1, the first exclusive ocean colour satellite of India along with microwave radiometer MSMR in 1999). In next decade, the major ongoing ocean colour missions were the NASA's Moderate Resolution Imaging Spectro-radiometer (MODIS in 2002), MERIS of ESA (2002) and OCM-2 (onboard Ocenasat-2, launched on September 23, 2009 by India). Another generation of ocean colour instruments was launched into polar orbit in 2011, named Visible Imaging Infrared Radiometer Suite (VIIRS) by Suomi National Polar Orbiting Partnership (NPP) spacecraft. All these satellites comprise of Ocean Colour Monitor (OCM) instruments that provides Top of Atmospheric (TOA) radiance emanating from water surface after passing through the atmosphere. TOA radiance is used in deriving geophysical parameters for ocean biology studies. Recently, Indian Space Research Organisation (ISRO) has launched EOS-6 satellite on 26 November 2022, which is having a payload Ocean Colour Monitor-3 (OCM-3) equipped with 13 bands in visible, near infrared and shortwave infrared region for ocean colour remote sensing applications. The potential applications with details of wavelengths of EOS-6/OCM-3 are given in following table 5.1.

ii. Geophysical parameters retrieval from Ocean Colour Sensors

The important geophysical parameters that are retrieved through OCM are chlorophyll-a, total suspended matter, aerosol optical depth and diffuse attenuation coefficient. These ocean colour geophysical parameters are used in algal blooms monitoring, cyclone and dust induced productivity, upwelling processes, biogeochemical cycle of ocean waters, sequestration of carbon, fixation of nitrogen and atmospheric aerosol studies.

iii. Phytoplankton chlorophyll-a concentration

Photoactive green pigment chlorophyll- a causes distinct changes in the colour of water by absorbing and scattering the light incident on water. Chlorophyll-a concentration can be estimated from remotely sensed spectral reflectance data by relating reflectance ratios in blue green bands to the concentration of chlorophyll-a. The physical basis of such algorithms is based on strong absorption in the blue region and the reflectance invariance in the green region for Case 1 waters. Development of an empirical bio-optical algorithm needs large number of simultaneous measurements of the in-situ reflectance and the corresponding Chlorophyll- a concentration data. A number of different bio-optical algorithms were developed for regional as well as global ocean waters to generate the chlorophyll-a concentration maps using analytical, semi-empirical and empirical approaches. The typical blue-green ratio based empirical algorithms; Ocean Chlorophyll-2 (OC-2) and Ocean Chlorophyll-4 (OC-4) are globally used for the derivation of chlorophyll-a. Global Ocean Chlorophyll-2 (OC-2) algorithm is a cubic polynomial function which uses remote-sensing reflectance ratio of 490 and 555nm bands and Ocean Chlorophyll-4 (OC-4) algorithm is a cubic polynomial function based band switching algorithm which uses maximum remote-sensing reflectance ratio of 443, 490 and 510nm out of 555nm band.

iv. Total Suspended Matter (TSM) Concentration

Processes such as tides and waves, river discharge, wind stress and turbidity currents modulate the transport and distribution of suspended sediments in coastal environment. It has been demonstrated by a large number of studies that satellite based remote sensing can be effectively used in detection and quantification of total suspended matter in coastal seas. The study of suspended matter has an ecological importance because it is the main carrier of various inorganic and organic substances (including pollutants) and becomes the main substrata for biogeochemical. The algorithm derived using reflectance in red band by Tassan et. al. (1994) is widely used for the determination of Total Suspended Matter (TSM).

v. Diffuse Attenuation Coefficient (Kd at 490nm)

Light availability in the oceanic water column is a critical regulator of oceanic and coastal production of phytoplankton. Diffuse attenuation coefficient, Kd, is of significance to a variety of problems associated with the penetration of natural light into the ocean and is also an important variable in evaluating propagation of artificial light in seawater for various optical, communication and surveillance systems. The knowledge of the optical attenuation within upper ocean water column is also useful to understand the warming of the upper ocean, which occurs through the absorption of solar irradiance (400- 800-nm). The diffuse attenuation coefficient (Kd) product is an apparent optical property, which defines the rate of decrease of down-welling irradiance decreasing with depth in the water column.

vi. Aerosol Optical Depth (AOD) Estimation

The basis of AOD estimation using NIR band for OCM data lies in the fact that for NIR bands (λ>700nm) ocean surface acts as a dark background because of the high absorption by water. The sensor-detected radiance can be assumed to be the sum of Rayleigh and aerosol path radiance produced by the scattering of light by air molecules and aerosols. The aerosol path radiance is calculated from the TOA radiance at 865 nm wavelength, knowing the value of Rayleigh radiance at this wavelength. The Rayleigh path radiance is computed as the spectral dependence of Rayleigh optical depth and Rayleigh phase functions. AOD images are generated from OCEANSAT OCM data. The OCM derived AOD images were found to be useful to understand spatial variability of marine aerosols over the oceans.

The four operation geophysical parameters viz. chlorophyll-a, total suspended matter, aerosol optical depth (870nm) and diffuse attenuation coefficient (490nm,) that have been derived using EOS-6/OCM-3 are shown in the following Fig. 5.11.

vii. Coloured Dissolved Organic Matter (CDOM) Studies

Another important geophysical parameter is Coloured (or Chromophoric) Dissolved Organic Matter (CDOM). CDOM is the fraction of Dissolved Organic Matter (DOM) that absorbs light over a broad range of ultraviolet and visible wavelengths and passes a filter typically of 0.2 µm pore size. CDOM comprises a significant fraction of the DOM pool in natural waters (10–90%). CDOM is a vital water constituent that affects the upper water column photo processes through availability of light for primary production. The spectral shapes of the CDOM variability are an indicator of its origin. ISRO's EOS-6/OCM-3 is having great potential to study CDOM in open ocean and coastal waters of ocean using bands1 and band5 (central wavelength 412nm &555 nm respectively).

viii. Oceanic applications of OCM

Bio optical characterization of seawater constituents is essential for understanding the role of biomass in the ocean and its impact on the ocean-atmosphere coupled system. Bio optical characterization of seawater can be done through ocean colour remote sensing.

Using ocean colour remote sensing we can obtain quantitative information of

(i) chlorophyll-a
(ii) vertical diffuse attenuation of the light (Kd) at 490-nm,
(iii) total suspended matter concentration and
(iv) Aerosol optical depth (AOD).

This quantitative information can be used to characterize and to understand ocean water and its role in marine ecosystem studies, modeling and mobilization of organic and inorganic materials. This information can also be used to study carbon cycle and biogeochemical modeling and many other ocean biology applications.

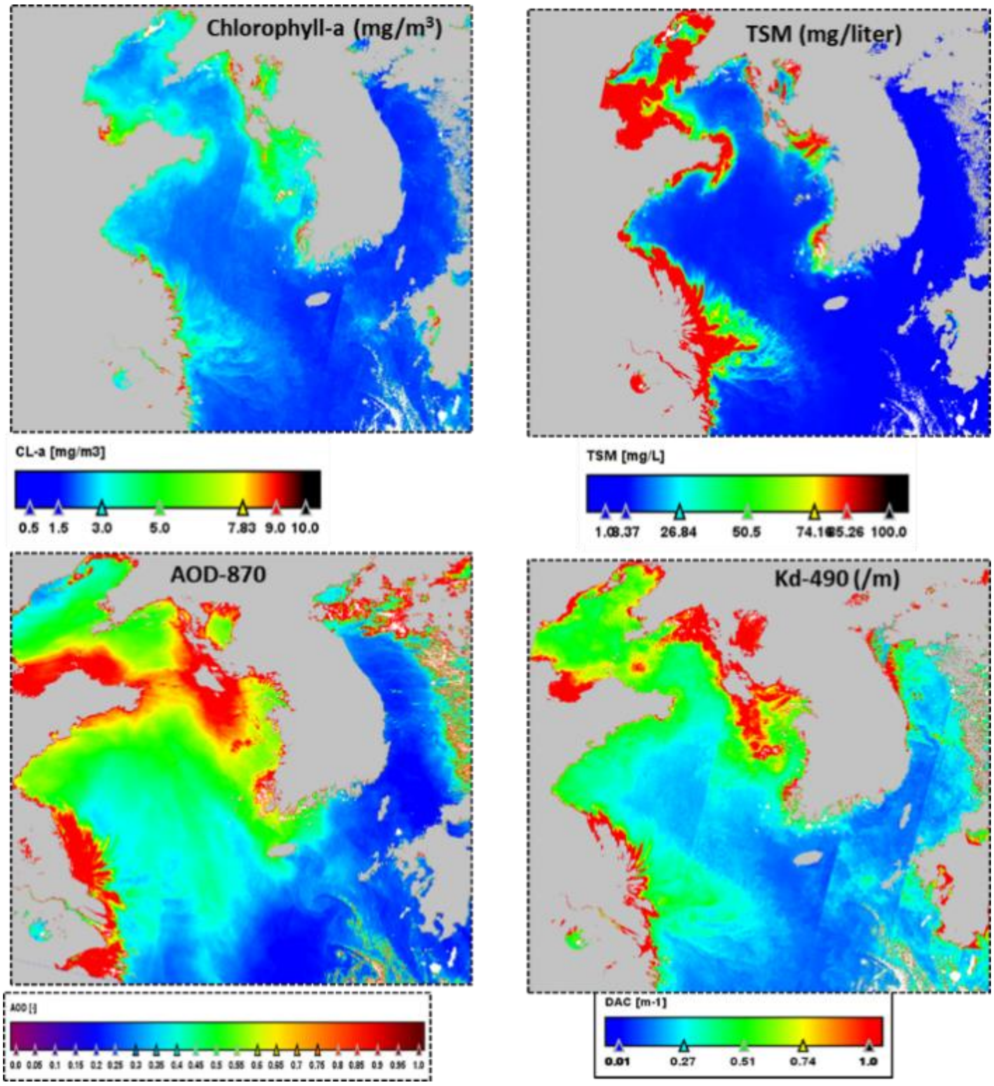


Fig. 5.11 Geophysical parameters derived from Ocean Colour Monitor of Indian Oceanographic Satellite (EOS-6, OCM-3) used in Ocean Biology.

Table 5.1 Spectral bands of EOS-6/OCM-3 and their applications

Band No.	Central Wavelength	Applications
Band 1	412	Coloured Dissolved Organic Matter
Band 2	443	Low chlorophyll detection for phytoplankton biomass / chlorophyll absorption
Band 3	490	Mild chlorophyll detection for phytoplankton biomass
Band 4	510	High chlorophyll detection for phytoplankton biomass

Band 5	555	Weak chlorophyll absorption
Band 6	566	Nitrogen fixing bloom studies for marine environment
Band 7	620	Total suspended matter application
Band 8	670	Baseline band for fluorescence
Band 9	681	Fluorescence peak detection
Band 10	710	Baseline band for fluorescence and for atmospheric correction
Band 11	780	Atmospheric correction for open ocean water
Band 12	870	Atmospheric correction for open ocean water
Band 13	1010	Atmospheric correction for coastal water/foams

5.3.2 Passive IR and Microwave sensors for Sea Surface Temperature

Sea surface temperature (SST) is one of the first oceanographic parameters to be measured from the space and is widely used by the ocean and climate researchers. SST can be measured from both Infrared (IR) and passive microwave radiometers, each with its own advantages and drawbacks. The SST varies on diurnal, seasonal, inter-annual, and on climate scale. Diurnal variability in SST has been observed up to 6°C. The first global composite of SST from the satellite measurements was prepared in 1970s. Since then, numerous satellites have been launched for the measurement of SST by several space agencies.

i. Measurement Principle: Thermal IR and Microwave Regime

Radiometers which can be imaging or non-imaging are passive sensors that operate in the visible, infrared, and microwave regions of electromagnetic spectrum. These radiometers detect naturally emitted or reflected radiation from the earth's surface. Thermal emission and absorption from atmospheric constituents mainly contribute to the EM energy in the thermal IR and microwave regions, whereas in the visible and near IR range it is the reflection/scattering of the incident solar radiation which is prominent. That is why the satellite measurements in the spectral bands within the visible region are sensitive to the reflectance/absorption properties of water constituents over oceanic regions, whereas in the infrared/microwave region, it is sensitive to the emission/absorption from the ocean surface as well as the atmospheric constituents. Reflectance of seawater is sensitive to the surface roughness, bathymetry, and presence of tracers such as salinity, chlorophyll, turbidity, etc.

The basic principle behind the passive radiometry is Planck's law which describes a relationship between thermal emission and the physical temperature of an ideal blackbody (with emissivity as unity):

$$L_\lambda = \frac{2hc^2}{\lambda^5 \left(e^{hc/\lambda kT} - 1\right)}$$

Where, h is Planck's constant and k is Boltzmann's constant. The relationship between the wavelength at which a blackbody emits the maximum radiation, λmax, and the physical temperature of the blackbody, T, is given by Wein's displacement law (i.e., λmax T = constant). At larger wavelength that is in the microwave region (1–40 GHz) Planck's law becomes the Raleigh-Jean approximation which states that the emitted radiation is directly proportional to the temperature of the emitting surface. The above relation is much simpler for microwave than the one for IR radiometry where the full Planck function must be used. For this reason, emitted radiation is sometimes simply referred to as the brightness temperature.

Since the aim of the radiometer is to measure the SST, a suitable spectral band is chosen such that the atmospheric attenuation is minimum and there is sufficiently large amount of energy received at the satellite sensor. These spectral bands in the electromagnetic spectrum are known as the atmospheric windows. There are two important atmospheric windows in the infrared spectrum, 3.8 µm midwave infrared (MWIR) window and 10–12 µm longwave or thermal IR (LWIR or TIR) window that are used for the SST retrieval. The peak of the emitted radiation from the sea surface having SST around 300 K is in the wavelength range 10–12 µm which is a window region. This allows to obtaining high spatial resolution SST with highest accuracy. On the other hand, the MWIR window has the advantage in terms of maximum sensitivity of the observed radiances with respect to the changes in the surface temperature due to shorter wavelengths. In the microwave region, the window region exists below 18 GHz where there is significantly smaller attenuation due to atmosphere even in the presence of the cloud. However, due to the longer wavelengths the sensitivity of the microwave radiometer observations to the changes in the surface temperature is smaller than that in the infrared. In addition to this, a small amount of radiated energy in this region of the EM spectrum causes a large noise equivalent ΔT (NEΔT) which necessitates a coarser spatial resolution or larger antenna to obtain a meaningful signal for the SST retrieval. The C-band (4–8 GHz) in the microwave spectrum is best suited for the SST retrieval due to its higher sensitivity and lower impact due to variable wind-induced surface roughness as well as other atmospheric attenuations. Keeping in mind the advantages they provide in the infrared and microwave parts of the EM spectrum; a blended product is possible by suitably combining the best features of both the sensors.

For SST retrieval, mainly the atmospheric windows in the MWIR (3.8–4 µm) and LWIR (10–12 µm) are used. However, due to the contamination of the emitted radiation by the reflected solar radiation in the MWIR band during daytime, this band is used to retrieve SST only during night-time, hence the name given to it as the night-time SST channel. During daytime, the LWIR window channels are used for SST retrieval. However, absorption in this band due to highly variable atmospheric water vapor makes SST retrieval erroneous. To correct for the water vapour absorption, the split window channels (i.e., 10.3–11.3 µm or T11 and 11.5–12.5 µm or T12) observations are employed. Absorption in the second split window channel is higher than the first channel; therefore, the difference of brightness temperature observations in these two channels gives a quantitative estimate of the atmospheric water vapor that is required for correction in the SST computation. Due to the weak water vapor absorption in these split window channels, the weighting function for these channels lies very close to the surface. Therefore, the amount of water vapour estimated from their differences is equivalent to the total column water vapor as more than 90% of the water vapor lies in the lowest few kilometers of the atmosphere.

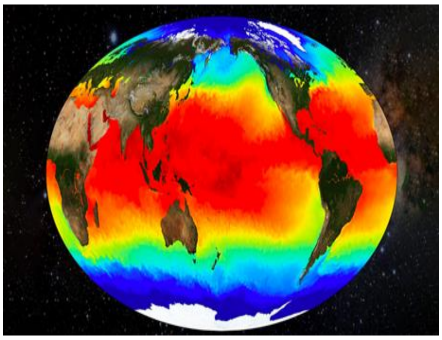
A simple form of the dual channel algorithm for SST retrieval is given as follows:

$$SST = A_1T_{11} + A_2T_{12} + \left[A_3\left(T_{11} - T_{12}\right) + A_4 \right]\sec\theta + A_5$$

Where, A1, A2, A3, A4, and A5 are coefficients derived using regression analysis between actual SST and the collocated satellite observations. Since water vapour absorption is strongly dependent on the observation zenith angle (θ), the relation needs correction for the zenith angle variation. The MWIR channel at 3.8 µm is highly sensitive to the surface temperature variations; so, this channel can replace T11 during night-time when contamination from reflected solar radiation is absent. During night-time, this channel along with the split window channels provides the accurate SST retrieval. Passive microwave radiometer measurements also involve similar empirical relationships.

Applications of Sea Surface Temperature

SST is a key "boundary forcing" to the atmosphere in the numerical weather prediction models and has a great influence on seasonal, interannual and to some extent on decadal predictions. Satellite-derived SST are assimilated in the ocean models for generating accurate ocean state forecasts. SST is the key variable in the air-sea interaction processes. High-resolution SST is quite useful in the determination of fine-scale horizontal thermal gradients or fronts (Fig.5.12). These fine-scale structures can lead to the vertical movement of the biomass nutrients and, therefore, have a potential application in the fishery industry. Thermal fronts also modify the air-sea interaction processes significantly through heat flux exchange. This alteration in the air-sea interaction sometimes can even change the cyclone track. Accurate and well-calibrated SST records are extremely useful for monitoring long-term temperature change and are pointers of climate change. SST fields help in detecting eddies and upwelling regions in the ocean, which are extremely useful for delineating potential fishing zones.



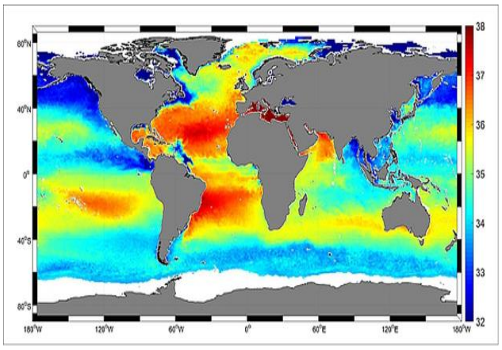


Fig. 5.12 Sea Surface Temperature form AVHRR and salinity from SMOS

ii. New Frontier in SST Measurements

Geostationary satellites can be quite crucial for providing synoptic measurements of SST at very high sampling frequencies. Efforts are on to increase the sampling rate up to 10 min interval so as to provide high frequency variability of SST under cloud-free conditions. Himawari-8/9 of Japan Meteorological Agency, GOES-R of NOAA and Meteosat of Eumetsat are providing SST at high temporal sampling. GISAT of ISRO to be launched in a couple of years' time which will be giving SST from geostationary platform at 1 km resolution at 10 min interval.

5.3.3 Passive microwave remote sensing for Ocean Salinity

Sea Surface Salinity (SSS) variations are key indicator of hydrological cycle encompassing evaporation, precipitation, freezing/melting of ice and river run-off. There have been several studies that highlight the importance of SSS in the studies concerning ocean circulation and climate change. Ocean salinity can be measured more accurately with ships, buoys and Argo floats at different depths in the ocean, but such measurements are very sparse. Although with Argo, scenario has changed considerably with dense global coverage of the salinity, still satellite based observations hold very good promise with repetitive and synoptic coverage. Ocean average surface salinity is about 35 psu with a range of 32 to 37 psu. However, in regions which are strongly affected by river water, salinity can go down to 26-27 psu also. Salinity retrieval from space is relatively new concept. Among various ocean surface parameters derivable from space-borne sensors, taking advantage of interaction of EM radiation with ocean surface, the only missing gap in ocean variables till the year 2010 was surface salinity. Soil Moisture and Ocean Salinity (SMOS) and Aquarius/SAC-D space-borne salinity missions paved the way for a new era in ocean remote sensing and filled this gap in ocean observables from space.

i. About SMOS, Aquarius and SMAP

The first instrument for ocean salinity was launched in the year 2010 by ESA named Soil Moisture and Oceanic Salinity (SMOS). SMOS used a dual-polarized L-band radiometer, and adopted 2-D aperture synthesis technique to achieve a ground resolution better than 50 km without putting a large antenna into orbit. NASA launched Aquarius mission in the year 2011. It carried 3 radiometers (1.4 Ghz) and 1 scatterometer (1.2 Ghz) having swath of 390 km and provided salinity with an accuracy of 0.2 psu on a monthly scale. Measurement of ocean surface salinity from the Aquarius was based on real aperture 3-beam push-broom design. Aquarius was a dedicated surface salinity mission with enhanced capability in terms of better signal to noise ratio. Unfortunately, it suffered from power supply failure and mission ended in 2015 and suddenly once again there was a void in surface salinity measurement from space. However, then came the Soil Moisture Active and Passive (SMAP) mission by NASA (in collaboration with JAXA). Although the primarily objective of SMAP was the estimation of soil moisture over land, however it had all the potential to map ocean salinity also. SMAP, the mission having both active and passive instrumentation, provides highest-resolution and wide swath (~1000 km) measurements. Surface salinity from SMAP are now available for Ocean research community and climate scientists. Unfortunately, the L-band synthetic aperture radar (active sensor) onboard SMAP stopped functioning during July 2015, but salinity data are continuing from this instrument.

ii. Measurement Principles and challenges for salinity retrieval from space

Theoretical basis for ocean salinity retrieval from passive microwave radiometric measurements is to exploit the sensitivity of emission to ocean salinity through its effect on dielectric constant of water. Dielectric constant of water decreases with the increase in salt content. The sensitivity of the brightness temperature signal to ocean salinity is maximum at low frequencies and the most suitable frequency is L-band (1.413 GHz). Hence salinity can be retrieved primarily from passive radiometer at L-band microwave frequency, with scatterometer or synthetic aperture radars used for correcting roughness effect. For salinity retrieval, normally mono-frequency is preferred. The salinity retrieval algorithm is normally based on an iterative convergence approach which minimizes the difference between satellite radiometer measured brightness temperature and those generated from forward model. Forward modeling is performed for ocean surface emissivity which depends on sea state, SST, viewing angle and polarization. Model also included the atmospheric effects, galactic radiation contamination and the sun glint effect.

Salinity measurements from space are based on sensitivity of emitted radiation to surface salinity at L-band. In the L-band the atmospheric attenuation is almost negligible. Nevertheless, one has to account for sea surface roughness, SST, foam, sunglint, rainfall, ionospheric effects and galactic background impact on brightness temperature. Another point to be mentioned here is the low sensitivity of brightness temperature to salinity (0.75 k at 30^{o} C, 0.5 K at 20^{o} C and 0.25 at 0^{o} C). This requires a radiometer with very high signal to noise ratio. Additional requirements are multi-angular and multi-polarisation measurements. Low sensitivity of brightness temperature to salinity requires more energy to be gathered so that it is above the noise level and hence foot print of the radiometer becomes large due to more dwell time. The active sensor scatterometer (onboard Aquarius mission) and synthetic aperture radar (onboard SMAP) were used for correcting roughness effect on brightness temperature. As mentioned earlier, SAR sensor onboard SMAP stopped working. SMAP instrument employs a single horn, with dual-polarization and dual-frequency capability (radiometer at 1.41 GHz and radar at 1.26 GHz). The SMAP radiometer provides a real aperture resolution in which the dimensions of the 3-dB antenna footprint projected on the surface meet the 40-km spatial resolution requirement. The radiometer measures four Stokes parameters at 1.41 GHz to provide a capability to correct for possible Faraday rotation caused by the ionosphere. The chosen 6 AM/6 PM sun-synchronous orbit conFiguration also minimizes such Faraday rotation. Global observation of ocean salinity with an accuracy of 0.1 psu, every 10 days at 200 km spatial resolution was envisaged under Global Ocean Data Assimilation Experiment (1997).

iii. Applications of satellite-derived salinity

Ocean surface salinity is increasingly being recognized as a key parameter in ocean atmosphere interaction. Apart from taking part in this interaction, surface salinity plays a vital role in oceanography in the standalone mode also by influencing ocean dynamics and thermodynamics. In the tropical Pacific, an in-depth understanding of the dominant El Nino Southern Oscillation (ENSO) event using numerical ocean circulation models is just not possible without a faithful representation of SSS in these models. Knowledge of the global salt distribution and its variations are critical to understanding the role of oceans in climate system. It is well established that ocean circulation, air-sea heat exchanges and heat transport play important role in regulating the climate. Three-dimensional ocean flow which is famously known as "thermohaline circulation" is largely governed by salinity variations due to evaporation and ice melting/freezing. Ocean surface salinity is linked to evaporation minus precipitation. Hence measuring salinity will be helpful to constrain the estimation of E-P and will help in better estimate of air-sea flux. Using 50-year of observed global surface salinity changes and global climate models, there is an evidence of intensified global water cycle at a rate of 8+/- 5% per degree of surface temperature warming.

The hydrological cycle in the ocean and atmosphere are intimately linked. This linkage is even much stronger in river dominated Bay of Bengal due to heavy river discharge. The stability caused by freshening isolates upper layer of northern Bay of Bengal from its interior which results in strong barrier layer. Observations suggest that storm-induced vertical mixing is limited to the upper warm layer which favours intense tropical cyclones in this region. Salinity from space will help unravel many unanswered processes at play in such regions.

Another very important aspect of global salinity measurements from space is its assimilation in models to improve the ocean state estimation for ocean process studies. Model simulations in the tropical Indian Ocean show surface salinity variability in the range from 0.2 to 1.5 psu, with larger values in regions with strong seasonal transitions of surface currents (south of India) and along the coast in the Bay of Bengal.

5.4 Numerical Models for marine information retrieval from EO satellites

In operational oceanography two most important aspects that require precise predictions are waves and circulation. The ocean waves include the wind generated waves that are generated from local wind conditions and the swells which are long waves that propagate to a certain place from distant storm. Ocean wave models essentially provide us information of wave height and direction and swell height and direction respectively. The ocean circulation models are used to simulate ocean currents and other important parameter s like ocean temperature and salinity. Most important aspect of these models are they provides the 3D ocean data with subsurface information that we don't get from satellites. However, the model performance suffers from various drawbacks like imperfect parameterization and inaccurate initial conditions. In particular, the performance is severely affected by the extreme rough sea conditions encountered during tropical cyclones. But with the emergence of high-quality space-based observations of SST, SSHA, wave heights etc by satellites, situation has turned for the better since these observations could be assimilated into the models for enhancing predictability of these models.

The coastal zones and deep oceans are important from the point of view of sustainable economic development based on fisheries, tourism, ship routing etc. Unfortunately, however, the coastal oceans are highly vulnerable to high waves and swells occurring during monsoon as well as during the pre- and post- monsoon cyclone seasons. Coastal currents are also important when we talk about the climate. Thus, this most important zone needs lot of monitoring and cannot be studied using satellites or in-situ alone. The data assimilative numerical waves/circulation models where the remote sensing and in-situ observations are combined provide an excellent tool for extracting geo-spatial marine information for coastal region.

5.4.1 Wave models

It is a standard practice to use wave models like WAM, SWAN, Wave-Watch III and MIKE 21 to simulate the waves in the Indian coastal regions. Most wave models in public domains are 3rd generation wind-wave spectral model that solves the random phase spectral action density balance equation for wave number-direction spectra. Mathematically

$$\frac{\partial N}{\partial t} + \frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\dot{\phi}N\cos\theta + \frac{\partial}{\partial\lambda}\dot{\lambda}N + \frac{\partial}{\partial k}\dot{k}N + \frac{\partial}{\partial\theta}\dot{\theta}_g N = \frac{S}{\sigma}$$

$$\dot{\phi} = \frac{c_g\cos\theta + U_\phi}{R}$$

$$\dot{\lambda} = \frac{c_g \sin\theta + U_\lambda}{R\cos\phi}$$

$$\dot{\theta}_g = \dot{\theta} - \frac{c_g \tan\phi \cos\theta}{R}$$

where t is time; λ is longitude; ϕ is latitude; ɵ is wave direction; N is the wave action density spectrum described in five dimensions (λ, ϕ, k, ɵ, t); k is the wave number; the over dot symbol denotes the wave action propagation speed in (λ, ϕ, k, ɵ) space; Cg is group velocity, Uϕ and Uλ are current components, R is radius of earth, σ is relative frequency; and S is the total of source/sink terms. In deep water, the net source term S is generally considered to consist of three parts,

$$S = S_{in} + S_{nl} + S_{ds}$$

Where Sin is wind-wave interaction term, Snl is non-linear wave-wave interactions term and Sds is dissipation term. In shallow water, additional processes have to be considered, most notably wave-bottom interactions (Sbot) and depth-induced breaking (Sdb).

5.4.2 Circulation Models

Circulation models or ocean general circulation models are extensively used to simulate the physical conditions of the oceans. Physical parameters like temperature salinity and density are correctly simulated using OGCMs. These also help us simulate the currents present in ocean These OGCMs are mainly based on, the Primitive Equations (PEs) are written as in

$$\frac{\partial Y}{\partial t} + \mathbf{u} \cdot \nabla Y + F(Y) = 0$$

Where u the velocity vector with zonal meridional and vertical component. Y=(**u**, *T*, *S*) is the prognostic continuous state vector of the ocean, and *F* includes all other terms of the PEs, including the Coriolis force, the pressure gradient force, the external forcing, etc. Because this equation is a highly non-linear one it has to be solved numerically means applying a discretisation" operator *to* the state vector *Y.*

5.5 Geographic Information System in Satellite Oceanography, Coastal processes and Marine ecology

Geographic Information system (GIS) is a computer system for capturing, storing, visualizing and analysing data with geospatial information. Various commercial and open GIS tools are available for visualizing and analysing geospatial data like ARCGIS, QGIS etc. GIS are vastly used in marine and oceanography domain for visualization and building decision support system. Web GIS is a Geographic Information System distributed across networked computer environment to integrate, disseminate and communicate geographic information visually on the World Wide Web over the Internet. SAC-ISRO has developed & hosted following Web GIS applications for the marine domain:

1) Ocean State Forecast
2) RIP Current Forecast
3) Potential Phishers zone
4) Oil spill

5) Eddy Current etc.
6) Optimum Ship Routine (On request basis)

Ocean State Forecast: This is an in-house developed WebGIS application and disseminates Ocean state forecast (Circulation as well as WAVE forecast) in near real time. This is being updated on daily basis. Forecast parameter like Ocean Surface currents, Wave height, Sea Level Pressure, Surface winds are visualized as raster images using GIS tools like Geoserver, PostgreSQL, Openlayers etc.

This application has raster datasets of Ocean Surface Currents, Surface Winds, Wave Height, Sea Level pressure, Heat Content Anomaly. Additionally, user can add multiple vector layers like Admin boundaries, port and create a complete mashup and perform better analysis for decision making.

RIP State Forecast: Waves and Tides can sometime cause flash rip currents which could take you away to the deeper waters. Life threatening rip currents forecast is disseminated as a Web GIS application over MOSDAC in near real time. This is being updated on daily basis. This forecast RIP current forecast risk for beaches all over the India. This also gives time series visualization of parameters like 'RIP current Risk', 'WAVE period', 'WAVE height', 'WAVE direction', tidal elevation. User can add multiple layers of vector datasets like Admin boundaries, beach location to perform better analysis. This application is very useful for tourism, coastal guards etc.

Potential Fisheries Zone (PFZ): An advanced potential fishing zones advisory has been developed by linking the essential ocean information available from various satellites, such as ocean colour, altimeter, scatterometer and radiometer with marine fishery potential zones. The proposed methodology for monitoring and forecasting of PFZ has been demonstrated for Indian Ocean (IO). A WebGIS application 'Fish Catch' is developed to display PFZ information over geospatial platform. Beta version of this application is released over intranet. This is being updated on daily basis.

Eddy Currents: The oceanic eddy parameter information was prepared 1993 – 2020 over Global Ocean using AVISO data. Merged and gridded satellite altimeter product of sea surface height (SSH) anomaly at 7-day interval having special resolution of 0.25o has been used for present study. Mesoscale oceanic eddies have been identified and tracked in weekly merged altimeter product of Sea Surface Height (SSH) from AVISO. An automated tracking algorithm has been employed to track these eddies with different lifetime. Web GIS application is designed for visualization and analysis of Ocean Eddies. This display both Cyclonic and Anti-Cyclonic eddies. This provides visualization of 'Eddy points' as well as 'Eddy Track'. User can overlay multiple layers like 'Marine protected area', 'ports', 'Cyclone Risk map', 'Admin boundaries' for further analysis.

Oil Spill: Lagrangian Coherent structures (LCS) arise in Ocean due to non-linear dynamics of Ocean. These 2-D structures have an ability to facilitate or block the material transport (of seawater + passive tracers) through them, thus organizing the flow pattern of passive tracers in the ocean. Its computation involves the 2-D advection of particles (starting from a well-defined grid) at a current time with altimeter velocities to a certain period of time (15 days in this case).

Optimum Ship Routine: This routing algorithm determines optimum safe routes based on estimated ocean state during the sailing period of ships. The technique on which the routing is based is Dijkstra's algorithm which provides solution to single source shortest path problem in graph theory. A fully automated module for safe ship routes is available at MOSDAC and an operational system for disseminating the email-based outputs of optimum routes to ships/vessels has been developed for users. In current safe ship route perspective, at MOSDAC, an automated e-mail-based dissemination technique is developed and made operational. Using this tool, a user can get an automatic e-mail response about the safe ship route by sending their source and destination points as an e-mail. This has also the scope to visualize over GIS application.

5.6 Conclusion

Remote sensing plays a crucial role in marine applications as it provides valuable information about the Earth's oceans and coastal areas. It enables scientists to remotely monitor and analyze various parameters, including sea surface temperature, chlorophyll concentration, coastal erosion, and the distribution of marine ecosystems. By utilizing satellite-based sensors and aerial platforms, remote sensing allows for the collection of extensive and continuous data over large spatial areas, providing a comprehensive understanding of marine processes and changes.

A major advantage of remote sensing in marine applications is its capability to provide frequent and near real-time observations. This is particularly significant for monitoring dynamic phenomena such as harmful algal blooms, ocean currents, and marine pollution. Remote sensing data facilitates the identification of potential fishing zones, mapping of coral reefs, detection of marine debris, and assessment of water quality. The insights gained through remote sensing contribute to a better understanding of marine ecosystems, support the sustainable management of coastal resources, and aid in the conservation and protection of marine environments. As technological advancements continue, remote sensing continues to evolve as an invaluable tool for studying the intricate and ever-changing nature of the world's oceans.

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Chapter 6

ATMOSPHERIC SCIENCE APPLICATIONS

Geospatial technologies have garnered significant attention in atmospheric science due to their diverse range of applications. By leveraging remote sensing data, model analysis, and in-situ observations within a geospatial framework, users can interact with and derive greater value from retrieved geophysical data. The integration of location-based frameworks can unlock the full potential of weather and climate-related data, particularly in domains such as disaster mitigation, event management, aviation, transportation, and the power sector. These applications underscore the importance of geospatial technologies in enhancing our ability to manage and respond to critical events and enable effective decision-making.

6.1 Introduction

Atmospheric science is a multidisciplinary field that comprises of the study of Earth's atmosphere and the physical, chemical, and biological processes that occur within it. Atmospheric scientists use a variety of methods, including satellite observations, field measurements, laboratory experiments, and computer simulations, to investigate the atmosphere's composition, structure, and dynamics. The use of remote sensing techniques to observe and measure atmospheric variables from space comes under the purview of 'Satellite Meteorology'. Satellites can provide us with information about temperature, humidity, wind speed, precipitation, and other meteorological variables over large areas, helping us to understand and predict weather patterns and climate change. One of the most significant advantages of satellite meteorology is its ability to provide synoptic coverage Satellites orbit the Earth, providing us with data from remote and inaccessible areas that are difficult or impossible to observe from the ground. This global coverage allows us to monitor weather patterns and climate change on a global scale, providing valuable insights into the Earth's climate system. Also, the recent advancements in satellite technology have paved the way for better capabilities in terms of spectral, spatial, and temporal resolution. There are three main pillars of Satellite meteorology: Retrieval, Modelling, and User Applications.

6.2 Retrieval

The atmosphere, considered as a fluid is a thermodynamic system that obeys the ideal gas laws. Its dynamic behaviour is governed by non-linear partial differential equations. The accurate solutions to these equations put a stringent condition of continuous and simultaneous requirement of atmospheric observations over the globe at all times. However, such a requirement is practically impossible to meet. Therefore, to accurately predict the atmospheric condition we need a set of observations that cover a complete specification of the thermodynamic and turbulent state of the earth's atmospheric system. Hence it underlines the importance of measurement of various state variables of the earth-atmosphere system. Table 6.1 presents the spatial and temporal requirements of ocean and atmospheric state variables.

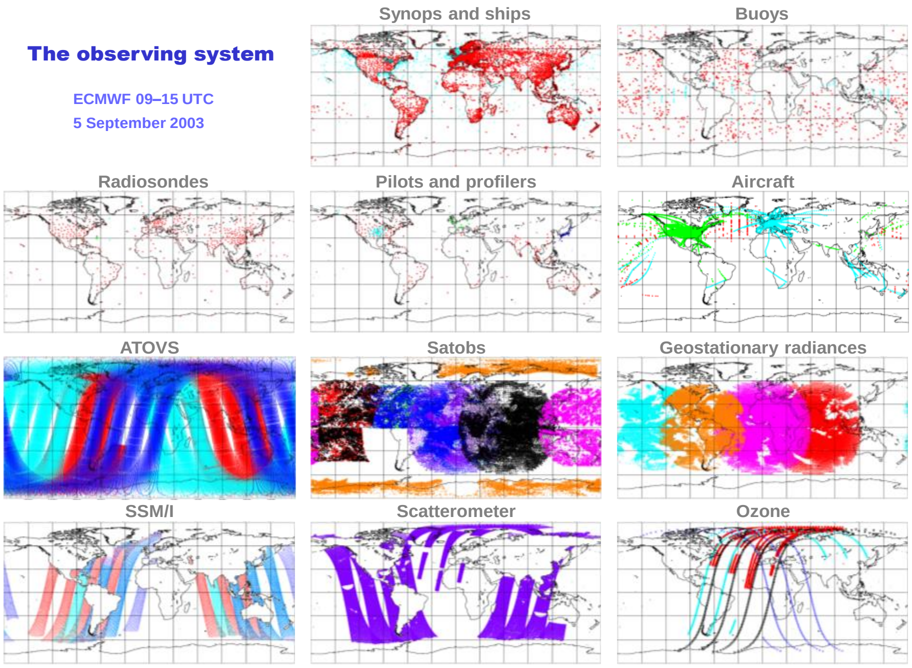

Fig. 6.1 The global distribution of various observations

Table 6.1 Spatial and temporal requirements of state variables

STATE VARIABLES (SV)	HORIZ. RESOL.	VERT. RESOL.	TIME RESOL.	ACCU./ UNITS
(1) ATMOSPHERE				
• wind	50-100 km	0.1-0.5 Km	3 hrs	2-5 m/s
• upper air temperature	50-100 km	0.1-0.5 Km	3 hrs	0.5-1.0ºK
• surface air temperature	50-100 km	N/a	3 hrs	0.5-1.0ºK
• sea level pressure	50-100 km	N/a	3 hrs	0.5 hPa
• upper air relative humidity/wv	50-100 km	0.1-0.5 Km	3 hrs	5%
• surface relative humidity/wv	50-100 km	N/a	3 hrs	1-5%
• precipitation (liquid/solid)	50-100 km	N/a	3 hrs	0.1 mm/ 5%
• clouds	50-100 km	By type	3 hrs	10% cover
• liquid water content	50-100 km	Column total	3 hrs	5% (Kg/m$^{2)}$
(2) OCEAN				
• upper ocean currents	100-500 km	N/a	1wk – 1 mo	cm/s
• upper ocean temperature	100-500 km	20 m	15 d-1 mo	0.3-0.5ºK
• sea level/surface topography	1000 km	N/a	1 mo-1 yr	mms to cms
• upper ocean salinity	500 km	20 m	1 wk-1 mo	ppt
• sea ice	25-100 km	10 cm	1 d-1 mo	2%-10%
• mid/deep ocean currents	100-1000 km	0.1-1 km	3 mo-10 yrs	Cm/s (tbd)
• mid/deep ocean thermal structure	100-1000 km	0.1-1 km	3 mo-10 yrs	0.5ºK (tbd)
• mid/deep ocean salinity structure	100-1000 km	0.1-1 km	3 mo-10 yrs	Ppt (tbd)
• ocean biomass/phytoplankton	100-500 km	0.01-1 km	3 mo-10 yrs	10% (tbd)

(3) LAND & WATER (TERRESTRIAL)

• topography/elevation	1-1000 km	1 cm-1 m	1-10 yrs	1 cm- 1 m
• land cover	1 m-100 km	N/a	1-5 yrs	5%
• surface soil moisture/wetness	1-100 km	10 cm deep	1 d-3 mo	$0.02 m^3/m^3$
• soil structure/type	1- 10,000 ha	30 cm, 1 m	1-10 yrs	5%
• vegetation (biomass above ground)	1-100 km	1 m (tbd)	1 wk-10 yrs	5-10%(kg/ha)
• water runoff	1-100 km	N/a	1 hr-1 mo	5%
• surface ground temperature	1-100 km	10 cm deep	3 hr-1 wk	0.5-1ºK
• snow/ice cover/depth	1-100 km	Depth	1 d-1 mo	10%
• sub-surface temp & moisture	1-100 km	20cm, 1 m	1 d-3 mo	0.5ºK/5% (cm)
• soil C,N,P, nutrients	1- 10,000 ha	30 cm, 1 m	1-10 yrs	5% (g/m^2)
• necromass	1-100 km	N/a	1 yr	10% (g/m^2)
• sub-surface biomass	1-100 km	N/a	1 yr	10% (g/m^2)
• land use	1 m-100 km	N/a	1-5 yrs	%- m^2 (tbd)
• ground water (& subterranean flow)	100 km (tbd)	Depth	3 mo-1 yr	5% (cm/s)
• lakes and reservoirs	1-100 km	Actual depth	1 wk-1mo	5% (cms)
• rivers and river flow/discharge	1-100 km	N/a	1 hr-1 mo	5% (m^3/s)
• glaciers and ice sheets	1-100 km	Depth	1 yr-10 yrs	10 $kgm/m^2/yr$
• Water-turbidity, N, P, dissolved O	1-100 km	1 m	3 mo-1 yr	%, ppt/ppm

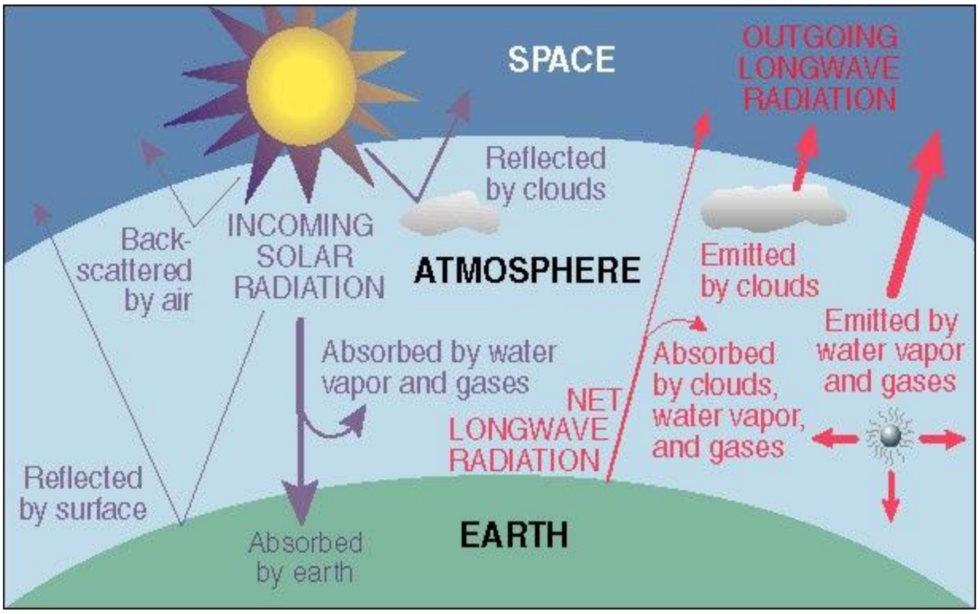

Fig. 6.2 A schematic diagram of the interaction of radiation

Ground-based (In-situ) observations provide very accurate measurements of atmospheric parameters but these measurements are generally sparse, expensive, and not available in geographically inaccessible regions. Most of ground-based measurements are not usually available beyond the troposphere. Additionally, ground-based measurements are expensive and instruments are not portable. It requires relatively larger manpower to maintain it and to take measurements. On the other hand, space-based platforms (satellites) provide high spatial and temporal atmospheric parameters at much lower cost over wider geographical regions.

Remote sensing of the earth atmosphere system is done by the reflection, emission, or scattered radiation. Sun is the only source of energy for earth atmosphere system. The energy from the sun interacts with this system and is either absorbed, emitted, reflected, or scattered by the various components of this system. The Fig. 6.3 shows a schematic diagram of radiation coming from the sun and then going back to space. The reflected radiation is visible spectra of radiation, the emission is in infrared (IR) and microwave (MW) regions of radiation whereas, scattering is prominent in VIS, ultraviolet (UV), and MW.

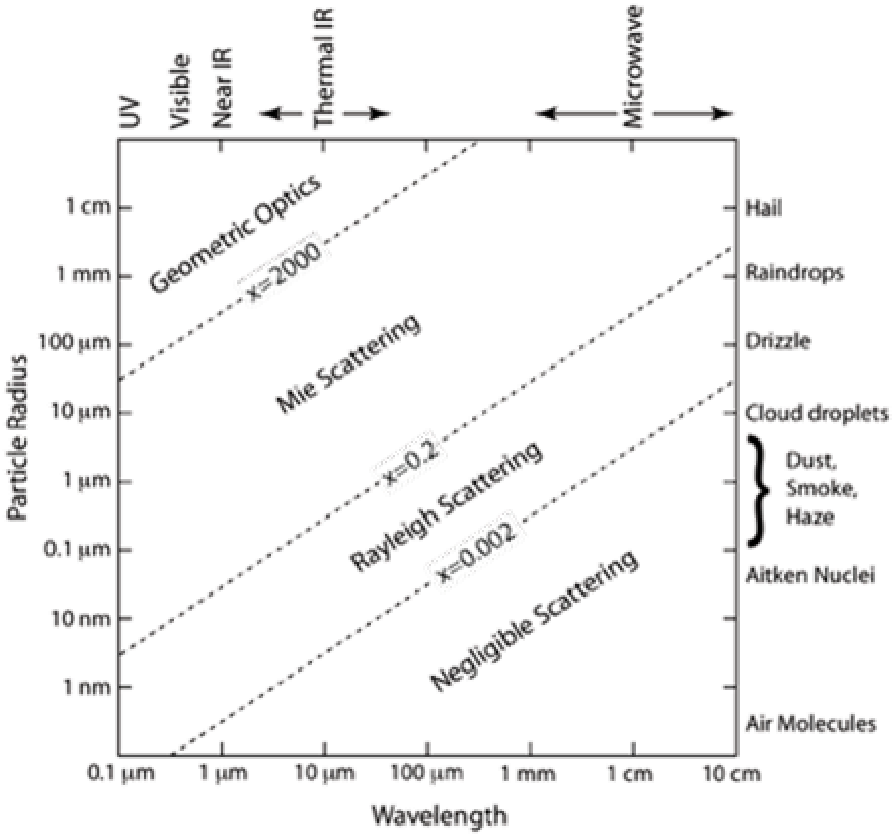

Fig. 6.3 Wavelength of radiation, particle size, and prominent scattering

The gaseous absorption (or emission) of radiation takes place in the following ways:

- Ionization-dissociation **(X-ray, UV)**
- Electronic transitions between quantized orbital energy levels **(UV, Vis)**
- Vibrational transitions **(IR)**
- Rotational transitions (**Far-IR & MW)**
- **Scattering of radiation** is determined by the **Size parameter:** $\mathbf{X = 2.\pi.}\boldsymbol{d}\mathbf{ / \lambda}$

Large values of size parameters are modelled using Geometric optics. The interaction of clouds in VIS radiation is an example of it. If the size parameter is comparable (0.1 to 50) to incoming radiation, then Mie Scattering takes place. Mie scattering takes place while MW radiation interacts with rain or aerosol (or dust particles) interacts with VIS radiation. In the case of very small particles with respect to radiation wavelength then it follows Rayleigh scattering. Rayleigh scattering explains the interaction of air molecules and VIS radiation or MW radiation with clouds. The Fig. 6.2 given above depicts various scattering regimes with respect to radiation wavelength and particle size and table 6.2 summarizes the same.

Table 6.2 Summary of scattering process and radiation of wavelength

CO_2	IR	14.3-16.7 µm	4.0-5.0 µm	2.5-3.3
H_2O	IR MW (Weak)	1.0-2.0 µm 22.36 GHz	5.9-6.7 µm 183 GHz (Strong)	Continuum> 18 µm Continuum > 200GHz
O_3	IR	10 µm		
O_2	MW	60 GHz (band)	118.75 GHz (single)	
Rain	MW	Affects almost all frequencies		
Windows	IR MW	3.5-4.0 1-16 GHz	10 to 12 30-50 GHz	70-118 GHz

The measurement of radiation could be done in active or passive mode. In active mode, the sensors on the satellite have its own source of energy that interacts with the earth's surface or the intervening atmosphere and returns back to the sensor, and then provides the required information. Scatterometer, LIDAR, Altimeter, etc. are examples of such active sensors which provide information of ocean surface wind speed and direction, cloud profiles, and sea surface heights respectively. On the other hand, if sensors onboard satellites measure only the (emitted, reflected or scattered) radiation then such sensors are called passive sensors. Most of such sensors are called radiometers. A few examples are Advanced Very High-Resolution Radiometer (AVHRR), Atmospheric sounders etc.

The simulation of radiations reached to the space-borne sensors for given state variables is often called the forward problem. It is often done by using appropriate radiative transfer models. The retrieval of the state variable (or variables) for a given measurement by space-borne measurements is called the inverse problem. Before discussing inversion methods, it is important to mention that the inversion method is governed by the principle employed to generate the required measurements. Additionally, parameters (or state variables) that are derived over only clear (or cloud-free) or rain-free regions. In IR, VIS spectrum, atmospheric or surface information is obscured by the cloud presence similarly MW observations though not affected by the presence of clouds but are influenced by the presence of hydrometeors. Hence, the parameters that require clear column assumption must filter out those pixels. At the same time, the retrieval of a few parameters such as rain, cloud top properties, etc. requires those measurements that are affected by the presence of clouds. Thus, most of the retrieval algorithms are preceded by some sort of flagging algorithms that segregate clear-cloudy, or rain-no rain pixels (or observations). These algorithms are thresholds based where thresholds could be dynamic and static and could be generated using hit and trial or by supervised (unsupervised) algorithms.

After the segregation of pixels, the parameter in consideration decides the choice of retrieval algorithm. For retrieval of ocean surface wind vectors from scatterometer observations a match up data of scatterometer observed backscattered and wind speed is prepared. This helps in retrieving wind speed from actual observations then a wind direction ambiguity removal algorithm is applied for retrieving proper wind direction. For sea surface temperature, either split channel observations (observations in two window channels with differential water vapour absorption) or dual path length observations (viewing the same pixel from two different angles) are taken. These observations are either used in preparing match up data using actual observations or simulation-based observation to generate regression coefficients for SST retrieval. For temperature profile retrievals, an appropriate set of observations are taken either in multispectral or hyperspectral wavelength ranges. If observations are taken in the hyperspectral wavelength domain, then by using Principal Component Analysis (PCA) or similar methods, first of all the dimension of observation is reduced. A one-dimensional variational (1D-Var) algorithm is applied to retrieve temperature and humidity profiles. Additionally, many artificial intelligence or machine learning based algorithms are also used for deriving such profiles. For several other parameters empirical methods (which are based on generating good match up data sets of satellite-based observations and actual observations) are attempted for retrieval of parameters such as rainfall estimation from visible and IR observations, and outgoing long wave radiation (OLR) from broadband observations. For such empirical methods, the choice of predictors and quality of observations are very crucial. Presently, many AI and ML-based methods are employed to retrieve various state variables using space-based observations. Cloud motion wind vectors (CMVs) and atmospheric motion wind vectors (AMVs) are derived from radiometer-based observations from satellites in geostationary orbits. These observations are available at the same location at different times. First of all, a methodology is applied to find appropriate tracers (that could be tracked in time sequence images) in an image. In the thermal infrared (TIR) band, cloud patterns are trackers whereas in the water vapour absorption band (upper or middle level) water vapour features are selected as tracers. Then these tracers are tracked in various images. The displacement of these tracers gives the estimation of wind at that particular atmospheric level. After that height assignment techniques are applied to find the height of derived wind vectors. If the height assignment technique is applied to cloud observations, then it also provides an estimation of cloud top height (or cloud top temperature). For some other parameters such as cloud optical depth (COD) or cloud effective radius, an extensive match-up data set is prepared by using a simulation exercise. This matchup data set contains the all-possible combination of state variables and corresponding observations. This kind of match-up data is called a lookup table. Then an algorithm is applied to optimally search the appropriate combination of state variables for a given set of observations from this lookup table. So, we can conclude that there is plethora of methods for inversion methods that employ forward simulations and complex mathematical techniques.

6.3 Atmospheric Modeling and Applications

Atmospheric modeling forms an integral part of weather and climate applications. The futuristic projections indicate a manifold increase in user demands and involvement in the weather sector. In the backdrop of global warming and climate change, it is anticipated that the scientists will be expected to not only provide not only predictions but also solutions for sustainable and climate resilient living.

Recently a survey by World Meteorological Organisation (WMO) reveals the share of major public weather service status by forecasting range, as given in the Fig 6.4 below.

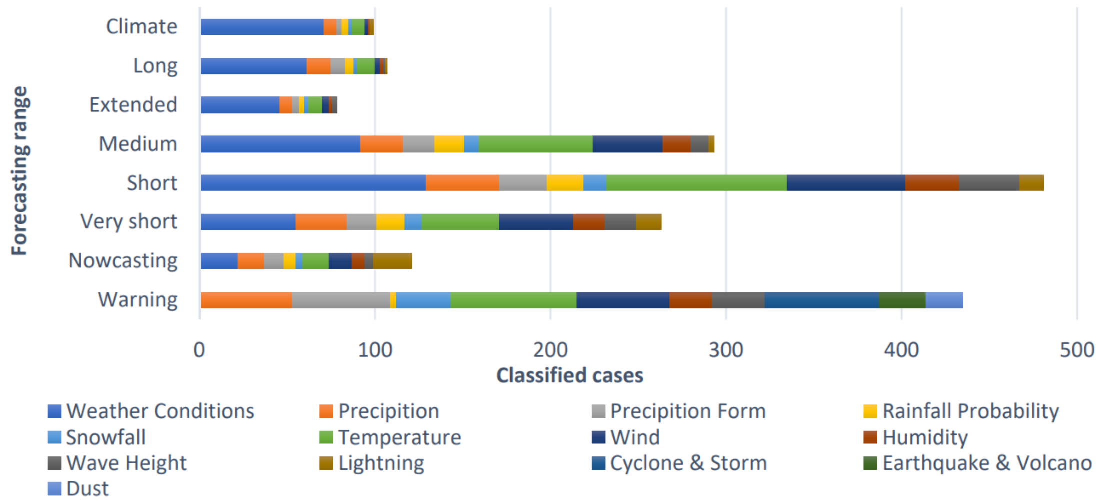

Fig. 6.4 A New Perspective on the Supply and Demand of Weather Services (Bang, C.H.; Leem, C.S. *Sustainability* 2020, *12*, 9049)

The above analysis clearly shows that each service is usually catered by all the forecast scales, albeit at different weightage. The above graph helps us in identifying the most critical weather services, which an individual model or set of models can target. Although this is not tailored specifically for satellite-based services, the guidance can serve as a benchmark.

6.3.1 Application based Modeling

The most important point of focus in drafting the weather modeling activities (current and futuristic) is to base it **on user demands rather than forecast scale**, because as seen clearly from the data above, each service may derive at least some meaningful information from models operating at different scales.

Currently, at ISRO, models run with different model scales for weather/ climate relevant to atmospheric processes may be categorized as:

- Long Range Forecast
- Short Range Forecast
- Nowcast
- Cyclone forecast
- Air Chemistry forecast

Identification of targeted applications and products, with their impact and priority index, is the first step for assigning particular model/models and optimizing resources. The main takeaway point is to use all possible data sources (satellite, radar, model, in-situ) to reconstruct and predict atmospheric state. The commercial aspect of weather services may yet be another area for focus.

6.3.2 Unification and Inter-linkage of Models

Secondly, the interlinking and collaboration between different models is one of the key areas, on which more thrust is needed. This particular effort will not only improve accuracy and lead time but also help in getting the complete big picture. This will also ensure focussing on different user demands under one umbrella. The major target areas in this respect can be:

- Blending of statistical and dynamical models
- Artificial intelligence/ Deep learning in weather modeling
- Feasibility of unified modeling in which there is a single modeling system (recent experiments like Finite--Volume Cubed-Sphere Dynamical Core (FV3), System for High-resolution prediction on Earth-to-Local Domains (SHiELD))

6.3.3 Cutting-Edge Research

Third, but most important aspect in fuelling up of space-based weather modeling is advanced research and technique development. In fact, the cascading of user demands leading to advanced research for a better understanding of physical processes manifest in optimum technique development, which in turn can shape up the operations sector with robust mechanisms.

It is also stressed here, that in the face of changing and challenging weather, cutting-edge science and process studies are the need of the hour. Operational or commercial applications, not supported by parallel and continuous efforts in the research domain will not be sustainable. As such, the R&D component of the weather and climate is the backbone of the entire setup.

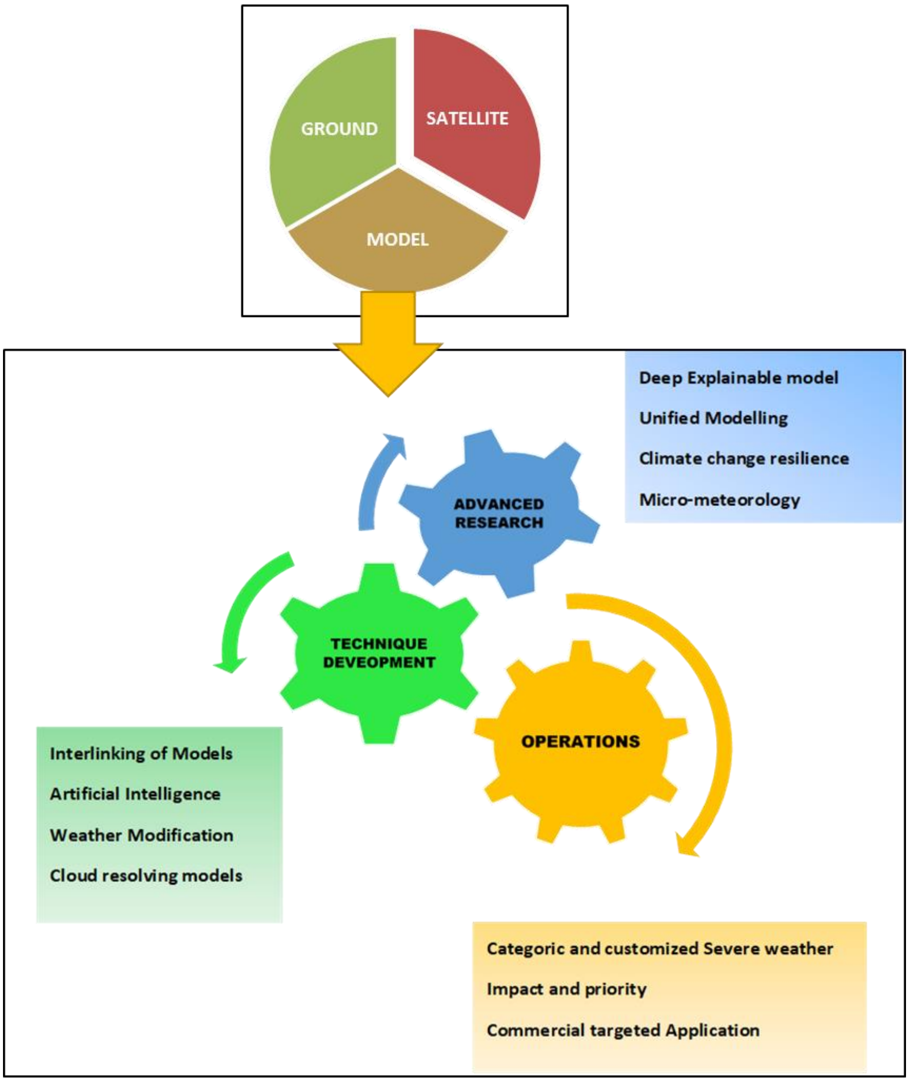

Fig. 6.5 Graphical flow chain of the Weather Modeling and Prediction system

Some major thrust areas in this regard are:

- Artificial Intelligence and Deep explainable models
- Cloud resolving models, Aerosol cloud interactions, micro-meteorology,
- Customized severe weather threat (urban flood, cloudburst, lightning)
- Climate change resilience, Weather Modification, Radiation budget
- Land-Ocean-Atmosphere coupling

Thus, the three wheels of Weather based applications and services are Research, Techniques, and Operations. The gearing of these three areas propels the system forward and the growth and development of the sector relies heavily on the interactions and balance of these subsystems. An infographic representation is given below for a snapshot of the entire process and future guidance.

6.3.4 Severe Weather Applications

Heavy Rainfall Events

In the recent past, there has been an observable increase in extreme weather events, particularly that of intense and severe rainfall leading to catastrophic flooding. Cooperative efforts are required not only for damage control of such disasters but also for the development of advanced techniques for risk assessment and early warning. The global satellite missions provide the necessary framework to facilitate an endeavour toward this direction. In ISRO, a satellite-based heavy rainfall alert system has been developed using the INSAT series of satellites. These alerts are available in real-time over MOSDAC web portal (www.mosdac.gov.in.). In addition to the heavy rainfall alerts, Cloudburst potential alerts are also provided regularly on MOSDAC for Western Himalayan region.

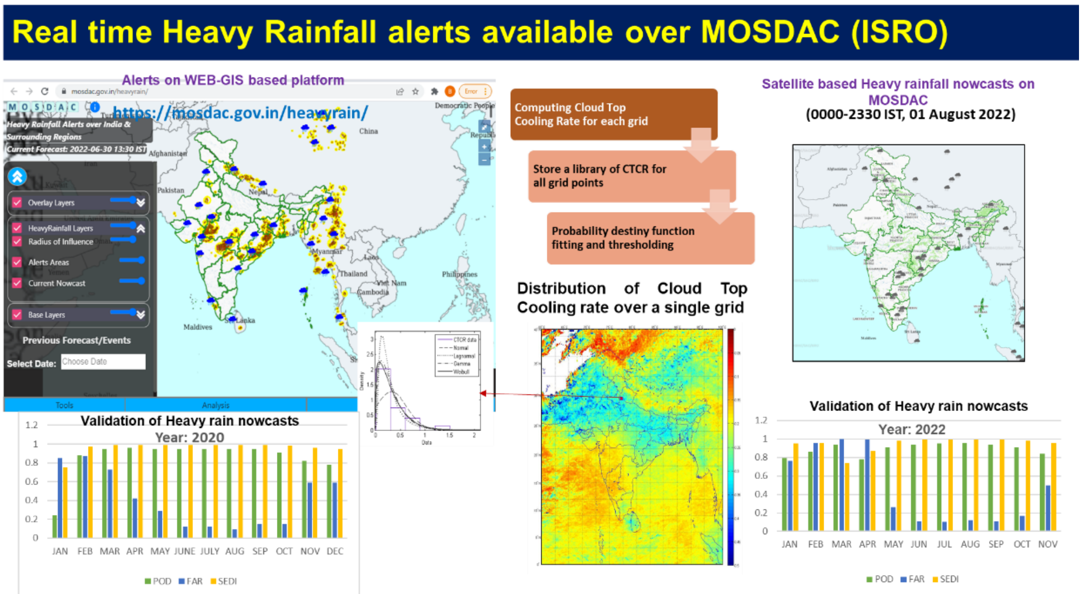

Fig. 6.6 Satellite-based Nowcasting for the Indian region

Tropical Cyclone

Tropical cyclones are one of the most disastrous weather hazards associated with strong winds, torrential rainfall, and storm surges that develop in the warm tropical oceans and causes huge loss of life and property as they approach to the coastal regions. The development, intensification, and propagation of these systems are continuously monitored by the meteorological satellites, which provide observations in different regions of the electromagnetic spectrum like visible (0.4 to 0.7 µm), infrared (1 to 100 µm), and microwave (0.3 to 30 cm) at different spatial and temporal resolutions. India is having its own indigenously developed geostationary satellites INSAT-3D and INSAT-3DR that provide very useful data for real-time monitoring and prediction of tropical cyclones. During the active cyclone conditions, INSAT-3DR satellite is used in the rapid scan mode to provide observations in every 4-8 minutes. The information is used to generate the forecasts of cyclogenesis, track, intensity, landfall, wind, and rainfall characteristics of the cyclones that helps the decision makers to generate alerts for mitigating the human and economic loss.

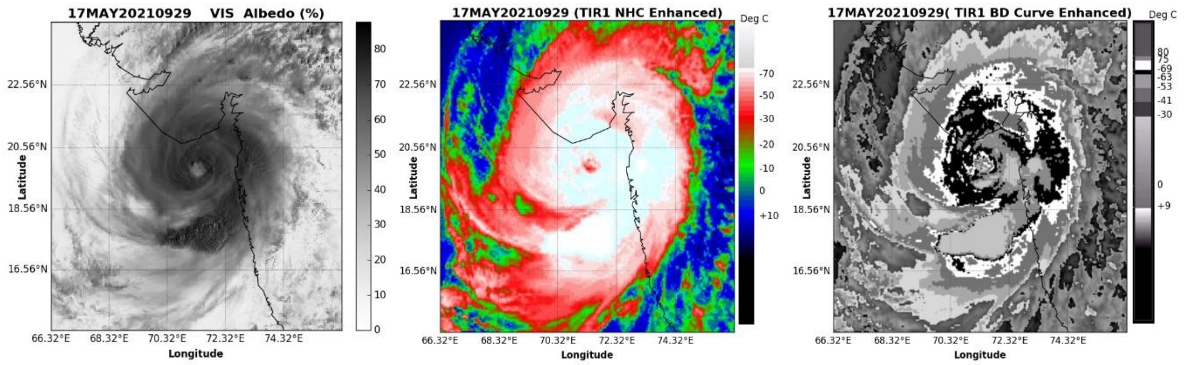

Fig. 6.7 Extremely severe cyclone Tauktae observed by INSAT-3D satellite

6.4 Geospatial Technologies

Geospatial technologies advocate a multi-disciplinary approach involving disciplines namely computer science, geography, photogrammetry, cartography, remote sensing, surveying, global positioning system (GPS) technology, statistics, and other disciplines concerned with handling and analysing spatially referenced data. Traditional GIS can only serve dedicated users with sophisticated software and hardware resulting in limited impact to the public. Advancements in the internet and interactive content of the World Wide Web (WWW) have made them a powerful means for people to access, exchange, process, and analysis the information. Most of the GIS-based web portals (geoportals) are designed for specific theme and targets specific class of users. Web GIS allows users to access application independent of hardware location through web browsers. Many vendors provide Map servers to serve maps over the internet that includes Autodesk MapGuide, ESRI ArcView Internet Map Server, ESRI MapObjects Internet Map Server, MapInfo Pro Server, UMN Map Server, etc. Apart from Web GIS, options for other Computing platforms are available that have evolved over time as shown in Fig. 6.8 but the accessibility and client-server processing capabilities are common deciding factors.

Geoportal makes extensive use of Web-based GIS tools and techniques that combines the power of the internet and GIS. Internet GIS uses "a web browser where geographic data are displayed as maps and graphs based on user-selected criteria". An application that uses and combines data or functionality from different sources to form a new service is known as web mashup. The role of web mashup technology is very important to develop further value-added applications at the user end by integrating the GIS data and services from diverse sources. Nevertheless, the degree of functional and technical sophistication increases as the resulting applications and system makes use of various software components and libraries; this poses significant challenges with respect to (1) handling and integration of multi-scale data sources (2) present information to decision makers that is understandable and user friendly.

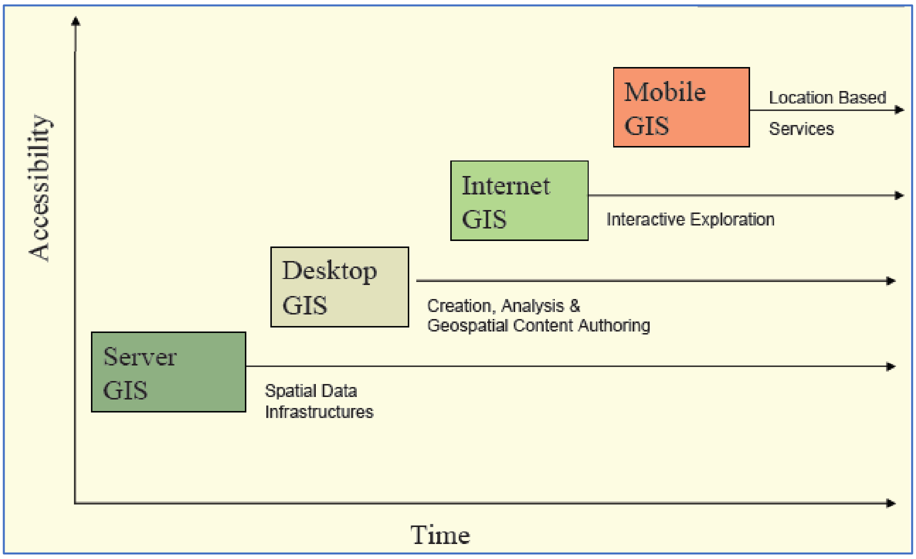

Fig. 6.8 Evolution of various GIS sources

6.4.1 Challenges

Multi-scale data integration

Data is available at different scales, granularity, and temporal resolutions. The issues are taken care by combining the latest web services, open geospatial standards, and service specifications with traditional types of geospatial web services (WMS, WFS, etc.). In practice, these standardized geospatial data models and service specifications are coupled with RESTful-based service-oriented architectures, as a de-facto form of implementation of web-based geoportals.

Delivery and Presentation of information

From the end user's perspective, geoportals are the visible face of back-end service-oriented systems. End-user experience depends on multiple factors including user interface, devices (desktop, handheld, etc.), and network bandwidth to name a few. Hence, delivering geospatial services over the network has multi-disciplinary challenges. Advanced geospatial techniques in collaboration with ongoing developments in areas of service-oriented and web techniques enable the rapid access, processing, and dissemination of geospatial data viz. remotely sensed (e.g., satellite) and atmospheric models output.

6.4.2 Geoportals

To understand the underlying technologies behind geoportals, it is essential to have a look at the basic architecture of such systems. System architecture plays a crucial role in defining the conceptual model of the system with structure, behavior, and views of the system. The basic architecture of geoportals is shown in the Fig. 15.9 below provides a glimpse of system architecture to deliver geospatial services. Customized solutions use variations of this basic architecture.

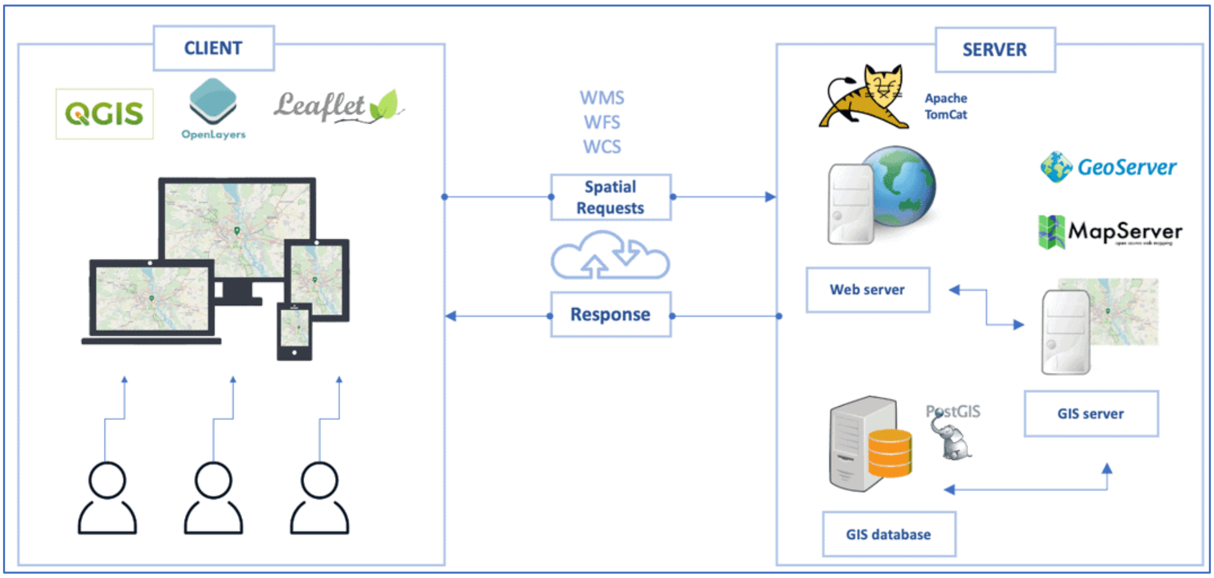

Fig. 6.9 Architecture of Geoportal

6.4.3 Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC)

MOSDAC is Multi-Mission Satellite Data Repository for the Indian Satellites like KALPANA1, INSAT3A, OCEANSAT-2, SARAL/Altika, Megha-Tropiques, SCATSAT-1, INSAT-3D, and INSAT-3DR. It hosts In-situ and CAL-VAL data like Automatic Weather Station (AWS), Agro-Met Station (AMS), Doppler Weather Radar, Optical & MET Buoys. MOSDAC is responsible for near real-time data dissemination of Meteorological and Oceanographic data and provides information services across India and worldwide. There has been continuous adoption of the latest tools and techniques to bring GIS tools over the web at MOSDAC. We are going to discuss certain analytics and visualization geoportals developed and made operational at MOSDAC that allow users to engage interactively with data to get deeper insights.

LIVE

Let's Interactively Visualise Earth (LIVE) (https://live.mosdac.gov.in) is an attempt towards providing integrated visualization of geospatial data. Data sources include satellites, in situ, models, and climatology. LIVE is a web-based visualisation and analysis system, which provides access to earth observation, meteorological and oceanographic products derived from satellites, model forecast, ground observations, and climatology all through a single platform.

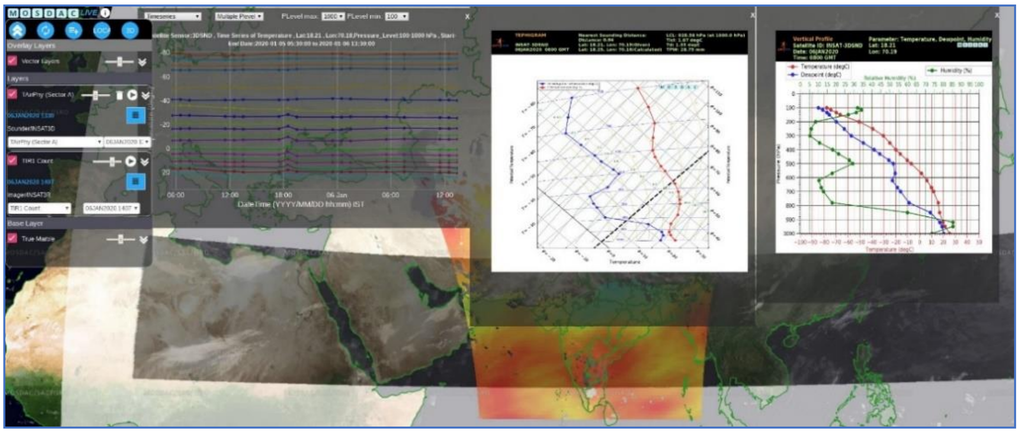

Fig. 6.10 Analytical capabilities at LIVE

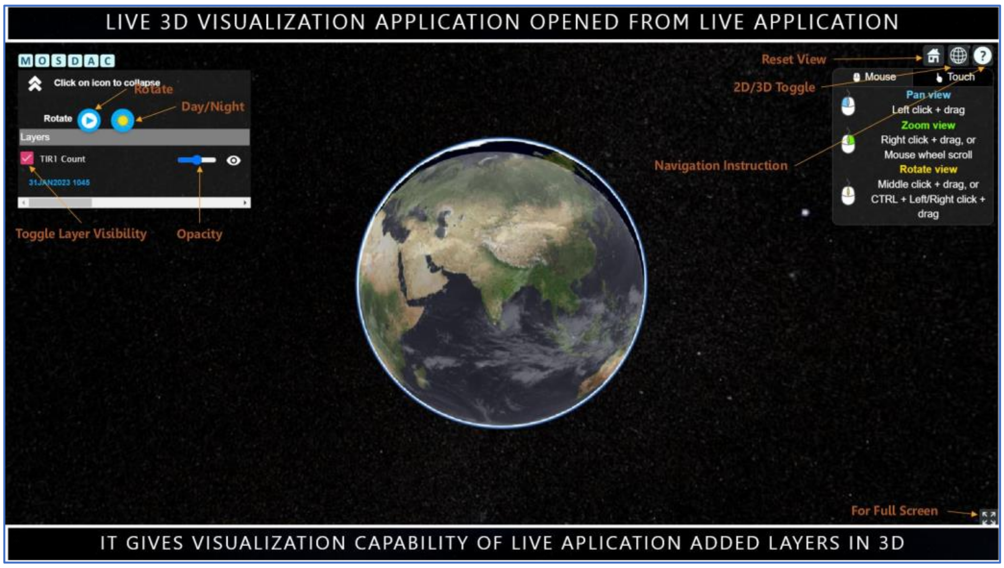

Fig. 6.11 Integration of multiple data sources & 3D visualisation through Geospatial technologies

Cyclone Forecast

It is a geoportal that disseminates real-time information right from cyclogenesis to track and intensity prediction. Spatial techniques used to derive and disseminate the cyclone information on the web that includes track, intensity, center, satellite imagery, ship avoidance regions, surge, inundation, cyclogenesis, landfall, and animation of satellite imagery for the lifespan of the cyclone.

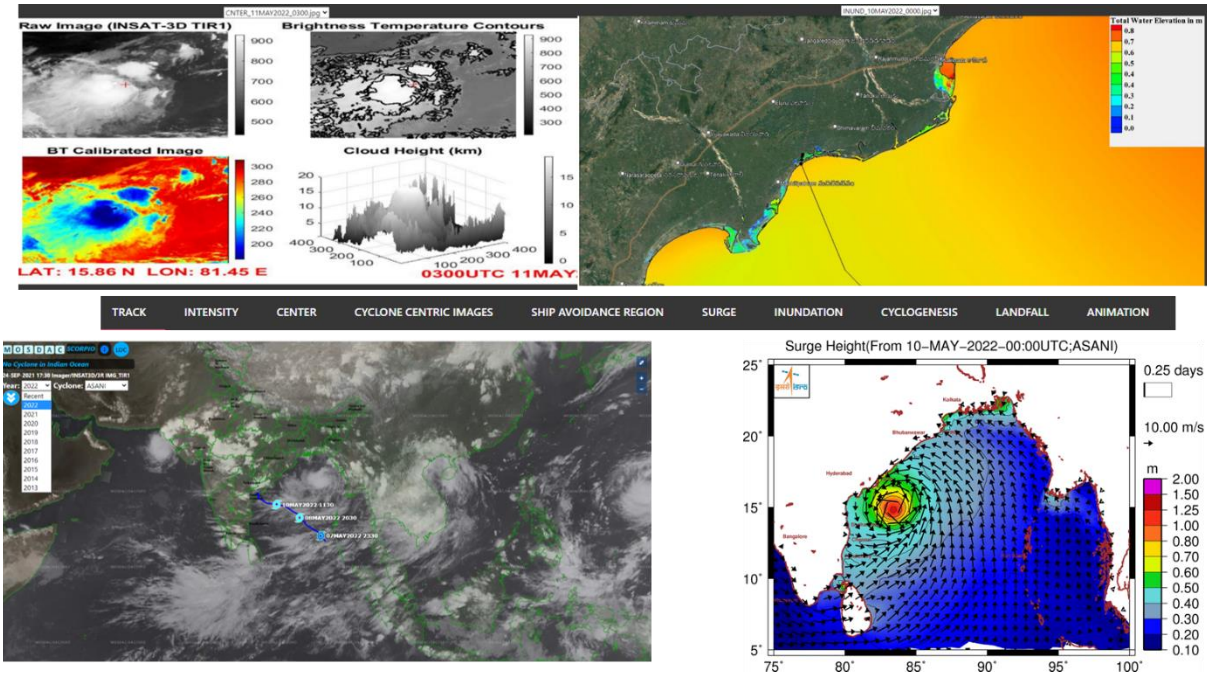

Fig. 6.12 Geoportal providing information on cyclones

Nowcast

Alert and Forewarning Portal: Geoportal is developed with the idea to combine the technologies of GIS and a Decision Support System to aid decision-makers with problems that have spatial dimensions. GIS techniques like GIS/ Map server, Web server, and spatial database to support spatial queries are combined with next-generation scalable OpenAPI micro services architecture. Nowcast alerts are generated every half hourly and are valid for the next six hours. These alerts are pre-processed and are ingested through an automated ingestion mechanism to the spatial database with all necessary metadata. Micro services are written using OpenAPI specifications and open-source technologies that extends the capabilities of running spatial queries over these alerts and other spatial data. These microservices can provide data in multiple formats viz. vector, JSON, etc. These alerts are available through **Indian State Portal and Southeast Asian Countries Portal.**

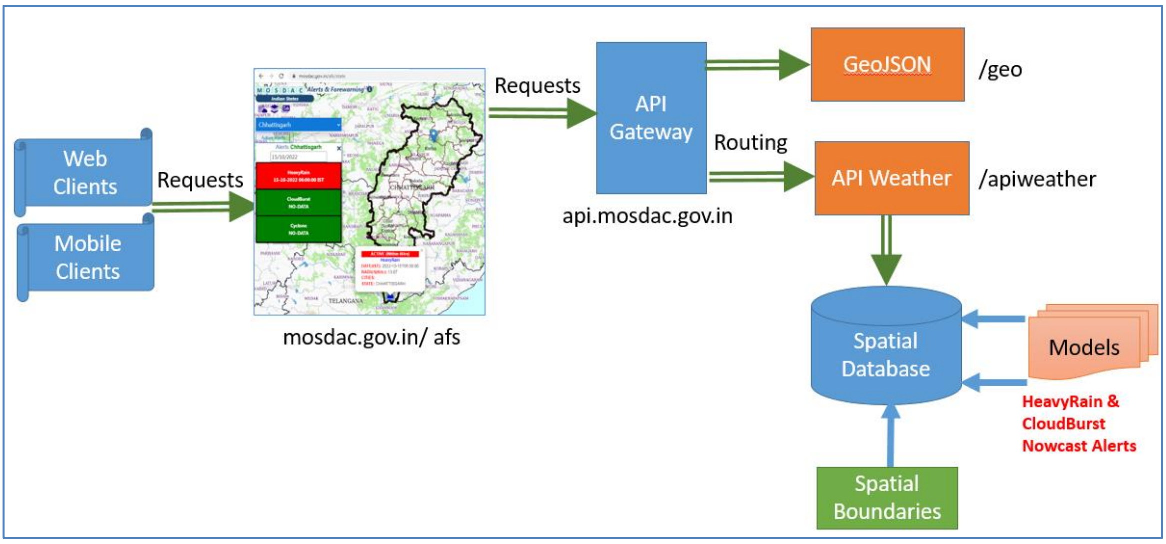

Fig. 6.13 Schematics of Nowcast Portal

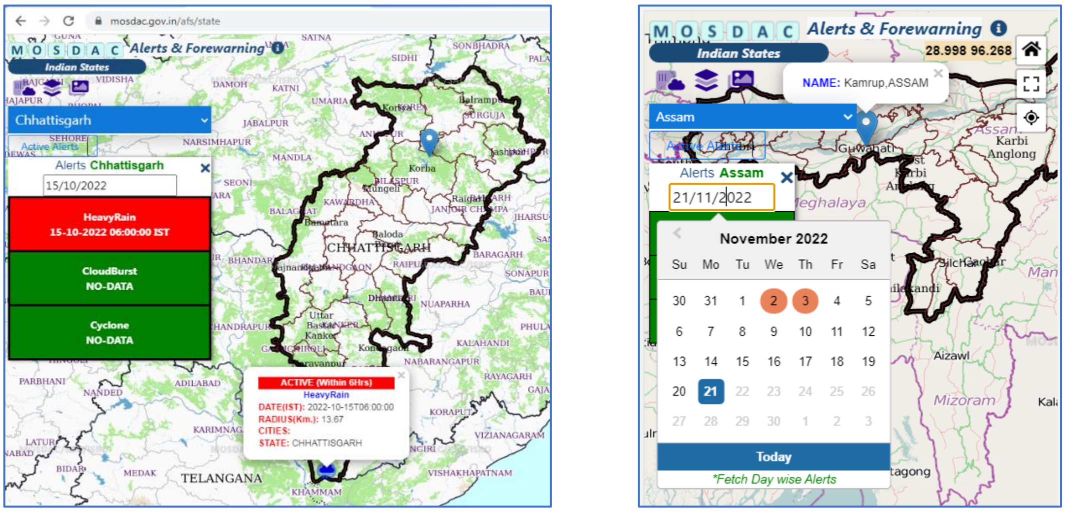

Fig. 6.14 Alerts for Indian states

Forecast

Geoportals are developed theme-wise to disseminate forecasts at varying spatial and temporal resolutions across India. A combination of multiple GIS technologies is used to provide location-based services. This includes the set of operations to compute statistics/ fetch information on points and/or areas of interest provided by users on the web. Web services often suffer from network latencies and poor bandwidth; hence, it is crucial to limit the amount of data to be transferred between client and server. A set of tools and techniques are optimized to maintain the performance of these portals and provide services with minimal response times.

Following is the list of multiple geoportals developed for the purpose of distributing forecast information:

- **Renewable Energy Forecast Portal**

  Providing solar flux and wind energy along with other parameters forecast at a temporal resolution of minutes.

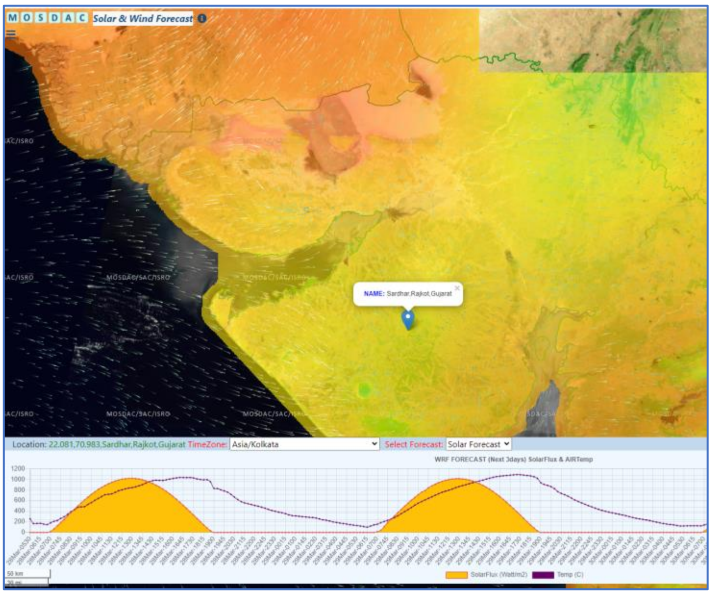

Fig. 6.15 Renewable Energy Forecast Portal

- **Weather Forecast Portal**

  Geoportal is capable to provide WRF based 72 hours weather forecast for the affected locations and/or locations of interest at a temporal resolution of 3 hours.

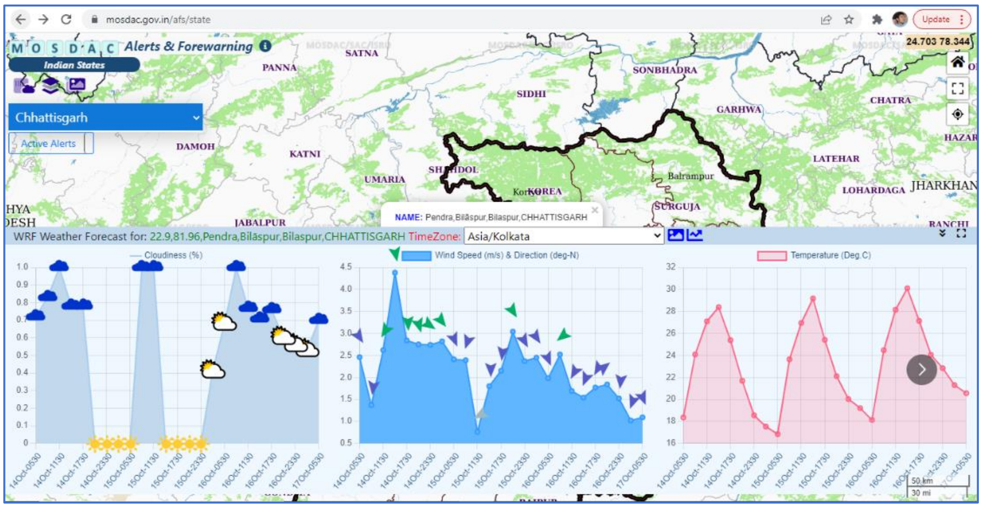

Fig. 6.16 Weather Forecast Portal

- **Heat Waves/ Cold Waves**

  Geoportal to provide forecast for Heat Wave and Cold Wave. Meteorological satellite products (INSAT - 3D/3DR), ground-based observations (Humidity, surface temperature, etc. collected from IMD/State weather stations), and weather models are used to generate hot weather forecasted products.

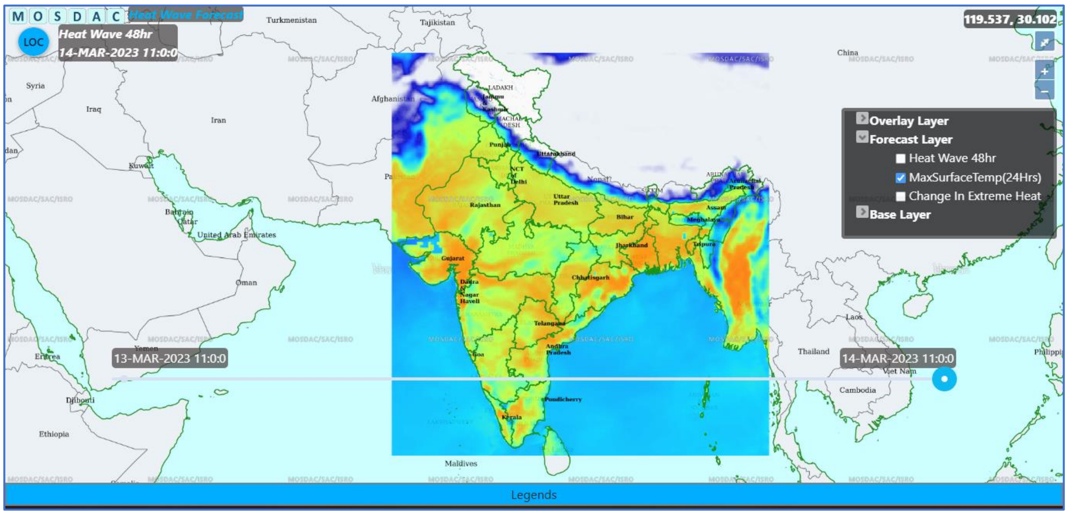

Fig. 6.17 Heat waves/Cold Waves forecast Portal

- **Heavy Rain**

  Geoportal to provide forecast for Heavy Rain.

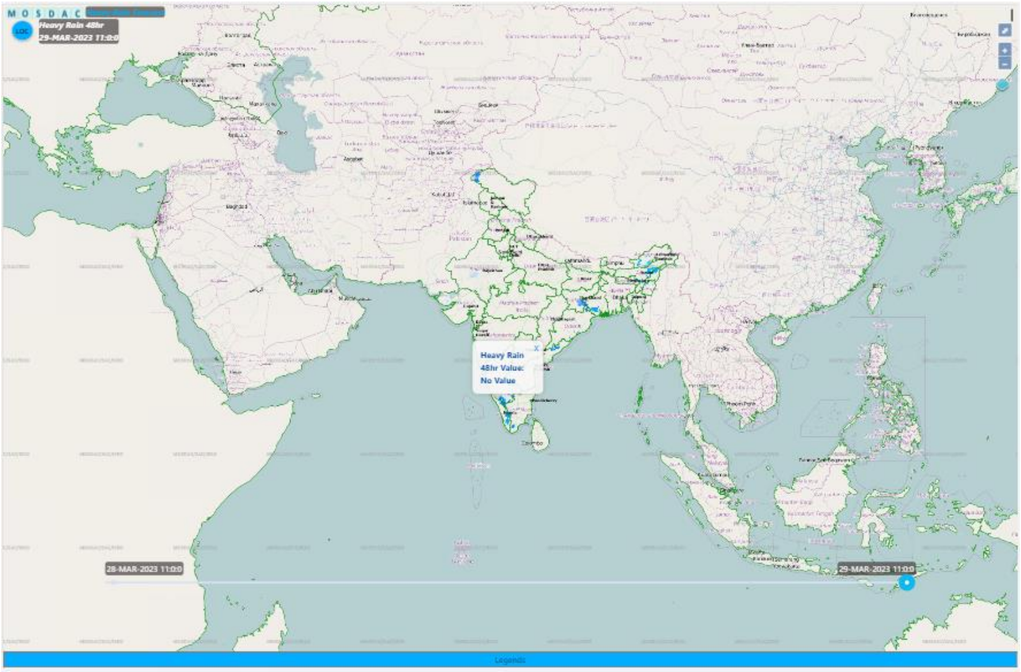

Fig. 6.18 Heavy Rain forecast Portal

- **Monsoon**

Geoportal to provide forecast for Monsoon Prediction for the year.

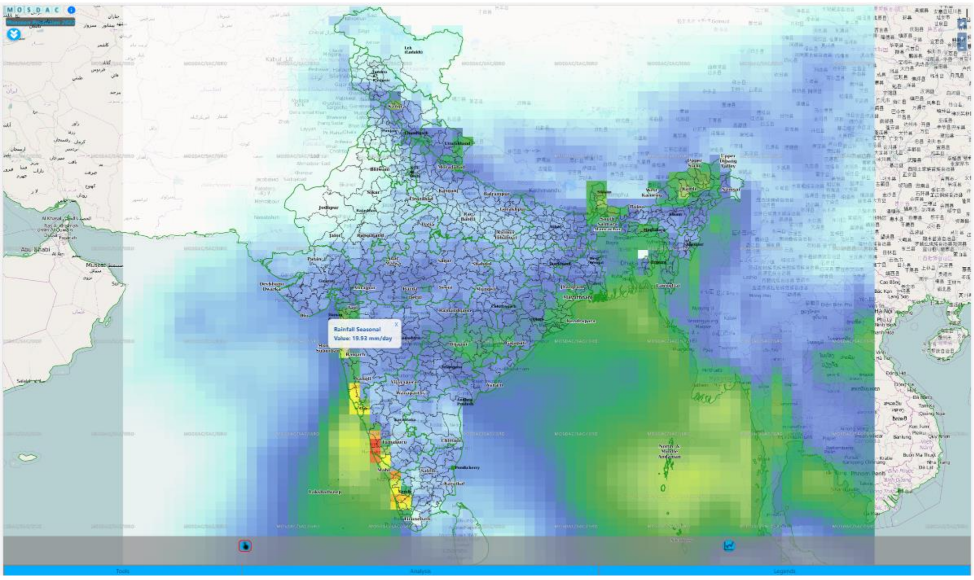

Fig. 6.19 Monsoon forecast Portal

- **Current Events:**

a. Insitu Observations: Doppler weather radar and Automatic weather stations data have been integrated into geoportal to quickly get a glimpse of ground conditions.

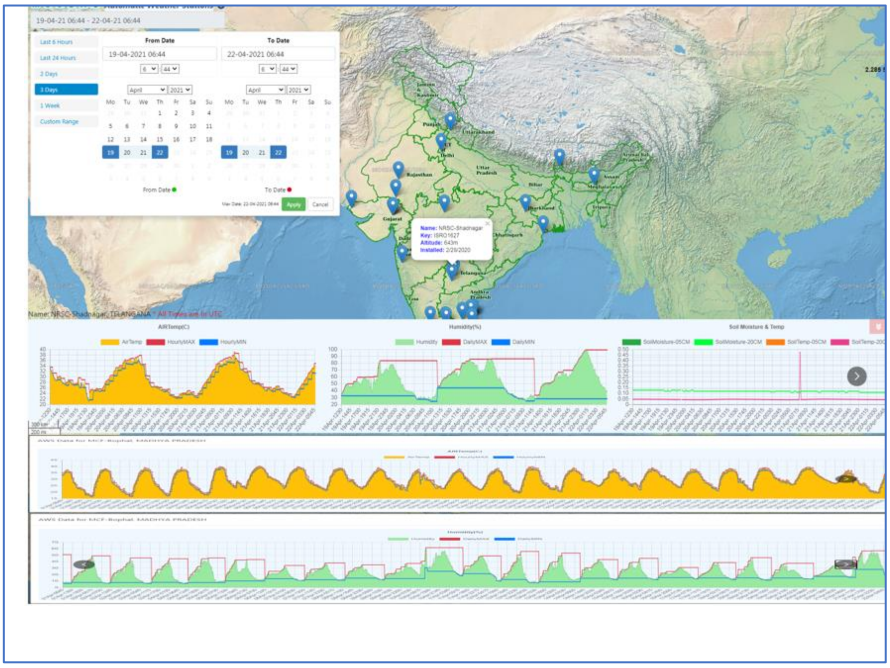

Fig. 6.20 Data Analytics portal for Automatic weather station

b. Heavy rain events from Satellite

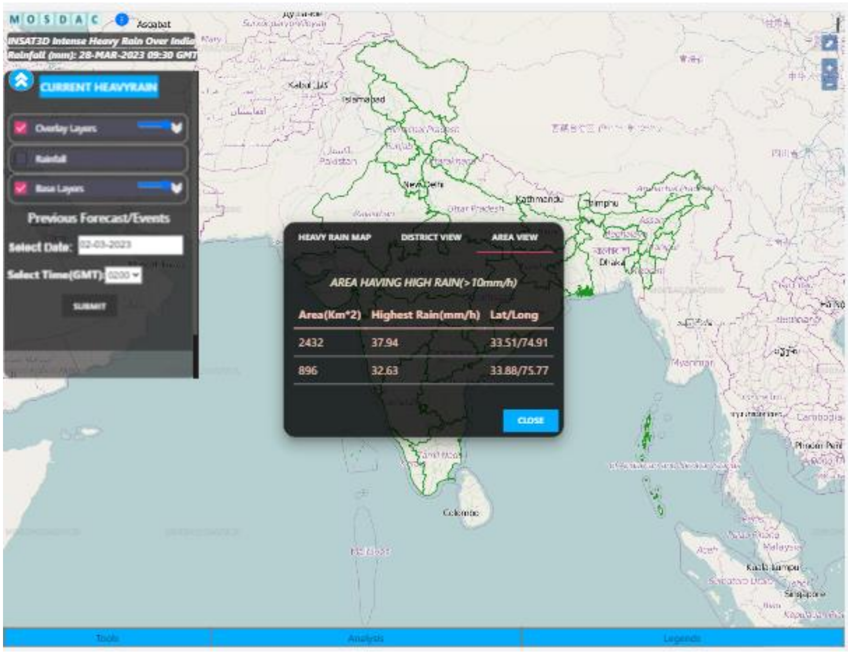

Fig. 6.21 Heavy rain events in the portal

Theme based geospatial applications

Apart from application specific portals, geospatial techniques have been extensively to demonstrate theme-based information portals.

- VARSHA: Geoportal with all information products and data for **rain** integrated into a single platform.
- VAYU: Geoportal with all information products and data for **air quality** integrated into a single platform.

Data Analysis Portal

Portal is equipped with all geospatial related libraries that allow users to perform computations and analysis over the web. MOSDAC Service for Analysis and Interactive Computing (MOSAIC) provides:

- Data and Computing resources are available 24X7 for remote access through a Web Browser
- All User Ordered MOSDAC Data are readily available (as Mounted File System) Geospatial analytical libraries and Sample Code for Visualization and analysis

6.5 Conclusion

Thus, the synergy of science, engineering, and technology has helped in developing user-centric applications for utilizing weather-related data for a range of applications. It is envisioned that future advancements in this domain have the power to further bridge the gap between the meteorology and its location-specific geospatial applications.

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Chapter 7

NATURAL DISASTER AND THEIR MANAGEMENT

7.1 Introduction

Natural disasters have a profound impact on society, affecting individuals, communities, and entire nations. The loss of life and injuries caused by natural disasters can be devastating, leaving behind a trail of human tragedy. Families are torn apart, communities shattered, and the social fabric is deeply disrupted. The physical destruction of infrastructure, including homes, schools, hospitals, and essential services, further exacerbates the impact. Displaced populations often struggle to find shelter, clean water, and basic necessities, leading to increased vulnerability and health risks. The psychological toll on survivors is significant, as they grapple with trauma, grief, and the long process of rebuilding their lives. The economic consequences are also substantial, with the loss of livelihoods, disruption of businesses, and the cost of rebuilding and recovery. Natural disasters can set back economic development, pushing communities into poverty and exacerbating existing social inequalities.

The impact of natural disasters is not limited to the immediate aftermath. Long-term effects can persist for years, hindering sustainable development and recovery. Disrupted education systems, damaged healthcare infrastructure, and environmental degradation can have lasting consequences on the well-being and future prospects of affected populations. Additionally, natural disasters can lead to social unrest, strained governance systems, and increased vulnerability to subsequent disasters. However, through effective disaster management, preparedness, and response strategies, societies can mitigate the impact of natural disasters and work towards building resilient communities that are better equipped to withstand future events.

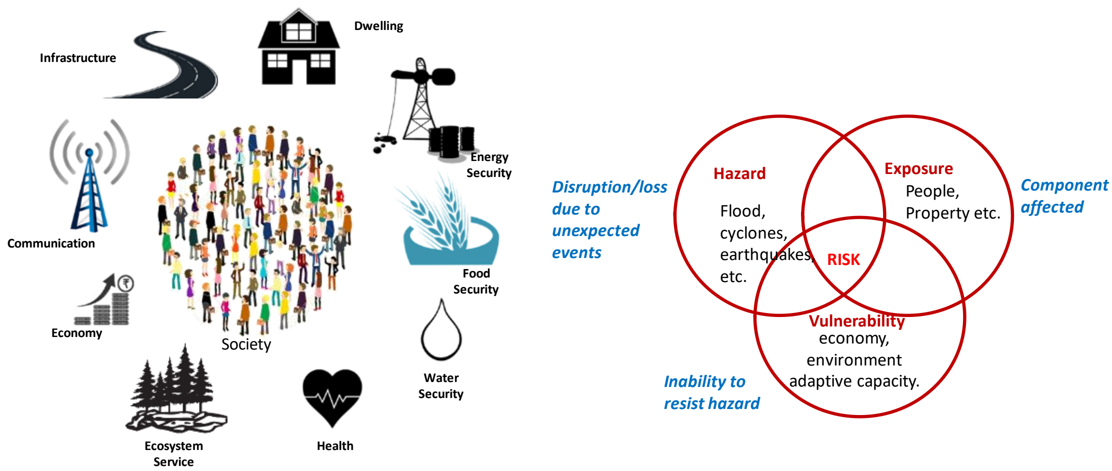


Fig 7.1 Premise of Natural Disaster: The population/Society and its components are the focus for natural disaster

Most of the natural disasters are in the tropical regions which are also home to most of the people on the earth. It is also a fact that more than 80% of the natural disasters affect the smaller and relatively less economically developed countries. A natural disaster in such scenario completely devastates a nation and its people. So, it is important that there should be a proper mechanism to manage the natural disasters so that there is minimum loss to life and property. Improvements in the various technological applications which can be used for disaster management has led to a whole suit of disaster management tools and today natural disaster management is solely dependent on cutting edge technology which involves advances in space technology, information technology as well as advances in communication technology. Today information and its availability is the key to effective disaster management. Information about the potential vulnerability, information regarding the probable occurrence and information regarding the geographic location has an immense role in mitigating the natural disaster and coordinate effective rescue and relief.

The global risks due to disasters seem to be increasing, with billions of people living in more than 100 countries being periodically exposed to at least one natural disaster, causing more than 184 deaths per day (UNDP, 2014). Further, there has been a rise in the frequency and intensity of natural disasters, due to global climate change. Diverse geoclimatic conditions, increasing population, unscientific exploitation of natural resources, inadequate carrying capacity of river systems, poor drainage characteristics, uncertain monsoon conditions, large areas of dry deciduous forests, environmental degradation have all made India one of the world's most disaster-prone countries. Empowering the public to overcome the risk in the pre-disaster phase and to adopt efficient coping mechanisms at the time of disaster occurrence, still remain major challenges to most of the federal Governments, more particularly in the developing countries like India.

Between 2000 and 2022, natural disasters have resulted in significant loss of life worldwide. These catastrophic events, such as earthquakes, hurricanes, tsunamis, floods, and other destructive phenomena, have caused the tragic death of thousands of people. For instance, the Indian Ocean earthquake and tsunami in 2004 claimed the lives of over 230,000 individuals, while the devastating earthquake in Haiti in 2010 resulted in an estimated death toll of around 230,000. Similarly, the Tohoku earthquake and tsunami in Japan in 2011 caused approximately 16,000 deaths, and Hurricane Katrina in 2005 resulted in the loss of over 1,200 lives. Numerous other natural disasters, including wildfires, landslides, and heatwaves, have also contributed to the loss of life during this period. The impact of these tragic events highlights the urgent need for investments in disaster preparedness, early warning systems, and resilient infrastructure to minimize the loss of human lives in future natural disasters

In 2022, the economic loss due to natural disaster events worldwide amounted to about 313 billion U.S. dollars. Between 2000 and 2022, natural disasters have had a significant economic impact globally, causing substantial financial losses. Noteworthy events include Hurricane Katrina in 2005, which became the costliest hurricane in U.S. history with an estimated economic loss of approximately $161 billion. The Indian Ocean earthquake and tsunami in 2004 resulted in an estimated economic loss of around $15 billion, affecting several countries including Indonesia, Thailand, Sri Lanka, and India. The Tohoku earthquake and tsunami in 2011 caused widespread damage in Japan, including the Fukushima nuclear disaster, with estimated economic losses amounting to approximately $360 billion. Hurricane Sandy in 2012 caused around $70 billion in economic losses, primarily in the northeastern United States. The Nepal earthquake in 2015 resulted in an estimated economic loss of around $10 billion. These and other natural disasters have inflicted significant damage on infrastructure, housing, agriculture, businesses, and tourism sectors, leading to long-term setbacks for the affected regions. Overall, the cumulative economic losses due to natural disasters between 2000 and 2022 amount to hundreds of billions of dollars, highlighting the urgent need for effective disaster preparedness, mitigation, and recovery measures.

Natural disasters have had a significant impact on India, a country prone to various types of natural hazards due to its geographical location and diverse climate. India has experienced numerous natural disasters between 2000 and 2022, resulting in loss of life, infrastructure damage, and economic setbacks. Floods are one of the most common and destructive disasters in India, affecting millions of people annually. States like Assam, Bihar, and Kerala are particularly vulnerable to devastating floods caused by heavy monsoon rains and overflowing rivers. Cyclones also pose a significant threat to India, especially in coastal regions. Cyclone Fani in 2019 and Cyclone Amphan in 2020 caused extensive damage to infrastructure, homes, and agriculture, particularly in the states of Odisha and West Bengal. In addition, India has experienced earthquakes, such as the Gujarat earthquake in 2001, which claimed thousands of lives and caused widespread destruction. Other natural disasters in India include droughts, landslides, and heatwaves, which have severe implications for agriculture, water availability, and public health.

The impact of natural disasters in India is far-reaching, affecting both rural and urban areas. These disasters result in the loss of lives, displacement of communities, and damage to critical infrastructure such as homes, schools, hospitals, and transportation networks. The economic consequences are substantial, with the disruption of agricultural activities, businesses, and tourism, leading to financial setbacks for affected regions. Vulnerable populations, including marginalized communities and those living in poverty, are disproportionately affected by natural disasters, exacerbating existing social inequalities. The Indian government, along with various agencies and organizations, has been working on disaster management, early warning systems, and resilience-building measures to mitigate the impact of natural disasters. However, continuous efforts and investments are required to strengthen preparedness, response, and recovery mechanisms to reduce the human and economic toll of natural disasters in India.

7.2 Role of Space technology in Disaster Management

Space technology plays a pivotal role in the field of disaster management, offering invaluable tools and information to enhance preparedness, response, and recovery efforts. Through the utilization of satellite imagery, remote sensing capabilities, communication systems, and geospatial data analysis, space technology provides crucial resources for monitoring natural disasters and assessing their impacts accurately and promptly. This advanced technology enables efficient decision-making processes, facilitates the implementation of early warning systems, and enhances coordination among response agencies, ultimately leading to the preservation of lives and the reduction of economic and environmental devastation caused by disasters. Given its diverse applications, space technology has become an indispensable asset in managing and mitigating the consequences of natural disasters on a global scale.

In India, space technology plays a vital role in supporting disaster management efforts across the country. The Indian Space Research Organisation (ISRO) has been at the forefront of leveraging space technology to improve disaster preparedness, response, and recovery. Satellite-based remote sensing and imagery provide crucial information for monitoring and assessing the extent of damage caused by natural disasters such as floods, cyclones, and earthquakes. These satellite images help in identifying affected areas, estimating the magnitude of the disaster, and guiding relief and rescue operations. Additionally, space-based communication systems enable efficient coordination and communication among various agencies involved in disaster response, ensuring a timely and effective deployment of resources.

SATCOM (Satellite Communications) and SATNAV (Satellite Navigation) applications play crucial roles in disaster management, providing essential communication and navigation capabilities during emergencies. In disaster situations, terrestrial communication infrastructure may be damaged or overwhelmed, making SATCOM invaluable for establishing and maintaining communication links. SATCOM enables rapid and reliable communication, allowing emergency responders to coordinate their efforts, share critical information, and provide updates in real-time. It facilitates communication between disaster-affected areas and emergency response centers, enabling timely deployment of resources and effective decision-making. SATNAV systems, such as GPS, play a vital role in disaster management by providing accurate positioning and navigation information. This is particularly important for search and rescue operations, as SATNAV devices enable responders to locate and navigate to affected areas with precision. SATNAV also aids in tracking the movement of emergency response teams, coordinating evacuation routes, and guiding relief efforts by providing accurate mapping and route planning. The combination of SATCOM and SATNAV applications in disaster management ensures effective communication, coordination, and navigation during crisis situations. These technologies enhance the speed and efficiency of emergency response, contributing to saving lives, minimizing damage, and facilitating recovery efforts in the aftermath of disasters.

One notable example is the ISRO's geospatial platform called Bhuvan, which offers high-resolution satellite imagery and thematic datasets for disaster management applications. Bhuvan provides real-time information on flood extent, cyclone tracks, and disaster-prone areas, enabling authorities to make informed decisions and take proactive measures. Moreover, India's indigenous satellite navigation system, NavIC, assists in accurate positioning and navigation during rescue and relief operations. Through the integration of space technology into disaster management strategies, India has significantly improved its capacity to handle emergencies, reduce response time, and minimize the impact of natural disasters on human lives and infrastructure.

ISRO's Disaster Management Support Programme (ISRO-DMSP) is an initiative by the Indian Space Research Organisation (ISRO) that utilizes satellite technology for disaster management. It integrates Earth observation satellites, data analysis techniques, and ground-based information to support various stages of disaster management, including preparedness, response, and recovery. ISRO-DMSP provides near-real-time satellite data and services to national and state-level disaster management agencies, assisting in rapid damage assessment, resource planning, and the coordination of relief operations. The program has been instrumental in supporting disaster management efforts in India and neighbouring countries, enhancing resilience and minimizing the impact of disasters.

7.3 Sendai Framework and Role of Space technology

The Sendai Framework for Disaster Risk Reduction, adopted in 2015, emphasizes the importance of utilizing technology, including space-based technologies, in disaster risk reduction (DRR) efforts. It recognizes that space technology can significantly contribute to understanding and addressing disaster risks, enhancing early warning systems, and improving overall disaster management. Space technology provides valuable data and tools for risk assessment, monitoring, and mitigation. It enables the mapping of hazard-prone areas, assessment of vulnerabilities, and identification of high-risk zones, which are crucial for developing effective DRR strategies and plans.

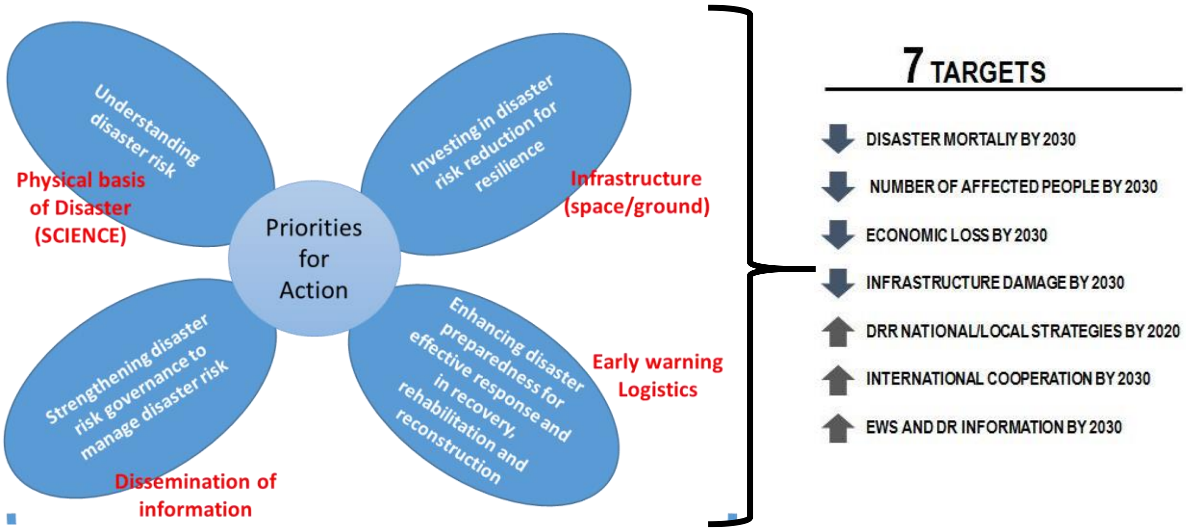


Fig 7.2 Sendai Framework: Priorities of Action and Targets

In the context of the Sendai Framework, space technology plays a pivotal role in strengthening disaster resilience and preparedness. Satellite-based remote sensing and imaging technologies enable the monitoring and assessment of various hazards, such as floods, droughts, wildfires, and earthquakes. These technologies provide real-time and high-resolution data, allowing for early detection and timely response to potential disasters. Space-based communication systems and geospatial data analysis also facilitate effective coordination and communication among disaster management agencies, enabling swift and well-informed decision-making during emergencies. By leveraging space technology, countries can enhance their capacity to mitigate risks, improve early warning systems, and ensure more efficient and targeted disaster response, ultimately contributing to the goal of reducing the impact of disasters on lives, livelihoods, and infrastructure.

7.4 Space based inputs for Disaster Risk Management

Space-based inputs play a crucial role in disaster management in India. The country relies on satellite imagery, remote sensing data, and geospatial technologies to monitor and assess various natural disasters. Satellite-based sensors provide real-time and near real-time information on weather patterns, cyclone formation, rainfall, and flood inundation, enabling early warning systems and proactive response measures. Earth observation satellites help in mapping and monitoring disaster-affected areas, assessing damage, and facilitating rescue and relief operations. Geospatial data and technologies aid in disaster risk assessment, vulnerability mapping, and land-use planning to minimize the impact of disasters. Space-based inputs also support post-disaster recovery and rehabilitation efforts by providing accurate and up-to-date information on infrastructure damage, population displacement, and resource allocation. Overall, space-based inputs enhance the preparedness, response, and recovery phases of disaster management in India, enabling effective decision-making and saving lives and livelihoods

Fig 7.3 Space based Disaster Management Support to Major Natural Disasters in India

7.5 Major Disasters and Their Types

India is prone to a variety of major natural disasters due to its diverse geographical and climatic conditions. These include severe floods, cyclones, earthquakes, droughts, and landslides. The country's vast river systems and monsoon rains often lead to devastating floods, affecting millions of people and causing extensive damage to infrastructure and agriculture. Cyclones, primarily occurring along the coastal regions, bring destructive winds, storm surges, and heavy rainfall, resulting in significant loss of life and destruction of property. India is also situated in a seismically active zone, experiencing frequent earthquakes, with the Himalayan region being particularly vulnerable. Droughts, mainly in arid and semi-arid regions, pose a severe threat to agriculture and water resources. Additionally, landslides in hilly areas are a recurring hazard. These natural disasters necessitate robust disaster preparedness, mitigation measures, and effective response systems to minimize the impact on communities and infrastructure. Natural disasters in India can be classified into various categories based on their nature and causes. In India the natural disasters can be classified into Geological disasters, Hydro-meteorological disasters, Environmental Disasters. These natural disasters pose significant challenges to India's disaster management efforts and necessitate comprehensive preparedness, mitigation, and response strategies.

7.5.1 Geological Disasters

Geological disasters pose significant threats to communities worldwide, with their devastating impacts stemming from natural phenomena such as earthquakes, volcanic eruptions, landslides, and tsunamis. These events result from the dynamic processes within the Earth's crust and can lead to widespread destruction and loss of life. Earthquakes, caused by the sudden release of accumulated energy, can generate powerful ground shaking that damages buildings, infrastructure, and essential services. Volcanic eruptions release volcanic ash, gases, and lava, posing risks to nearby populations and ecosystems. Landslides can occur in hilly or mountainous regions, triggered by heavy rainfall, earthquakes, or human activities, burying communities and blocking transportation routes. Tsunamis, typically triggered by undersea earthquakes, can generate colossal ocean waves that inundate coastal areas. Understanding the geological hazards, monitoring their occurrence, and implementing appropriate mitigation measures are vital for minimizing the impact of these geological disasters and safeguarding lives and infrastructure in vulnerable regions.

i. Earthquakes

Earthquake hazards are a result of the sudden release of accumulated energy in the Earth's crust, causing ground shaking and potential destruction. These seismic events pose risks such as building collapse, landslides, and tsunamis. Understanding fault lines, monitoring seismic activity, and implementing resilient infrastructure are crucial in mitigating earthquake hazards.

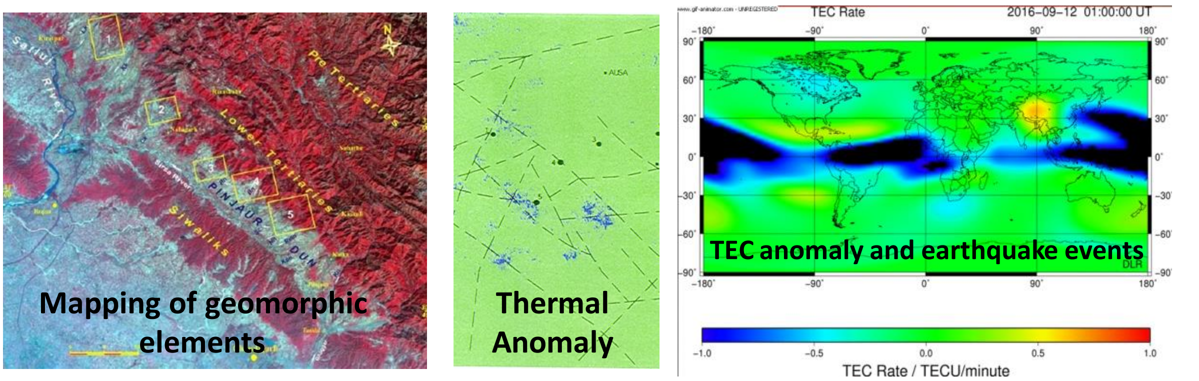


Fig 7.4 EO for Geological Earthquake Hazard

Earth observation for earthquake related disaster involve monitoring and observation of the impact of recent as well as imprints of past earthquakes which leaves geomorphological signatures on the surface of the earth. Advanced remote sensing techniques like InSAR based observation have been extensively used for detection of land subsidence which provide information on the extent of land deformation and hence damage to the area. Apart from this Earth Observation is also able to provide information on thermal anomaly which is an indication of potential geological activity in a region. This along with new techniques like TEC (Ionospheric Total Electron Content) anomaly which is observed 14 days to few hours before a major earthquake are potential geospatial early warning indicators for earthquakes.

ii. Landslide

Landslide is the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another. Landslides are one of the most frequent natural disasters in the mountainous regions of the world and results in extensive loss to life and property as well as infrastructure.

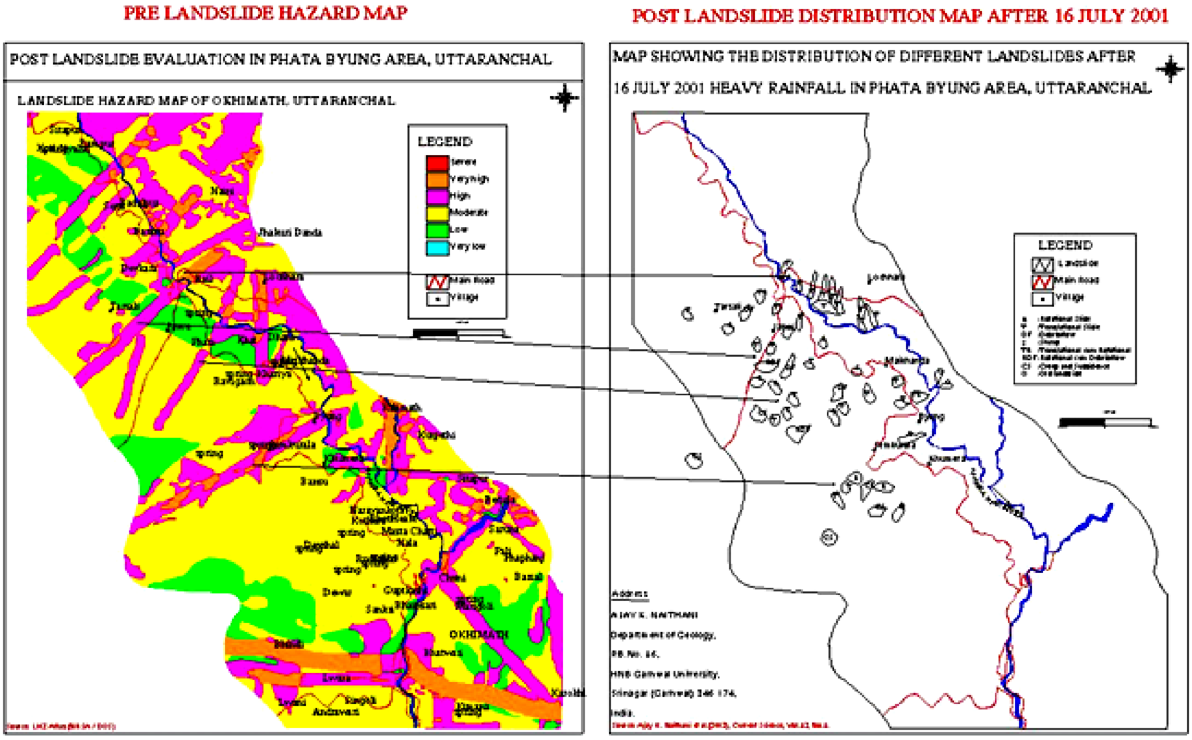


Fig 7.5 Geospatial technology for landslide monitoring and hazard assessment

Geospatial technology plays a vital role in landslide monitoring and early warning systems (EWS). By employing satellite imagery, remote sensing, and geographic information systems (GIS), geospatial technology enables the identification and mapping of landslide-prone areas. Advanced tools like PSInSAR and other methods are able to provide the stability of slopes in the land slide prone areas. It provides valuable data for monitoring terrain stability, detecting changes in land features, and assessing landslide risks. These technologies also facilitate the development of EWS by integrating real-time data from weather monitoring stations, rainfall sensors, and ground-based sensors. By analyzing this data and utilizing geospatial models, authorities can issue timely warnings and evacuation orders to at-risk communities, mitigating the potential impact of landslides and saving lives. Geospatial technology enhances landslide preparedness, response, and recovery efforts, contributing to more effective disaster management strategies.

iii. Tsunami

Tsunamis are formidable natural hazards, generated by undersea earthquakes, volcanic eruptions, or landslides, which can unleash massive ocean waves with devastating consequences. These waves travel across vast distances, striking coastal areas with tremendous force, causing widespread destruction and loss of life. Implementing effective tsunami warning systems, which rely on real-time seismic monitoring and ocean buoy networks, is essential to provide timely alerts to at-risk communities. Coastal mapping and land-use planning help identify vulnerable areas and support the development of resilient infrastructure. Additionally, public education and preparedness campaigns play a critical role in ensuring communities understand the signs of an approaching tsunami and know how to respond swiftly, ultimately reducing the impact of these destructive events.

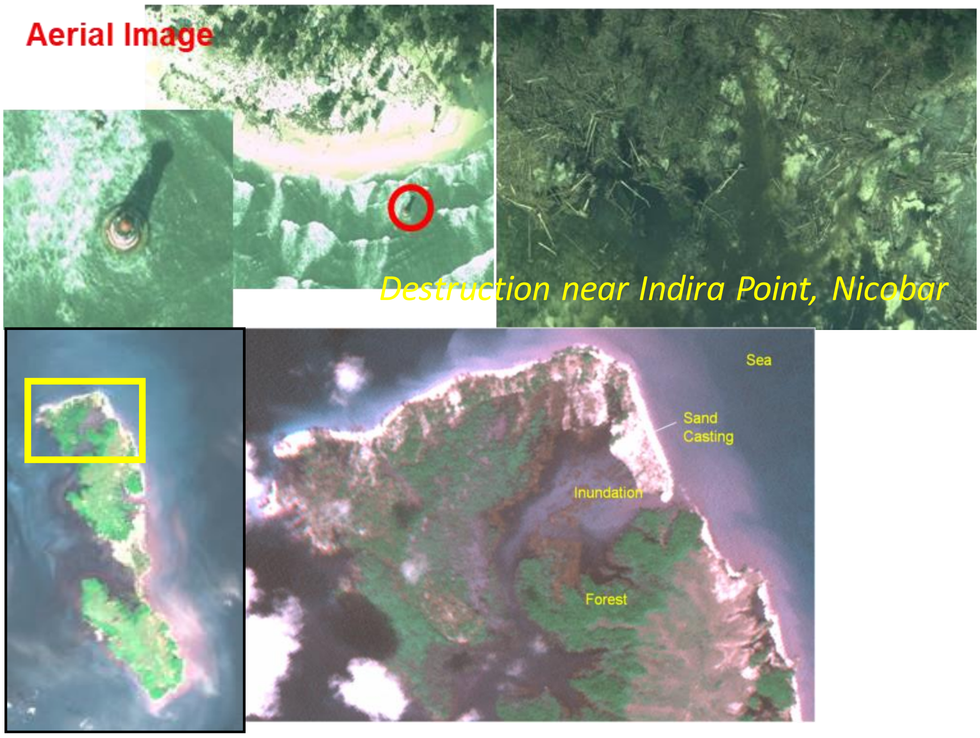


Fig 7.6 Satellite data for identification of damage caused due to Bay of Bengal Tsunami-2004

Space technology plays a significant role in the tsunami early warning system where in the space-based communication system along with in-situ sensors are integrated into a sensor network. On receiving a signal of underwater earthquake, the location and magnitude and type of displacement on the ocean/sea floor is sent to the Tsunami early warning center, which based on the preliminary computation identifies the best fit simulated scenario and the warning for tsunami alert is sent within a few minutes of the event. This helps to save lives and property in the affected areas as the people are moved to safer places and the high value properties are secured.

iv. Volcanoes

Volcanoes are one of the most spectacular natural disasters observed. The volcanoes are vents or fissures on the earth's crust through which magma which is basically molten rock reaches the earth's surface. Although it is not extensive in its distribution and limited to the areas where the continental plates are joined or are either colliding against each other or scraping against each other. The volcanoes can cause extensive damage to life and property in a region apart from causing changes in the global climate due to the enormous amount of gas and dust it shoots up in the stratospheres. It has been estimated that the entire population the Roman cities of Pompeii and Herculaneum was wiped out by the eruption and the pyroclastic flows from the Mount Vesuvius. According to Toba catastrophe theory 75,000 to 80,000 years ago a super volcanic event at Lake Toba had reduced the human population to 10,000 or even 1,000 breeding pairs creating a bottleneck in human evolution. Such events are distinctly possible in the event of various tectonic movements of the earth. In such a scenario, the entire human civilization as we perceive now may be wiped out in a matter a month.

Barren Island, the only active volcano of South Asia lies in the Andaman Sea within Indian territory. The current active phase began in 1991 with low to moderate scale ash and lava eruption. However, it has become very active since 2005, particularly during active seismic periods in Andaman Sea. The different volcanic features, thermal anomalies, track of the transport pathways and the extent of volcanic ash have been studied during the active phases of the Volcano during 2000-2022.

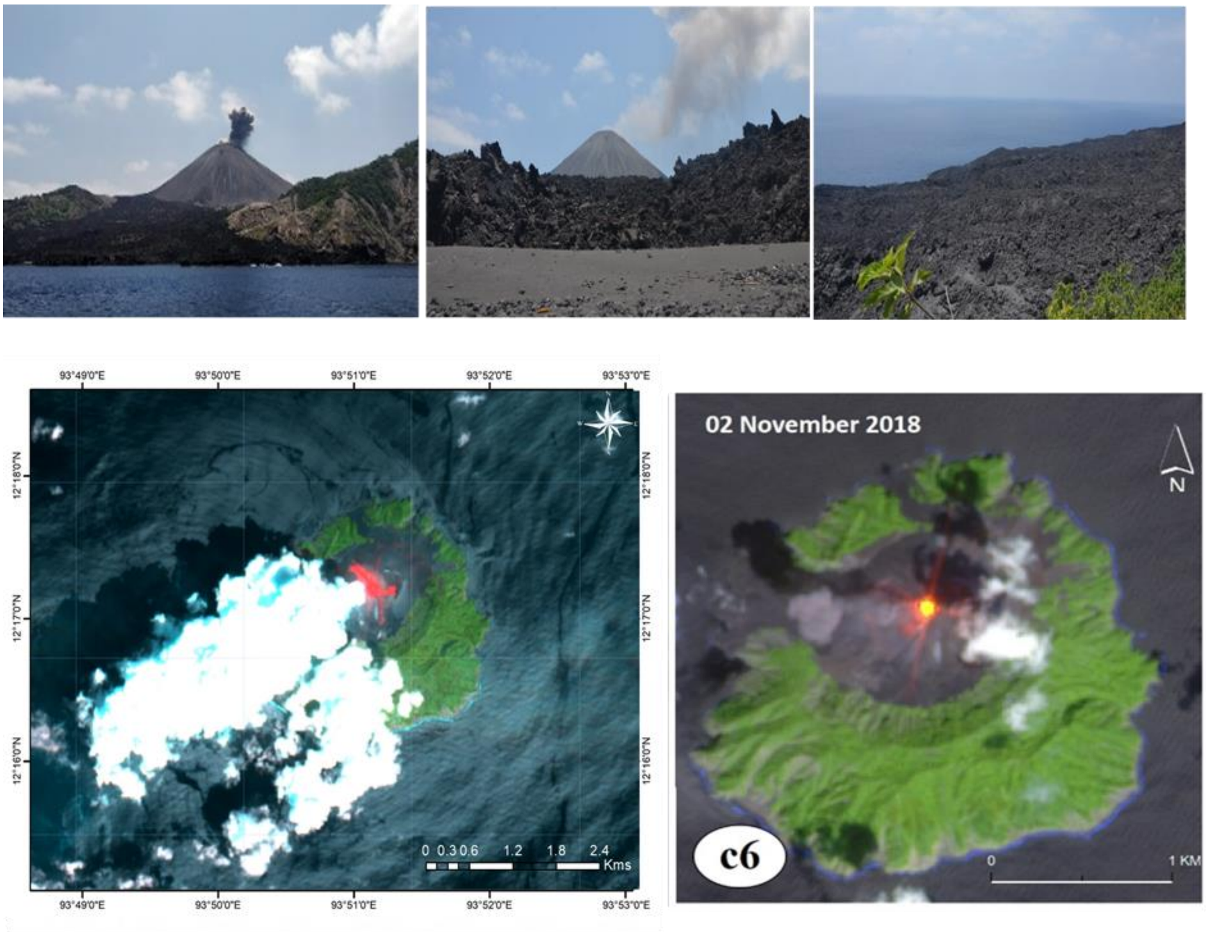


Fig 7.7 Barren Island Volcanic eruption captured using Sentinel 2 data: Images on the top is the actual eruption captured during ground truth.

7.5.2 Hydro-meteorological Disasters

Hydro-meteorological disasters pertain to severe events resulting from the interactions between weather systems, water, and the Earth's atmosphere. These disasters encompass a broad range of natural phenomena, including hurricanes, cyclones, tornadoes, floods, droughts, and blizzards. They emerge as a consequence of the intricate interplay among various meteorological factors such as temperature, humidity, air pressure, and wind patterns. The amplified frequency and intensity of hydro-meteorological disasters can be attributed, in part, to climate change, which has devastating implications for human lives, infrastructure, and the environment. The understanding and mitigation of risks associated with these disasters are of utmost importance, emphasizing the need for early warning systems, resilient infrastructure, and effective disaster management strategies. Remote sensing data is highly valuable in data sparse regions due to its ability to provide wide coverage and timely information over large and inaccessible areas. By integrating data from multiple sensors, it offers a comprehensive view of the target area. Its historical archives allow for long-term trend analysis, aiding in understanding environmental processes and climate change impacts. The non-intrusive nature of remote sensing enables monitoring in sensitive or inaccessible regions. The multi-spectral information it captures enables the derivation of valuable insights about land cover, vegetation health, and other important parameters. In disaster-prone regions with limited infrastructure, remote sensing aids in disaster response and management by identifying affected areas and facilitating relief operations. There are various types of hydro-meteorological disasters, each with its own characteristics and impacts. Some of the commonly experienced Hydro-Meterological Disaster are: (1) Hurricanes and Cyclones; (2) Extreme Precipitation events or Cloudburst; (3) Floods; (4) Droughts; and (5) Heatwaves.

i. Hurricanes and Cyclones

Earth observation plays a vital role in monitoring and early warning systems for hurricanes and cyclones. Earth observation satellites capture detailed images and data of the Earth's surface, atmosphere, and oceans, providing valuable information for meteorological agencies. These satellites can track cloud patterns, measure sea surface temperatures, analyze wind fields, and monitor other relevant meteorological parameters. This data is crucial for accurately predicting the formation, intensity, and trajectory of hurricanes and cyclones. By continuously monitoring these storms from space, meteorological agencies can issue timely warnings, enabling vulnerable communities to prepare and evacuate in advance, ultimately saving lives and minimizing damage.

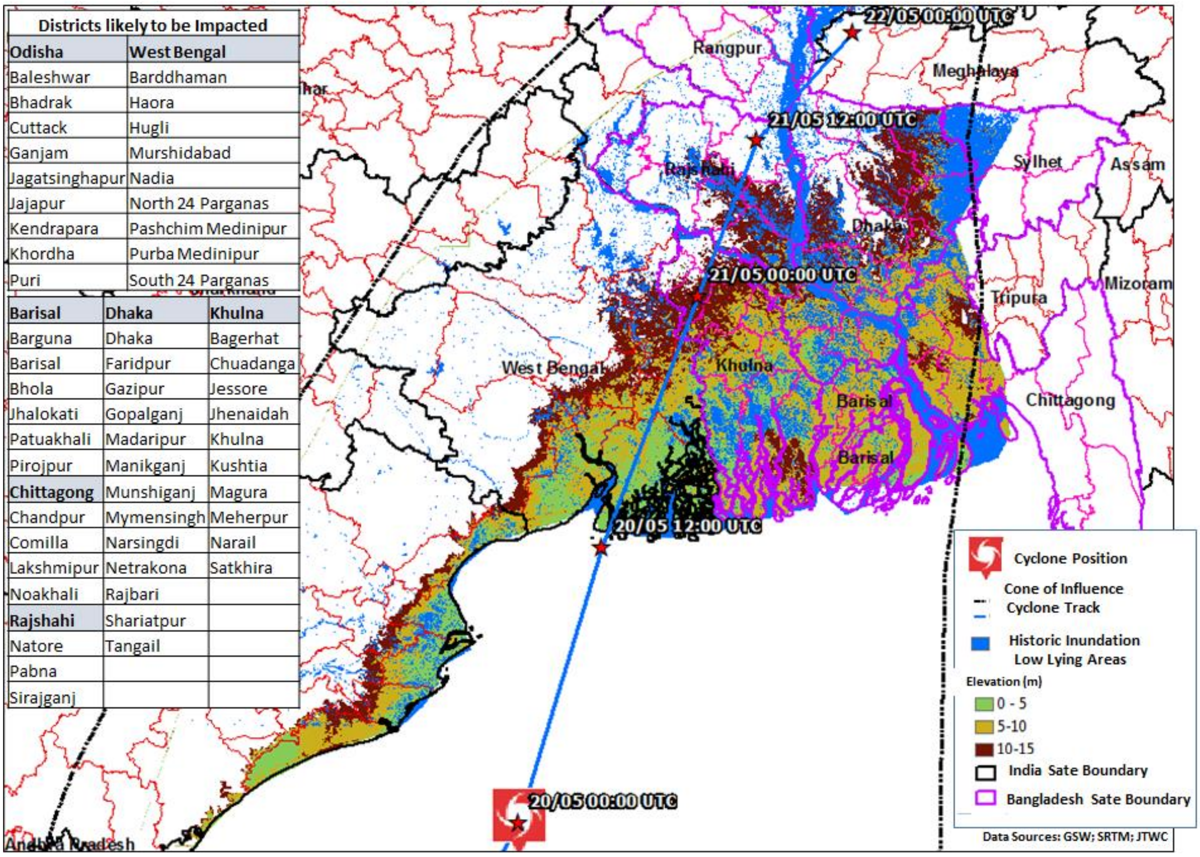


Fig 7.8 Prediction of cyclone path, landfall and extent of inundation during Cyclone Amphan, May, 2020 (Credits: C.M. Bhatt, IIRS)

In addition to real-time monitoring, earth observation also assists in post-event analysis and recovery efforts. Satellite imagery before and after the event helps in assessing the extent of damage caused by hurricanes and cyclones. This information enables rapid damage assessment and aids in determining the areas most in need of assistance. Earth observation data also facilitates the identification of critical infrastructure disruptions, such as damaged roads or flooded areas, enabling efficient deployment of rescue and relief resources. Moreover, long-term monitoring through earth observation helps in analyzing the impacts of hurricanes and cyclones on ecosystems, coastal areas, and climate patterns, leading to improved understanding and preparedness for future events. Overall, the use of earth observation for monitoring and early warning systems for hurricanes and cyclones enhances the effectiveness of disaster response, supports informed decision-making, and contributes to building more resilient communities.

ii. Extreme Precipitation events or Cloudburst

EO (Earth Observation) technology plays a crucial role in monitoring and understanding extreme precipitation events or cloudbursts. Satellites equipped with advanced sensors and instruments can detect and track cloud systems associated with heavy rainfall. These satellites provide high-resolution images and data that help meteorological agencies identify the spatial extent, intensity, and movement of intense precipitation systems. By monitoring the evolving cloud patterns and rainfall rates, EO technology enables the early identification of potential cloudbursts, allowing for timely warnings and evacuation measures to be implemented in vulnerable areas. Additionally, EO data helps in quantifying the amount of rainfall and assessing its spatial distribution, aiding in flood forecasting and management.

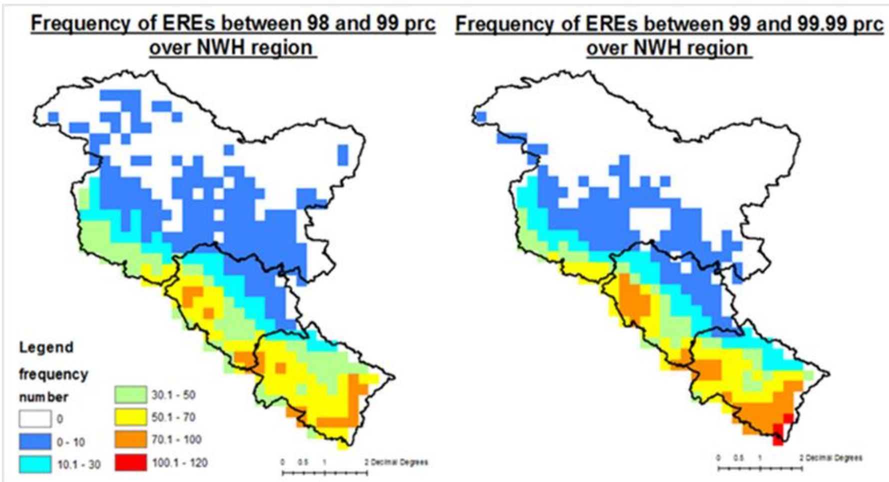


Fig 7.9 Extreme Rainfall Event/Cloudburst detection using Tropical Rainfall Measuring Mission (TRMM) 3B42 version 7 precipitation data (Bharti & Singh et. al., 2016)

Moreover, EO technology assists in the analysis and modeling of extreme precipitation events. By combining satellite data with ground-based observations and other meteorological parameters, scientists can study the atmospheric conditions and dynamics that contribute to cloudburst formation. This information helps in improving our understanding of the processes leading to extreme precipitation and refining weather prediction models. EO data also supports post-event analysis, allowing for the assessment of the impact of cloudbursts on land use, infrastructure, and hydrological systems. This knowledge is vital for developing effective mitigation strategies, such as improved urban planning, flood control measures, and early warning systems, to reduce the risks associated with extreme precipitation events and enhance resilience in affected regions.

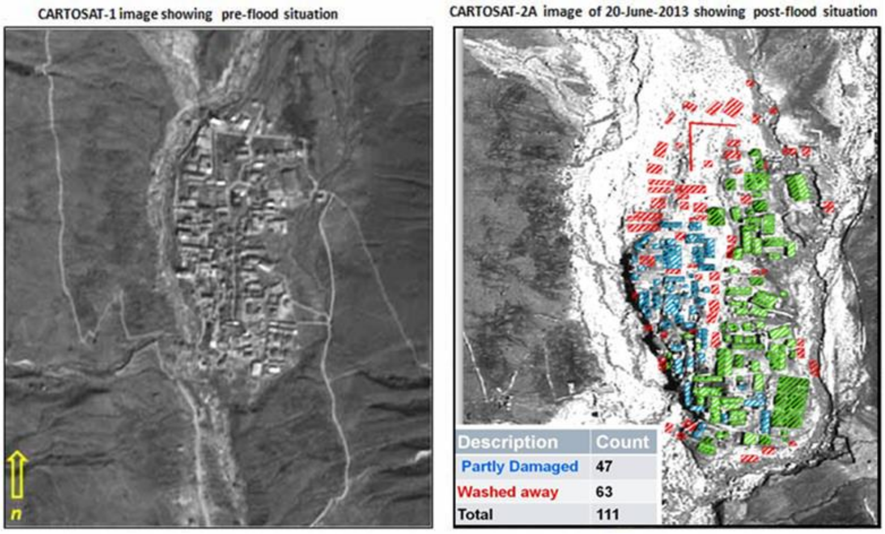


Fig 7.10 Damage due to cloudburst associated with GLOF in 2013 at Kedarnath, Uttarakhand

iii. Flood

Monitoring floods using remote sensing techniques is a valuable approach for assessing and understanding flood events. Remote sensing involves the use of satellites and aerial platforms equipped with sensors that capture data from the Earth's surface. In the context of flood monitoring, remote sensing provides crucial information on the extent and dynamics of floodwaters. Satellite imagery, acquired before, during, and after the flood event, can be utilized to map and analyze the flooded areas. By comparing images captured at different times, floodwater progression and recession can be tracked, enabling the estimation of flood duration and the identification of areas most impacted by flooding. Remote sensing data also aids in assessing floodwater depths and understanding the spatial patterns of flood inundation, which is crucial for planning rescue operations, identifying evacuation routes, and determining areas in need of immediate assistance.

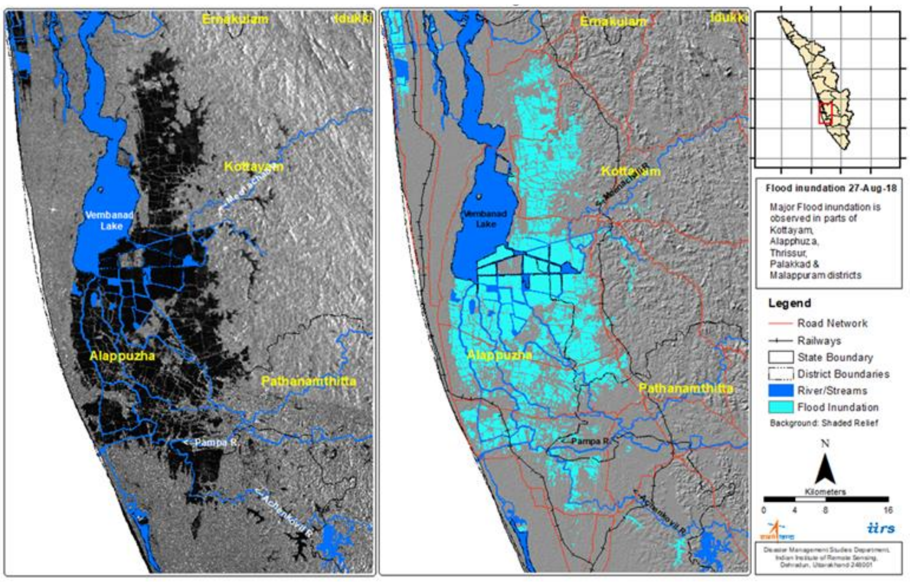


Fig 7.11 Mapping flood inundation in Kerala using microwave data during August 2018 (Credit: C.M. Bhatt, IIRS)

Remote sensing also offers the advantage of providing data on various flood-related parameters. Optical sensors capture visible and infrared wavelengths, enabling the detection of flood extent and the classification of flooded land cover types. Radar sensors, on the other hand, can penetrate through clouds and vegetation, allowing for flood mapping even in challenging weather conditions. These sensors measure the backscattered radar signals, which can provide information on floodwater depth and the roughness of the flooded surface. Additionally, remote sensing data can be integrated with other geospatial data, such as digital elevation models and rainfall data, to enhance flood monitoring and prediction capabilities. Overall, remote sensing plays a vital role in flood monitoring by providing comprehensive and timely information that supports decision-making, emergency response, and post-flood assessment and recovery efforts.

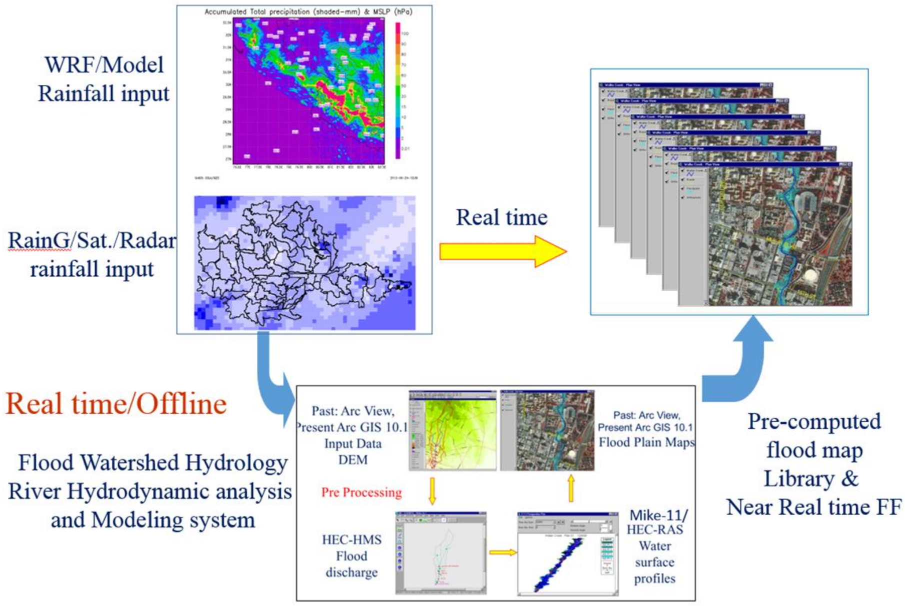


Fig 7.12 Schematic diagram for flood early warning system

ISRO's flood modeling efforts have significantly aided disaster management authorities, as demonstrated during the 2018 Kerala floods in India. Through satellite-based flood modeling and mapping, ISRO provided real-time inundation maps, enabling authorities to identify affected areas, plan rescue operations, and allocate resources effectively. Their flood modeling techniques incorporated satellite data, hydrological models, and rainfall data to generate flood forecasts and estimate potential inundation areas. The accurate predictions and early warnings helped in evacuating vulnerable populations and locating safe areas for relief camps. Additionally, ISRO's flood mapping facilitated the identification of critical infrastructure at risk, aiding in prioritizing rescue and recovery operations. The success of ISRO's flood modeling highlights the valuable role of remote sensing technologies in enhancing disaster management and mitigating flood impacts.

EO technology also provides valuable data for flood forecasting and early warning systems. Satellites can monitor rainfall patterns and provide information on precipitation distribution over large areas, which is crucial for predicting potential flood events. By integrating rainfall data with topographic information and hydrological models, flood forecasters can generate accurate predictions of flood timing, magnitude, and affected areas. This enables authorities to issue timely warnings and implement appropriate evacuation measures, thereby saving lives and minimizing property damage. Furthermore, continuous monitoring of flood events through EO technology helps in assessing the effectiveness of flood mitigation measures and supporting post-flood recovery efforts by providing critical information for damage assessment and resource allocation.

iv. Drought

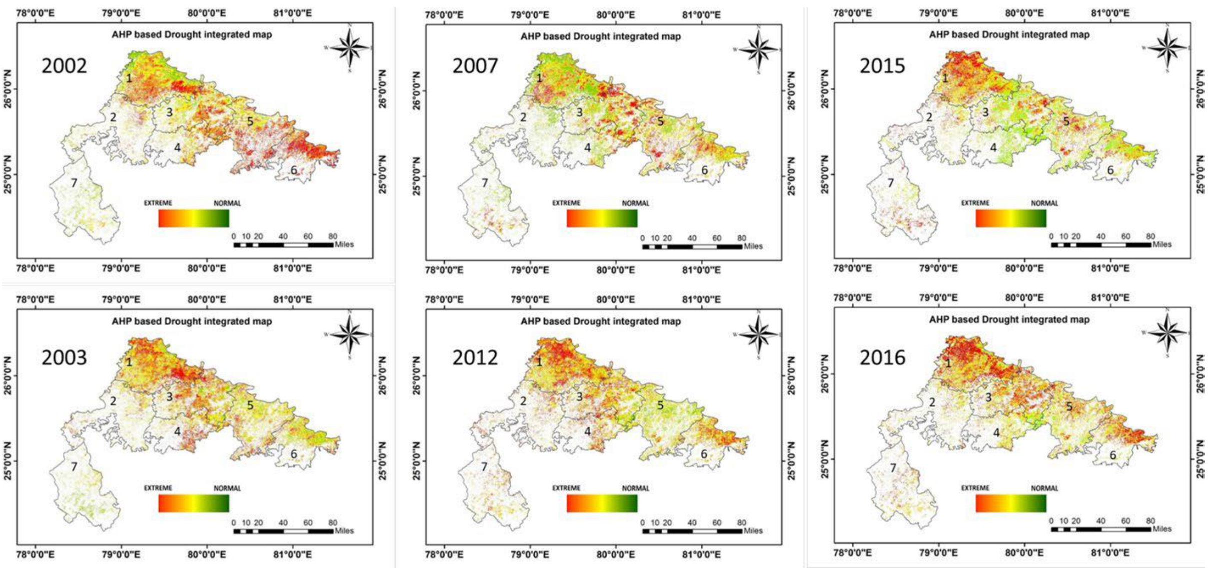
Drought is a characterized by a prolonged period of abnormally low precipitation, resulting in water scarcity and an imbalance between water supply and demand. Droughts can have significant socio-economic and environmental impacts, affecting agriculture, water resources, ecosystems, and human livelihoods. They can lead to crop failure, livestock loss, reduced water availability for drinking and irrigation, increased risk of wildfires, and ecological disruptions. Droughts can also have long-term consequences, as they can deplete groundwater reserves, affect water quality, and result in the degradation of land and ecosystems. Effective monitoring, early warning systems, and proactive water management strategies are crucial for mitigating the impacts of droughts and building resilience in affected regions.

Agricultural Drought Monitoring

Unlike point observations of ground data, satellite sensors provide direct spatial information on vegetation stress caused by drought conditions and the information is useful to assess the spatial extent of drought situation. Satellite remote sensing technology is widely used for monitoring crops and agricultural drought assessment. Over the last 20 years, coarse resolution satellite sensors are being used routinely to monitor vegetation and detect the impact of moisture stress on vegetation. AVHRR on NOAA's polar orbiting satellites has been collecting coarse resolution imagery worldwide with twice daily coverage and synoptic view.

Remote sensing plays a vital role in drought monitoring by providing valuable data and information on various drought-related indicators. Satellite-based remote sensing techniques enable the continuous and widespread observation of key parameters associated with drought conditions. One essential aspect is the measurement of vegetation health and moisture content. Remote sensing sensors can capture data on vegetation indices, such as the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), which indicate the vigor and density of vegetation cover. By monitoring changes in these indices over time, remote sensing can identify areas experiencing vegetation stress and drought-induced impacts.

Integration of remote sensing derived inputs on land cover and bio physical parameters with crop simulation models under GIS environment would enhance the accuracy of crop monitoring and crop yield estimation methods in agriculture. The Drought Monitor of USA using NOAAAVHRR data (www.cpc.ncep.noaa.gov), Global Information and Early Warning System (GIEWS) and Advanced Real Time Environmental Monitoring Information System (ARTEMIS) of FAO using Meteosat and SPOT – VGT data (Minamiguchi, 2005), International Water Management Institute (IWMI)'s drought assessment in South west Asia using Modis data (Thenkabail, 2004) and NADAMS drought monitoring in India with IRS–WiFS/AWiFS and NOAAAVHRR (Murthy et al., 2007) data are the proven examples for successful application of satellite remote sensing for operational drought assessment.



District representation: 1- Jalaun; 2- Jhansi; 3- Hamirpur; 4- Mahoba; 5- Banda; 6- Chitrakoot; 7- Lalitpur

Fig 7.13 Satellite remote sensing based spatial distribution of agricultural drought in parts of Uttar Pradesh and Madhya Pradesh

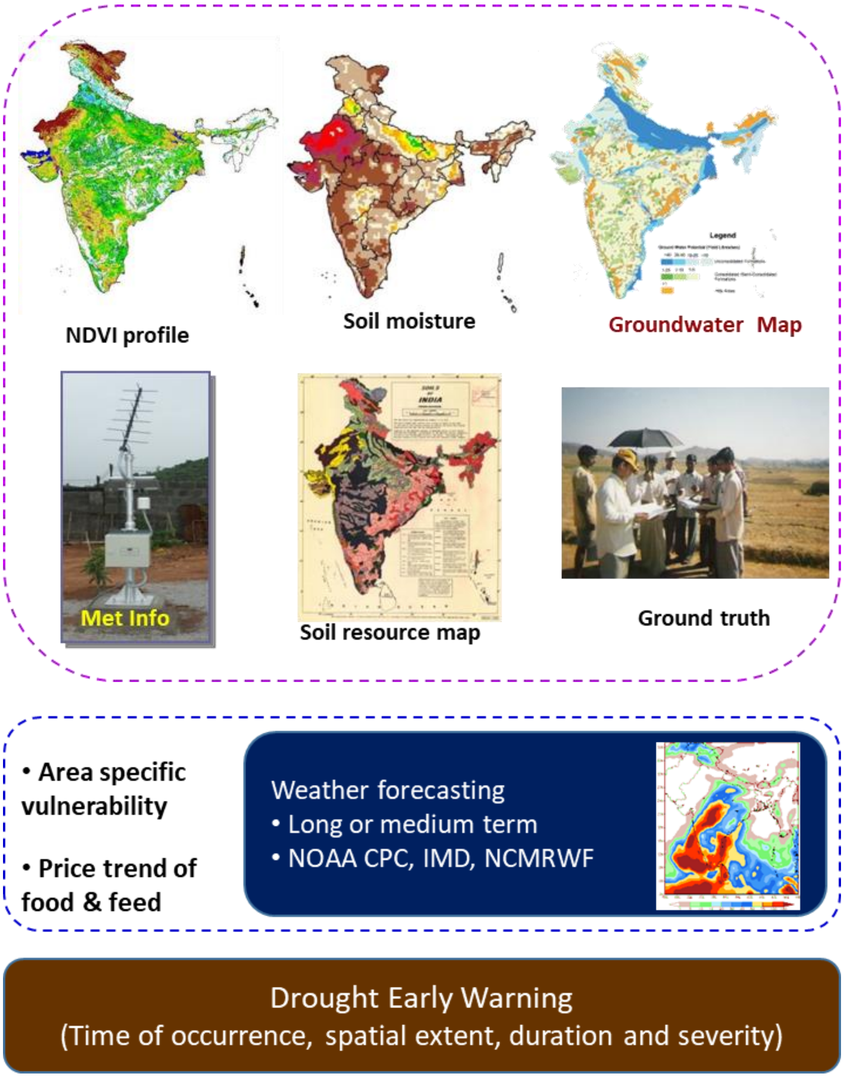


Fig 7.14 Drought Early warning using geo-spatial technology

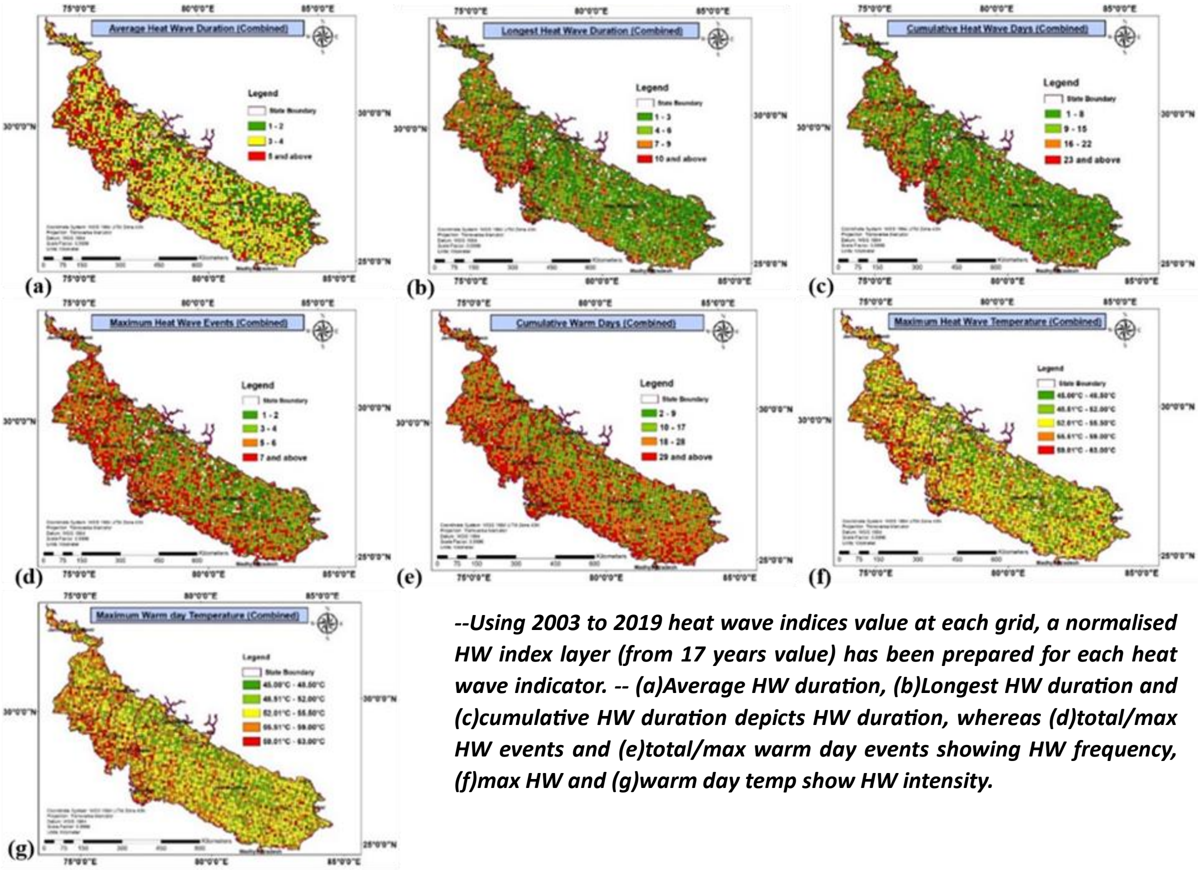
Furthermore, remote sensing can provide data on surface temperature and soil moisture content, both crucial for drought monitoring. Thermal sensors onboard satellites measure land surface temperature, allowing for the identification of areas experiencing heat stress and dry conditions. Microwave sensors, such as those using synthetic aperture radar (SAR), can estimate soil moisture levels by measuring the backscattered signals, which are influenced by the soil's water content. These measurements enable the assessment of soil moisture anomalies and the identification of areas experiencing drought conditions.

By integrating data from multiple remote sensing sources and combining it with meteorological and hydrological data, drought monitoring systems can provide comprehensive and accurate assessments of drought severity and spatial extent. This information helps decision-makers in water resource management, agricultural planning, and disaster preparedness to better understand drought patterns, allocate resources effectively, and implement mitigation strategies. Remote sensing-based drought monitoring enables timely interventions, improves drought resilience, and supports the sustainable management of water resources in drought-prone regions.

v. Heatwaves

A heat wave refers to a prolonged period of excessively hot weather, often accompanied by high levels of humidity, that occurs in a specific geographic region. Heat waves are characterized by significantly elevated temperatures that surpass the average climate conditions for that area, persisting for an extended period of time. These extreme heat events pose significant risks to human health, agriculture, infrastructure, and the environment. Heat waves can lead to heat-related illnesses and deaths, exacerbate drought conditions, strain energy resources, and impact various sectors of society. The frequency and intensity of heat waves have been increasing in many parts of the world due to climate change, emphasizing the need for effective monitoring, preparedness, and adaptation strategies to minimize the adverse impacts associated with these extreme weather events.

The intensity, frequency and duration of HW found to be increasing worldwide especially in India which has seen major HW in last one decade. HW conditions have been studied by analysing ground-based observations worldwide, however, it fails to provide spatial variability at local scale. HW indices to analyse duration, frequency and intensity of HW have been identified and can be computed from Moderate Resolution Imaging Spectroradiometer (MODIS) Land Surface Temperature (LST) product to provide Generally phenomenon of heat wave has been studied using ground-based observations of ambient air temperature (temperature at 2m) (Papanastasiou, Melas, & Kambezidis, 2014). However, absence of extensive spatial coverage of this data is found to be one of the limitations as the spatial variability of HW is not captured. One of the alternative data set could be MODIS Land Surface Temperature (LST) which has a daily day and night pass and is available continuously from 2003 onwards (Bahi, Rhinane, & Bensalmia, 2016). A significant number of studies have shown that LST is highly correlated with ambient temperature (Good et al., 2017; Kawashima et al., 2000, Bahi et al., 2016), hence MODIS LST could be used as one of the best available proxies for ambient air temperature to study the spatial phenomenon of heat wave.



--Using 2003 to 2019 heat wave indices value at each grid, a normalised HW index layer (from 17 years value) has been prepared for each heat wave indicator. -- (a)Average HW duration, (b)Longest HW duration and (c)cumulative HW duration depicts HW duration, whereas (d)total/max HW events and (e)total/max warm day events showing HW frequency, (f)max HW and (g)warm day temp show HW intensity.

Fig 7.15 Spatial Distribution of each Heat Wave Index normalized into single representative layer from 17 years of LST observation

7.5.3 Environmental Hazards

Environmental hazards refer to threats and dangers posed to the natural world and ecosystems, as well as the well-being of human beings. These hazards arise from various sources and activities, such as industrial pollution, deforestation, climate change, and the release of harmful chemicals into the environment. They can have severe consequences on the health of both humans and wildlife, leading to air and water pollution, habitat destruction, loss of biodiversity, and even global warming. Environmental hazards also contribute to the degradation of natural resources and ecosystems, threatening the delicate balance of our planet. Addressing these hazards and adopting sustainable practices are crucial to protect the environment and ensure a healthy and sustainable future for all living beings. Some of the important environmental hazards are Forest Fire, Habitat Destruction and pollution.

i. Forest fires

Forest fire or wildfire is emerging as one of the important and pervasive natural hazards, which have far-reaching implications at global and regional levels. The tropical and subtropical areas in both northern and southern hemispheres have witnessed extensive incidences of wildfires during last two decades (ref). This is affecting the entire ecosystem by damaging the native forest biodiversity, providing opportunity to invasive species as well as causing excessive carbon emission as a result a degrade air quality at zonal scale (Gomez et al. 2015; Syaufina et al. 2018; Sannigrahi et al. 2020).

The changes in the environmental parameters due to climate changes have ensued the conditions suitable for forest fire to initiate and spread more intensively (Sharples et al. 2016; Abram et al. 2021). A number of studies have indicated that the anthropogenic climate change triggered global warming will result in significant increase in the forest fire incidences across the world majorly over the tropical and subtropical regions (Luo et al. 2013; Abatzoglou and Williams 2016; Virgilio et al. 2019; Williams et al. 2019; Dowdy et al. 2019; Halofsky et al. 2020; van Oldenborgh et al. 2021). Although most of the forest fires are of anthropogenic origin (Pyne 1994; Guyette et al. 2002; Mann et al. 2016; Harvey 2016), however the environmental conditions provide the appropriate circumstances for the forest fires to initiate and spread. The increase in the fire incidences over the past few decades has been reported across the temperate and even at higher latitudes in Chile, Russia, Canada and United States (Marlon et al. 2012; Shvidenko and Schepaschenko 2013; Urrutia-Jalabert et al. 2018; Coogan et al. 2019). There is an undeniable essentiality for establishing the existing hypothesis and model-based results on increase in the fire incidences because of the climate change induced warming. Space based records on the active fire from MODIS is available for the past 20 years which along with the temporal data on the environmental proxies provide an excellent opportunity to relate the changes in the environmental parameters with the MODIS based fire incidences.

a) Forest fire Detection- Active fires

Active forest fire detection using space-based Earth observation has become an invaluable tool in monitoring and managing wildfires. Satellites equipped with specialized sensors and imaging technology can detect and track forest fires from space, providing crucial information to emergency responders and land management agencies. These satellites can capture images in various wavelengths, including thermal infrared, which allows them to detect the heat signatures associated with active fires. By continuously monitoring large areas, they can quickly identify fire hotspots, track fire spread, and provide real-time updates on fire behavior. This information helps authorities make informed decisions regarding fire suppression efforts, resource allocation, and the safety of nearby communities. Space-based Earth observation plays a vital role in enhancing early warning systems, improving fire management strategies, and ultimately mitigating the devastating impacts of forest fires.

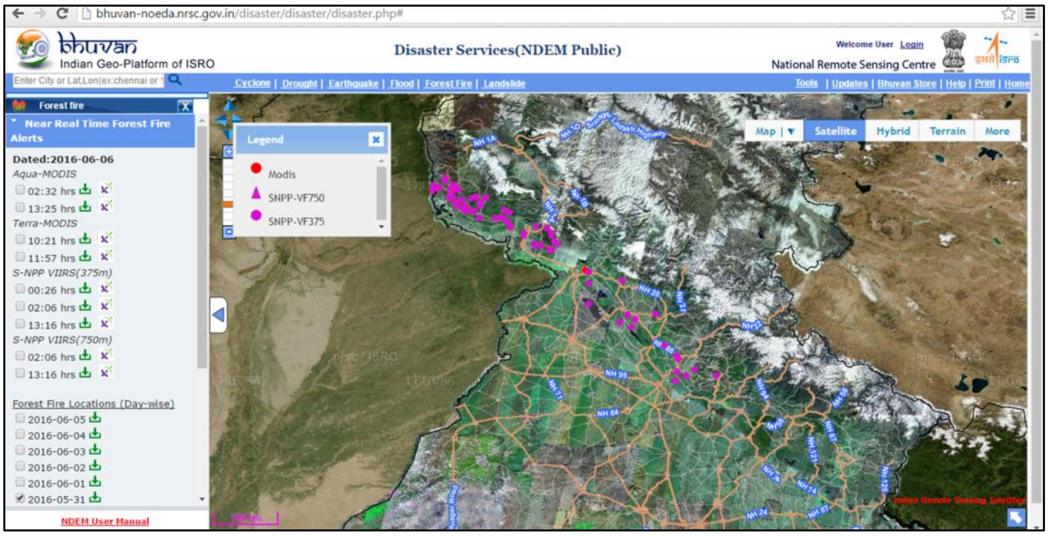


Fig 7.16 Active Forest fires detected using MODIS and SNPP-VIIRS (Source: Bhuvan, NRSC, ISRO)

b) Forest fire damage assessment: Burnt area mapping

Forest burnt area detection using remote sensing is an essential method that utilizes satellite imagery and remote sensing technology to identify and assess areas affected by forest fires. Remote sensing instruments, such as satellites, capture data in various wavelengths, including thermal infrared, enabling the detection of heat signatures associated with active fires and the extent of burned areas. Through the comparison of pre-fire and post-fire satellite images, analysts can accurately map and quantify the burnt areas, providing valuable insights into the fire's impact on the ecosystem. This information is crucial for post-fire management, including reforestation planning, assessment of ecological damage, and evaluation of fire suppression strategies. Forest burnt area detection using remote sensing enables effective monitoring and management of forest fires, facilitating prompt response and mitigation measures.

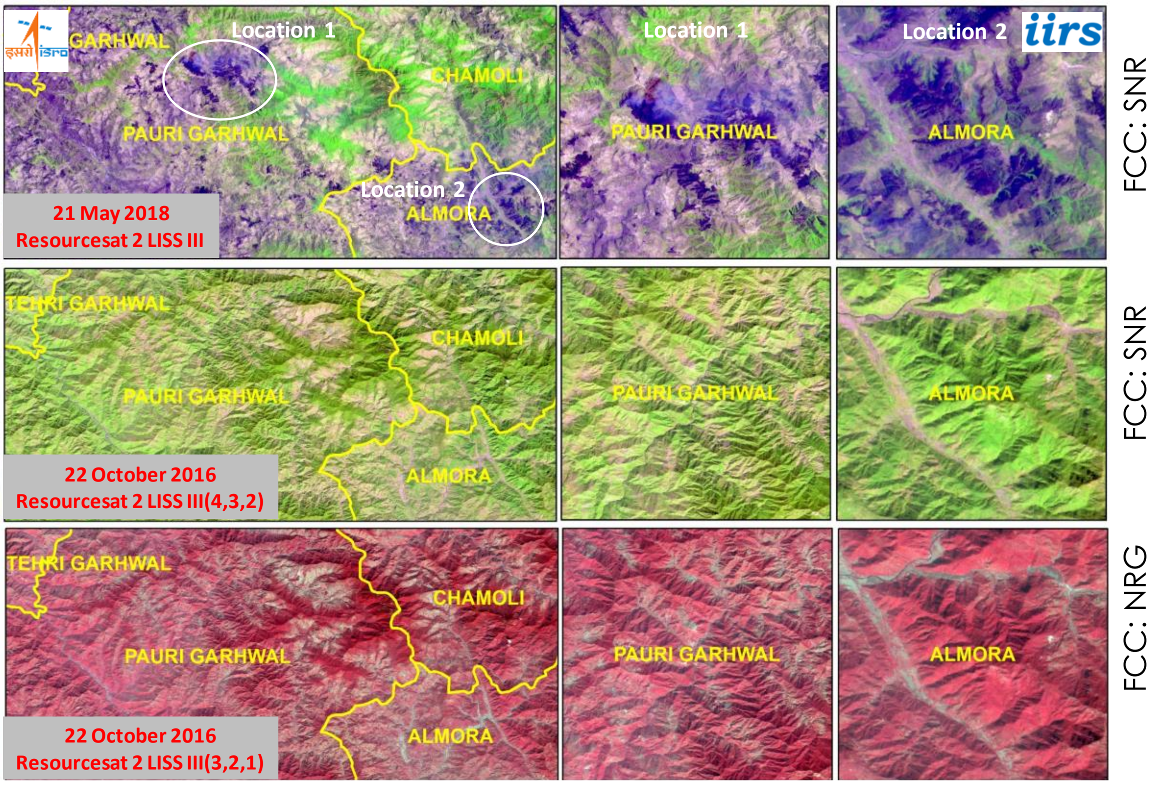


Fig 7.17 Burnt area estimation using satellite data

c) Forest Fire Risk Advisory and Monitoring System (FRAMS)

Forest Fire Risk Advisory and Monitoring System (FRAMS) is a model-based forest fire risk index developed for western Himalayan region. The system is developed as an automated digital workflow, which generate the advisories on daily basis using space-based inputs and ground information. Daily forest fire risk map is generated using a spatial model developed at IIRS for the western Himalayan region of India.

Model Description: The model takes Land surface temperature and other weather parameters such as rainfall, humidity, wind speed/direction, temperature etc. as inputs as dynamic factors and topography, vegetation and land use as well as distance from roads and settlements as static parameters for generating the forest fire danger index on a daily basis (Fig 1). The model accuracy ranges between 82-94% with the active fire locations from MODIS/SNPP-VIIRS (Bhuvan/FSI).

Online Geo-processing and Modelling System: The Geo-processing engine of FRMS has been developed as open system architecture using Python and GDAL/OGR library. The system automatically downloads the daily MODIS, Near Real Time (NRT) product and generate the fire risk map and danger index. The different forest administrative boundaries such as Circle, Range and Beat are overlaid on Fire Risk map and daily advisories are generated for field officials and decision makers. The advisories are sent to the forest officials of Uttarakhand State as SMS. The same input is also being sent to NDRF and USDMA

FRMS Geoportal- FRMS Geoportal has been developed for interactive map visualization, location-based queries, data analysis and other user-defined services. The developed geo-portal is a responsive web application, which is compatible with desktop and mobile platforms. URL of the geo-portal is https://forestfire.iirs.gov.in/fire/

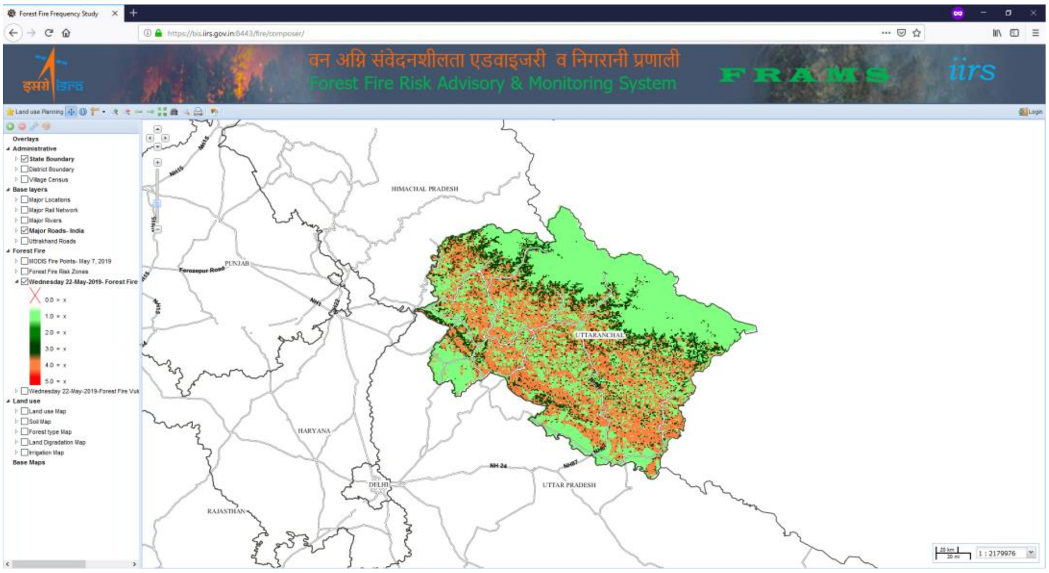


Fig 7.18 Forest Fire Risk Advisory & Monitoring System (FRMS) - Geoportal

Forests work as carbon sinks, which means they absorb more carbon than they release. Due to uninterrupted burning, they release an excessive amount of carbon dioxide into the atmosphere, which adversely affect the atmosphere. Keeping in view the state of the climate crisis, the loss of large amount of forest is a serious concern. Forest burning increases the concentration of various pollutants in atmosphere, carbon monoxide in one of them, this pollutant is often associated with traffic, but here the satellite images show the increase in atmospheric concentrations following the fires. Naturally, once in the air, it can cause problems for humans by reducing the amount of oxygen that can be transported in the bloodstream. Similarly, large quantities of other pollutants like Formaldehyde, Sulphur Dioxide, Nitrogen Dioxide etc. are emitted into atmosphere severing degrading the air quality and affecting the health of living beings.

7.5.4 Atmospheric Pollution

Atmospheric pollution can indeed be considered a disaster due to its severe impact on human health, ecosystems, and the overall environment. While not as sudden or dramatic as other types of disasters, atmospheric pollution, particularly air pollution, has far-reaching consequences that can be devastating. Air pollution, primarily caused by emissions from industrial activities, vehicular exhaust, and the burning of fossil fuels, releases harmful pollutants into the atmosphere. These pollutants include particulate matter (PM), nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds (VOCs), and ozone (O3). Prolonged exposure to high levels of these pollutants can lead to numerous health problems, including respiratory diseases, cardiovascular disorders, and even premature death. In addition to its impact on human health, atmospheric pollution poses a significant threat to ecosystems. Acid rain, for example, is caused by the deposition of sulfur and nitrogen compounds from the atmosphere, leading to the acidification of water bodies, soil degradation, and damage to vegetation. Pollution can also disrupt ecological balance, impair biodiversity, and contribute to the deterioration of ecosystems. Furthermore, atmospheric pollution exacerbates climate change by contributing to the greenhouse effect and global warming. Greenhouse gases, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), trap heat in the atmosphere, leading to rising temperatures, altered weather patterns, and the melting of polar ice caps.

Atmospheric Pollution monitoring from Space

Space-based monitoring plays a crucial role in the assessment and monitoring of atmospheric pollution. Satellites equipped with specialized sensors and instruments provide valuable data for tracking and analyzing various pollutants on a global scale.

Aerosol Monitoring: Satellite-based monitoring plays a vital role in assessing and monitoring aerosols and suspended particulate matter (SPM) in the atmosphere. Satellites equipped with specialized sensors, such as multi-spectral imagers and lidar instruments, provide valuable data on the concentration, distribution, and characteristics of aerosols and SPM on a global scale. These satellites measure the reflectance, scattering, and absorption properties of aerosols at different wavelengths, allowing for the estimation of aerosol optical thickness (AOT) and the retrieval of aerosol size distribution and composition. This information helps in understanding the spatial and temporal variations of aerosols and SPM, identifying pollution sources, and studying their transport patterns. Satellite-based monitoring provides a comprehensive view of aerosol and SPM pollution over large areas, including remote and inaccessible regions, complementing ground-based monitoring networks and contributing to improved air quality assessments and pollution control strategies. Satellite observations, along with ground-based measurements and modeling, contribute to the calculation of Air Quality Index (AQI), which provides an overall assessment of air quality and health risks. This information is essential for informing the public, policymakers, and health organizations about the current air quality conditions and potential health impacts.

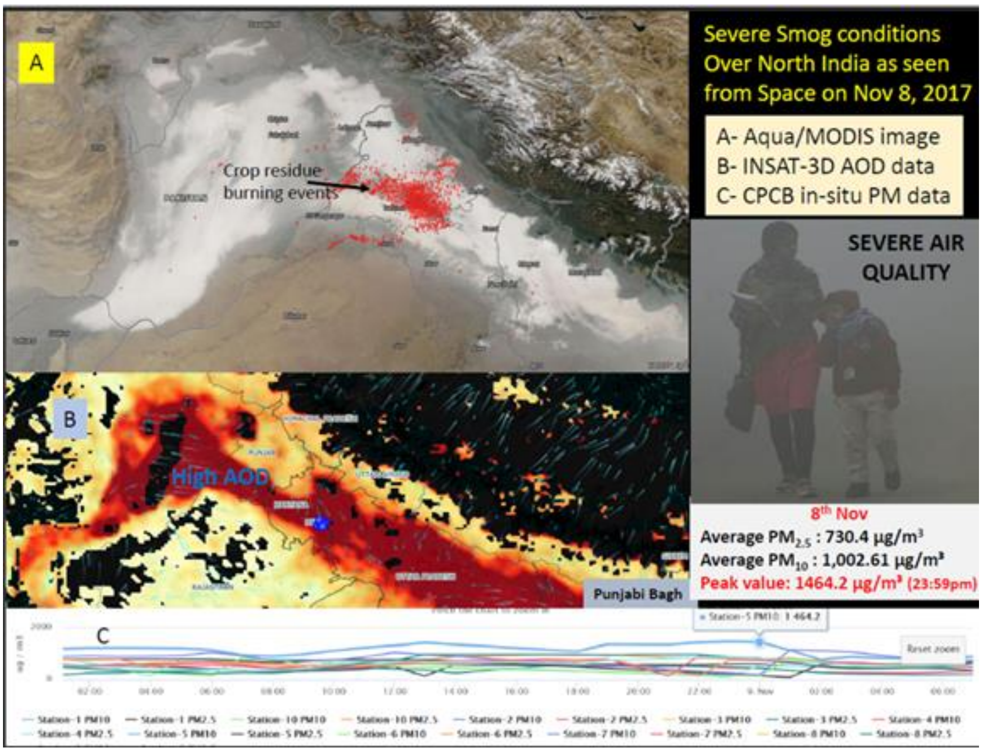


Fig 7.19 Satellite based monitoring of Aerosol and SPM

Trace Gas Detection: Trace gas detection from space involves the use of satellite-based sensors to measure and monitor various atmospheric gases that are present in low concentrations but have significant impacts on air quality, climate change, and environmental processes. Satellites equipped with specialized spectrometers and radiometers can detect trace gases such as carbon dioxide (CO2), methane (CH4), nitrogen dioxide (NO2), ozone (O3), and sulfur dioxide (SO2) by analyzing their unique spectral signatures. These sensors capture the sunlight reflected or emitted by the Earth's atmosphere and surface, allowing the identification and quantification of trace gases through spectroscopic techniques. Space-based measurements provide global coverage, enabling the monitoring of trace gas distribution and variations on regional and global scales. This data helps in understanding the sources, transport, and transformation of trace gases, assessing their impacts on climate and air quality, and supporting policy-making and mitigation strategies for addressing environmental challenges.

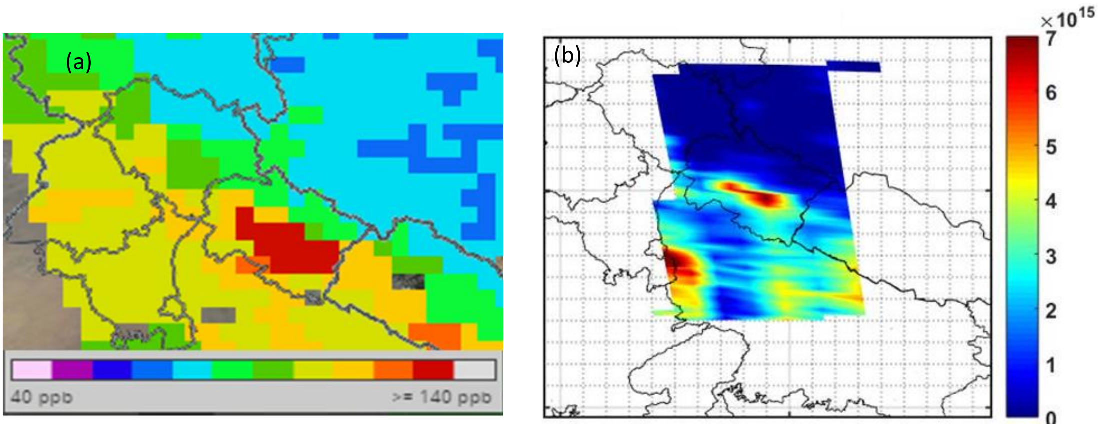


Fig 7.20 Detection of trace gassed using space based sensors (a) retrieval of CO from Aqua and (b) retrieval of NO2 (molecules/cm2) from Aura (Ozone monitoring instrument)

Pollution Source Identification: Satellite data, combined with advanced modeling techniques, can help identify pollution sources, such as industrial complexes, power plants, and urban areas, by analyzing the concentration and distribution of pollutants. This information assists in targeting emission reduction strategies and assessing the effectiveness of pollution control measures. Continuous satellite monitoring provides long-term datasets, allowing scientists to study trends and changes in atmospheric pollution over time. This information is vital for understanding the effectiveness of pollution control policies, evaluating the impact of human activities on air quality, and assessing the success of pollution mitigation efforts. Satellites offer global coverage, providing a comprehensive view of atmospheric pollution on regional, national, and global scales. This is particularly important for studying transboundary pollution, tracking pollutant transport across borders, and addressing pollution issues that require international cooperation.

Space-based monitoring of atmospheric pollution complements ground-based monitoring networks and provides valuable data for policymakers, environmental agencies, and researchers. It enhances our understanding of air pollution dynamics, supports pollution control efforts, and aids in the development of effective strategies for improving air quality and mitigating the impacts of atmospheric pollution on human health and the environment.

7.6 Disaster Management - New Paradigms

The approach towards natural disaster today is towards disaster management with the global thrust in this aspect. The various drivers towards this are the Lessons Learnt; Yokohama Strategy for a Safer World; IDNDR Proceedings; HPC; Advancements in Technologies to name a few. There are many approaches which are being implemented or in the process of being implemented. Some of the major disaster management aspects are (EM-DAT, 2014):

7.6.1 Reducing Social & Economic Vulnerability - through Risk Management Approach

- Increased investment in Long-term Mitigation Activities - Preparedness, Capacity Building, use of state-of-the-art Technology Tools [Space, IT, Modeling, …]
- Integration of DM with other development sectors
- Good Governance, Accountability, and focus on Bottom-up Approach - involving increased participation of community/ stakeholders
- India is also on the way toward creating proper legislative and administrative infrastructure for establishment of disaster management protocol. Some of the important aspects are:
- Inclusion of Disaster Management in the Concurrent list of VII Schedule of the Constitution
- Enactment of the National/ State Acts for Calamity Management
- Enforcement of Detailed Regulations/ Codes - through Law

7.7 Aspects of Disaster Management

Natural hazards are there to stay. It is for us to adapt ourselves to the events of the natural hazards and keep ourselves safe through proper use of prior information, planning and mitigation. Any natural hazard management and mitigation involves the following basic processes:

Observation: This is one of the critical components of natural hazard. Having a continuous observatory on the earth's surface is one of the prime requirements of natural hazard mitigation.

The advances in the technology have been one of the most important contributors to the increase in the awareness to the potential natural hazards. In this aspect space plays an important role in providing a synoptic coverage of the earth. With increase in the spatial and temporal resolution of the observations from space borne sensors, the chances of detection of the natural hazards have increased.

Detection: With the observatories in place, the continuous monitoring and detection of any anomalies in the observation for potential natural disasters can be tracked.

Early warning: This aspect involves use of communication, information technology and early detection of impending natural disaster. The effective early warning systems give us adequate time for effective evacuations and safeguarding of the critical assets which can reduce the loss of life and property due to the disaster.

Vulnerability assessment: This is a continuous process which has to be carried out in regular intervals to assess the vulnerability of a region to the natural disasters and have in place the effective early warning and rescue and relief mechanism in place. For example, the effective early warning systems in the Western and Central USA has resulted in almost negligible death due to tornados.

Rescue and relief: This is a post disaster event and is one of the most challenging aspects of the disasters. Since post disaster most of the communication and road links are disrupted, the work becomes even more risky. Coupled with this is the adverse weather, which hampers the rescue and relief efforts with time as premium.

7.8 Technology for disaster management

The technological inputs disaster management is at four stages:

- Early Warning Systems
- Detection and Monitoring
- Rescue and Relief
- Rehabilitation

We will discuss the influence of technology in disaster from the aspect of the above four stages in various types of disaster management, and how the technology can be utilized to the full in various stages of disaster management.

Early warning systems are one of the most important aspects in any disaster mitigation. It is a well-known fact that when we have prior information of the impending natural disaster, the impact of the disaster in terms of loss of human lives and property can be minimized to a great extent. The information on the location of the disaster as well as the escape routes are some of the important information for the planning and mitigation. The first and foremost aspect is generation of information. The continuous advances in the space and land-based observatories are continuously influencing the outcome of the various Decision Making Systems to generate timely information on the various facets of the information bank for disaster management.

Most of the loss of life and property due to natural disasters occur in the regions where the human development index is relatively low. In these circumstances the need to communicate the information about the impending disaster is of prime importance and that too in a cost effective and efficient way. The innovative use of technology like IT, space and communication is of prime importance in providing the head start for initiating preventive measures for reducing the loss of life and property.

The technologies for early warning are through satellite-based data, simulation models and communications. The satellite-based information can be incorporated with various models to predict the probability of occurrence of the event. The early warning systems for various types of disaster will be discussed in the following sections.

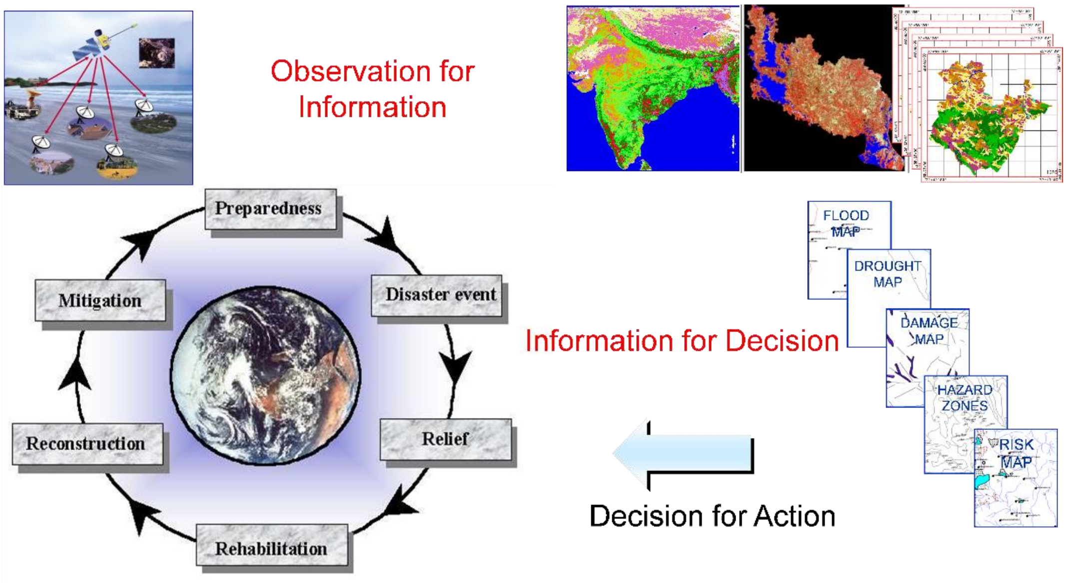


Fig 7.21 Space Technology for disaster management and Disaster Risk Reduction

7.8.1 Shaping of the technology

Natural disasters though inevitable can be managed through early information regarding the various facets of the disaster, their types and intensity. In this regard the role of space technology, information technology and communication technology will play an important role in determining the extent and relevance of the decision making and execution of the information to help in prevention and mitigation of the natural disasters. In all the above discussion on the management of natural disasters, whether in early warning, monitoring and mitigation or rescue, relief and rehabilitation, the role of the above-mentioned technology is going to be one of the key factors in its success. Described below is the trend of space based, information system and communication technology for disaster management.

7.9 Future of efficient disaster management

The future of technology for disaster management is spatial decision support system (SDSS) wherein the space based, ocean based and land-based sensors will help in identification of the potential disaster-prone areas, impending disasters and in case of disaster how to carry out efficiently the relief and rescue in the affected areas. The future of the SDSS is a sensor web wherein the earth observation (EO) satellites as well as the communication satellites will be able to communicate to each other as with the ground-based sensors. The data will be integrated to the various simulations and models being developed across the globe for studying the various components of the earth to identify the regions of anomaly.

In this direction the various governments are working towards a common goal to use the various information for generating the information of the biosphere processes so that the models are ready for integrating it with the decision support systems. The main challenge lies in integrating the different information which are in different formats and different domain. The interaction of the different wings of the government machinery is also important. Seamless integration of the information system with the data and its dissemination is the future of the technology. The advent of the mobile information devices in form of smart phone or even wearable devices can be used to provide early warning to the people so that they can be prepared for the impending disaster and keep them from harm.

The technology can also be used for evacuation and relief by providing accurate and best path to reach the affected areas. For example, in case of major hurricane or tsunami a lead time of a few hours are available and the time can be used to plan proper evacuation using the GIS based maps and information on population density and road network. Similarly using a high temporal resolution satellite data, the progress of tornados or forest fire can be traced and evacuation can be planned accordingly. Furthermore, use of cloud computing has to be used for spatial decision support due to the enormity of the data and high cost of maintaining redundancy in keeping copies of the data at several locations.

One of the important aspects in future of disaster management is "Crowdsourcing" which allows various stakeholders and general public to contribute to the information. One of the recent applications in crowd sourcing is MANU (Map the Neighbourhood in Uttarakhand) which has helped as well as creating a database by collecting real-time data on the recent disaster in Uttarakhand.

In case of rescue and rehabilitation the information on the terrain and infrastructure can help in planning and executing the various rescue and relief efforts. Availability of high-resolution digital elevation models helps us in simulating the flight path of the rescue helicopters in the treacherous hilly terrains for safe evacuation. Availability of high tensile lightweight materials for building of the bridges washed away by the floods can greatly help in rescue and relief.

Disasters have a very high impact on the global economy. Since the beginning of this millennium the natural disasters have cost the global economy more than $ 2.5 trillion. The enormous loss of life and property makes a huge strain on the economy of the individual countries as has been very vividly apparent in case of Haiti after the crippling earthquake which has resulted in complete anarchy and lawlessness due to enormous strain on the economy.

Natural disasters are inevitable. The technology will enable us to make a better and informed decision for disaster mitigation. In this respect space technology, communication technology and information technology will play an important role in mitigating the disasters. Prior warning of impending disaster can help is translocation of high value movable assets there by preventing collateral loss to the economy. Furthermore, in case of emergency the mobile communicating devices can act as beacons as well as method for transmitting local information to the community. This will enable the community to take informed decision in case of natural disaster induced emergencies.

7.10 Promotion of the technology

The biggest concern today in promoting technology is inertia in the line departments. The technology is available as has been evident from the analysis of the Kedarnath Tragedy in

Uttarakhand in June 2013. But the methodology of dissemination of the technology to the common man is not taken up with due diligence. In a country like India, there is an urgent need to identify innovative method to disseminate the information of the impending disaster. Sending the information through digital media is one of the methods but it has its limitation as the internet penetration in the rural India is still very less. A very innovative method for dissemination may be through region wise SMS which can be tracked through the cell towers and all the mobiles which are within the vicinity of the cell towers where the impending disaster is likely to occur can be informed through the SMS. Another appliance can be community radio which can be utilized for the same.

It is also important that the stake holder in disaster managements like the administration at district level especially in the disaster-prone regions like Bihar, Assam, Uttarakhand, etc are made aware of the technological capabilities in the area of disaster management.

7.10.1 Areas of concern

The use of cutting-edge technology in disaster management is dependent on the development, communication and information technology. Whether it is GPS, or GPRS, extreme weather events or natural disasters in most of the time the communication channel is down. Furthermore, with the rate the technology is changing, passing the technological knowhow to the field level rescue and relief workers.

Although the governments all over the world is putting a lot of resources in the disaster management, there is still a dearth of a structured civilian organization in place in most of the countries to tackle the situations in most of the countries. The armed forces are the key player in almost all the rescue and relief operations. And in most of the time it is post disaster where the damage and destruction to the life and property has already taken place. The need of the day is prevention or fore warning than rescue and relief.

7.10.2 Managing technological innovations on Disaster Management

The technological innovations in the field of disaster management need to be managed in a way that it is available to the stake holders in the least possible time. This includes creation of suitable dissemination mechanism, identification of dedicated communication channels and availability of information regarding the pre-disaster physiognomy and infrastructure as well as post disaster infrastructure for effective rescue and rehabilitation. There is an urgent need to work in close association with the stake holders in the disaster management. The need of the stake holders like the NDMS and the state level bodies involved in relief and rehabilitation. One of the important aspects of technology transfer is to train the people involved to use the information and take appropriate decision based on the information. In this regard proper training and handholding is required by the organizations.

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Chapter 8

WATER RESOURCE MANAGEMENT

8.1 Introduction

8.1.1 Importance of Water Resources

Water is fundamental to many aspects of sustainable development and is under threat. Access to safe water, sanitation and hygiene is the most basic human need for health and well-being. Rapid population expansion, urbanisation, and mounting demands from the agricultural, industrial, and energy sectors are all contributing to an increase in water demand. Thus, the water stress has worsened and ecosystems that provide clean water have been damaged through many years of misuse, poor management, over-extraction, and contamination. This, in turn, affects human health, economic activities, and food and energy supplies (United Nations, 2022). In addition, several countries in the world are facing growing challenges linked to degraded water-related ecosystems, water scarcity caused by climate change, under-investment in water and sanitation and insufficient cooperation on transboundary waters. Climate change is further exacerbating these challenges by altering precipitation patterns and increasing the frequency and severity of extreme weather events. If the civilization doesn't wake up and start conserving water, billions of people won't have access to this essential utility.

8.1.2 Water Resources of World and India

The total volume of water on earth is estimated to be 1.4 billion km³, of which about 97.5% is saltwater and the remaining 2.5% is freshwater (United Nations, 2021). However, only about 0.3% of this freshwater is available for human use, as the rest is either locked up in ice caps and glaciers or lies too deep underground to be economically accessible. The available freshwater is distributed unevenly around the world, with some regions having abundant water resources while others face water scarcity (World Bank, 2021).

India is among the water-stressed countries in the world, with a population of more than 1.3 billion and an economy dependent on agriculture. The country faces several challenges related to water resources management, such as uneven distribution of water resources, increasing water demand, deteriorating water quality, and climate change. The country has 4% of the world's freshwater resources, but it has to support 18% of the world's population (Ministry of Jal Shakti, Govt. of India, 2022). The average annual rainfall in the country is about 1,170 mm, but it varies widely across regions and seasons. The Himalayan region and the northeast receive the highest rainfall, while the western and central regions receive the least. The country has 20 major river basins and over 4000 small rivers and tributaries. The major rivers of India are Ganga, Brahmaputra, Indus, Godavari, Krishna, and Cauvery. The groundwater resources of the country are also significant and are used for both domestic and agricultural purposes.

As per the Central Water Commission (2019), the total water availability of India received through precipitation is about 3,880 Billion Cubic Meter (BCM) per annum. After evaporation, 1,999.20 BCM water is available as natural runoff. Due to geological and other factors, the utilisable water availability is limited to 1,122 BCM per annum comprising 690 BCM of surface water and 432 BCM of replenishable ground water. Out of this, the utilised water potential is around 699 BCM, comprising 450 BCM of surface water and 249 BCM of groundwater. The total requirement of the country for different uses for high demand scenario for the years 2025 and 2050 has been assessed as 843 BCM and 1,180 BCM, respectively.

8.1.3 Water Requirements of India

Water is used for various purposes, including agriculture, industry, energy production, domestic use, and environmental services. Agriculture is the largest consumer of freshwater, accounting for around 70% of global freshwater withdrawals. Industry and energy production account for around 20% of freshwater withdrawals, while domestic use accounts for around 10%. However, the actual water use for these sectors varies widely depending on regional factors such as climate, land use, and economic development.

Indian water resources utilization is mostly dominated by agricultural sector nearly accounting to 428 km^3 (around 69% of total water use) with 300 km^3 from surface resources and 128 km^3 from ground water resources. To meet the increased food production requirements and to achieve food security, the agriculture sector would command a quantum jump in water utilization and is expected to be in the order of 708 km^3 by the year 2050. Domestic water requirements are around 25 km^3 at 5% of total usage, out of which surface water contributes 7 km^3 and ground water contributes 18 km^3. With the significant urbanization of population, it is expected that around 54% of population would be living in urban areas by 2050, and which may increase the domestic demand to 90 km^3. Industrial usage is in the order of 15 km^3 which is likely to grow up to 103 km^3 by 2050.

The total water requirements of the country are expected to be around 1450 km^3 by the year 2050, which is significantly higher than the present estimate of utilisable water resources potential of 1122 km^3. It is estimated that Indian ground water overdraft is of the order of 66% which places food and livelihood security at great risk and could lead to 25% reduction in India's harvest. The per capita availability of 1820 m^3 (2001) is fast depleting due to rising demand and likely fall to 1191 m^3 by 2050 leading to precariously closer to water scarce condition.

8.1.4 Challenges in Indian Water Resources Management

The rainfall has a wide temporal and spatial variation in India. The driest parts of the country receive as little as 50 mm of rain in Leh, Ladakh in comparison to 11,872 mm of rain in the wettest part of India, in Meghalaya. Climate change has recently been one of the factors to exasperate this variation causing more extreme rainfall events; with the number of days, and duration in which the rainfall events occur are reducing, but the intensity of rainfall has increased. This implies that the water utilisation plans based on rainfall received and water management must be put in place to accommodate for the growing demands for all lifestyle activities including farming practices must be take into account the variations in rainfall patterns. A recent example of this was observed in Mumbai during monsoon season of 2020; according to the local weather stations, representative of south Mumbai, the rain received surpassed the monthly average with 293 mm of rain over a 12-hour period and 332 mm over 24 hours.

With an ever-expanding population growth, unchecked and unabated pollution of the waterways, encroachments of unprotected stretches of waterbodies, and serious rise in demand, if the water scarcity issue is not resolved, it is estimated to cost the country a loss of approximately 6% of the GDP and thousands of lives along with it by the year 2030. According to the Central Ground Water Board (CGWB) in 2017, 256 Districts of the country are water stressed (where the demand is more than supply), and 1186 blocks of these Districts are over-exploited (where the recharge of water is significantly lower than the recharge of water). Despite of these harrowing statistics, it is suggested that the water available (1123 BCM) is enough to sustain 22.8 billion people – 17 times of the current population (Down to Earth, 2020); thus, the solution surely lies in management of resources and infrastructures to allow for the optimised usage of the available water. The problems associated with the water resources development are varied and complex. Some of them are: i) Spatial and temporal variations in availability; ii) Falling per capita availability of the country; iii) Expanding multi-sectoral demand; iv) Under and inefficient utilisation of irrigation potential; v) Loss of surface storage due to reservoir sedimentation; vi) Frequent floods severely affecting the flood prone area development; vii) Recurring drought; viii) Over-exploitation and depletion of the ground water resources; ix) Deteriorating water quality and environment and x) Climate change impact on water resources.

Coping and managing the above problems largely depends upon our preparedness through a well-structured system. It calls for great challenges in the best use of available water resources through surface water capture and storage, long distance conveyance and inter-basin transfer, ground water exploitation, watershed management, conjunctive use of surface and ground water and desalinisation. This necessitates having relevant information at appropriate time for arriving at rational decisions which would support sustainable water utilisation. The geospatial techniques promise to be potential tools to aid water management decisions.

8.1.5 Climate Change Impact Assessment

Since the advent of Industrial Revolution, humans have continued to invent new ways of managing earth's resources for human consumption. Energy resources played as a key driving force of the economic development that was achieved in the last two centuries. Human activities have resulted in increased concentration of carbon-di-oxide, methane, nitrous oxide, and other trace gases in the atmosphere as well as, in addition, the changes in the land use/ land cover (LULC) have resulted in deforestation, urbanisation, increase in area under irrigation. Due to green-house effect of gases, the global mean surface temperature has increased by 1.5°C above land areas in comparison to pre-industrial period (1850-1900). IPCC (2021) reported that the decadal average global mean surface temperature has been consistently increasing in last 4 decades indicating each of the last four decades have been subsequently warmer.

Climate Change is expected to alter the spatio-temporal distribution of water throughout the globe. According to Clausius-Clapeyron relationship, the global total precipitation is predicted to increase by 7% with temperature increase by 1 degree (Ivancic and Shaw, 2016). This theoretical implication indicates towards intensification of the hydrologic cycle at large scale. The climate change is likely to alter the intensity, frequency, and duration of precipitation events throughout the globe (IPCC, 2021). The increasing surface and air temperature would lead to increased evapotranspiration and precipitation at global scale. The climate change impact assessment is useful for studying its likely impact on natural resources, preparation of adaptation and mitigation plans, and prioritising efforts in this direction.

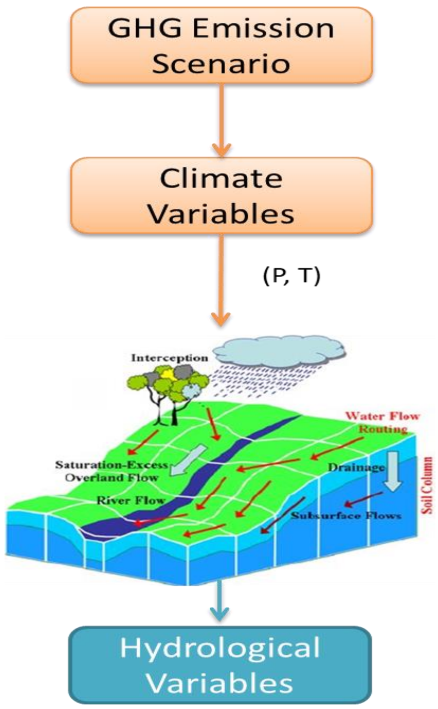


Fig. 18.1 Top-down framework of climate change impact assessment on water resources (Source: Cole and Moore, 2009)

The General Circulation Models (GCMs) simulate earth's climate in three-dimensional framework by using physical laws of mass, heat, and momentum conservation. The state-of-the-art GCMs employ thousands of mathematical equations to represent processes over land surface, atmosphere, ocean, sea ice and the interaction among them. Such models are also known as Atmosphere Ocean coupled General Circulation Models (AOGCMs) (IPCC, 2014). The recent advances have led to development of Earth System Models (ESMs). In addition to the components of AOGCMs, ESMs can physically represent atmospheric chemistry, components of biosphere; therefore, they can simulate changes in concentration of greenhouse gases unlike GCMs. GCMs are an effective tool to simulate climate of a particular region. Their outputs are, therefore, used for studying the impact of climate change on natural resources. A hydrological model simulates various water balance components such as runoff, evapotranspiration, soil moisture, infiltration, deep percolation, etc. for a precipitation input. These components of water balance are further used for managing water resources. Fig. 18.1 shows the general framework of climate change impact assessment. The hydrologic model is typically parameterised using past climate and streamflow information (Singh & Biswal, 2019).

8.1.6 Remote Sensing of Water

Remote Sensing technology is useful in monitoring the extent and characteristics of water bodies, and its interaction with various atmospheric and land surface attributes. Optical satellites data-based indices such as Normalized Difference Water Index (NDWI) (Gao et al., 1996) and Modified Normalized Difference Water Index (mNDWI) (Xu et al., 2006) are used to identify water pixels in a satellite image. Generally, such indices make use of relative difference in reflected energy in different part of electromagnetic spectrum. Pure water scatters incident solar radiation in blue region and absorbs energy in the other part of visible region. Nearly all incoming energy in NIR region is absorbed by the water bodies and therefore, a pure and deep-water body appears blue in VNIR image.

The remote sensing data is useful to assess some of the inland water body constituents such as suspended matter, chlorophyll-a and dissolved organic carbon. Fig 8.2 shows the energy recorded by a satellite sensor including atmospheric path radiance R_A (λ), reflected energy from water surface R_{AW} (λ), back-scattered radiance from water column RW (λ), reflected energy from the bottom of water body R_B (λ). The constituents present in water column, such as dissolved organic carbon, phytoplankton, and sediments affect the R_W (λ) in different ways. Apart from water molecule, these constituents participate in absorption and scattering of incident solar radiation. Bukata et al. (1995) showed that increasing concentration of dissolved organic carbon in a water body leads to more absorption of radiation in blue region.

Remote Sensing based water quality studies utilise in-situ data for calibration and validations of statistical models developed to assess water quality. Empirical approaches primarily rely on statistical relations between in-situ data and radiometric response recorded by a remote sensor. On the other hand, physical models simulate volumetric reflectance from a water body for different concentration of constituents. Essence of physical models rely on the assumption that constituents such as suspended solids, chlorophyll-a, dissolved organic matter influence the volumetric reflectance from a water body by scattering and absorption processes.

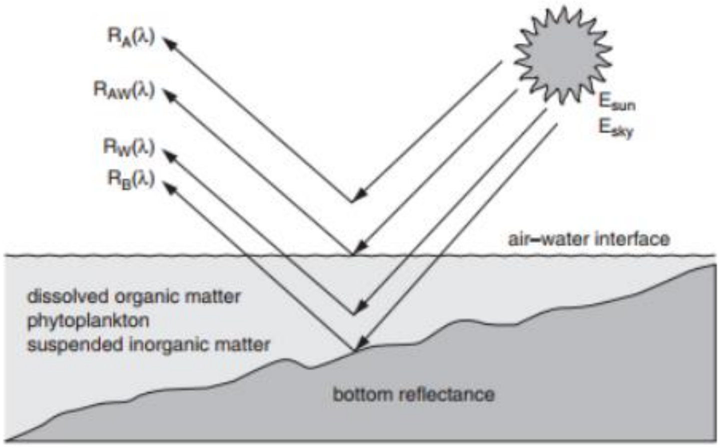


Fig. 18.2 Interaction of incident solar radiation within a water body (*Source:* Bukata et al., 1995)

Measurements from satellite remote sensing provide a means of observing and quantifying land and hydrological variables over geographic space and support their temporal description. Remote sensing instruments capture upwelling electromagnetic radiation from earth surface features which is either reflected or emitted. The former is reflected solar radiation and the latter is in thermal infrared and microwave portions of electro-magnetic spectrum. The thermal emission in the infrared is used for surface temperature, energy fluxes and microwave for soil moisture, snow and glacier, flood, etc.

Remote sensing has several advantages over field measurements. First, measurements derived from remote sensing are objective; they are not based on opinions. Second, the information is collected in a systematic way which allows time-series and comparison between schemes. Third, remote sensing covers a wide area such as entire river basins. Ground studies are often confined to a small pilot area because of the expense and logistical constraints. Fourth, information can be aggregated to give a bulk representation, or disaggregated to very fine scales to provide more detailed and explanatory information related to spatial uniformity. Fifth, information can be spatially represented through geographic information systems, revealing information that is often not apparent when information is provided in tabular form.

Earth Observation Satellite (EOS) data has been extensively used to map surface water bodies, monitor their spread and estimate the volume of water. The SWIR band of IRS-P6 is found to be useful in better discrimination of snow and cloud, besides delineating the transition zone and patch snow covered areas. Snowmelt runoff forecasts are being made using IRS-WiFS and NOAA/AVHRR data. Monitoring reservoir spread through seasons has helped to assess the storage loss due to sedimentation, updating of rule curves. Satellite data derived spatial and temporal information on cropping pattern, crop intensity and condition forms basic inputs for developing indicators for agricultural performance of the irrigation systems and bench marking of systems. Satellite data derived geological and hydro-geomorphologic features assist in prospecting the ground water resources to plan aquifer recharging, water harvesting and drinking water sources. High resolution satellite data remarkably augmented the remote sensing services extending it to infrastructure planning & management.

The overall applications of geospatial technologies in water resources management can be broadly categorized into the following: a) Water resource assessment, b) Water resources planning and development, c) Water resources demand and utilisation, d) Water resources monitoring and evaluation, e) Watershed management, f) Hydrological extremes, g) Hydrological and hydraulic modelling, h) Advanced applications and i) Water resources informatics.

8.2 Water Resources Assessment

8.2.1 Cryosphere

The term "cryosphere" traces its origins to the Greek word 'kryos' means frost or ice cold. The cryosphere is part of the Earth's climate system that includes solid precipitation, snow, glaciers and ice caps, ice sheets, ice shelves, sea ice, lake and river ice, icebergs, permafrost, and seasonally frozen ground. The occurrence and distribution of cryosphere depend predominantly on temperature, precipitation, and wind. In general, the temperature decreases with latitude and altitude, while precipitation decreases with increasing continentality. The cryospheric components like snow and glaciers form large sources of fresh water for millions of people particularly in mountainous region like Himalaya.

i. Snow cover mapping

Terrestrial snow is the second largest geographic extent of the cryosphere components. It covers nearly 50 million km^2 of the northern hemisphere in winter. The snow accumulates during winter months of October to February and melts during summer months of March to June providing fresh source of water for domestics, industrial, irrigation and hydropower requirements. The mapping and monitoring of snow cover over highly rugged and inhospitable terrain is difficult, time consuming and cost ineffective through traditional surveys. Satellite remote sensing has proven as a useful tool for snow cover mapping and monitoring of vast and in accessible areas such as Himalaya (Negi et. al, 2009). The snow cover extent can be mapped using optical and microwave remote sensing data. The snow cover appears bright white due to high reflectance of snow in visible region of electromagnetic spectrum but sometimes presence of cloud cover can also provide similar reflectance in visible region. Snow and cloud can be differentiated in Shortwave Infrared (SWIR) region due to high absorption and high reflectance characteristics correspondingly. National Remote Sensing Centre

(NRSC) of Indian Space Research Organisation (ISRO) has been mapping and monitoring snow cover extent for entire Himalaya on daily basis using Suomi-NPP VIIRS satellite data from 2015 onwards and web published on Bhuvan NHP portal (*https://bhuvan.nrsc.gov.in/nhp/webgis-snow/map*). In addition, NRSC also monitors snow cover over Himalaya using Resourcesat-2 satellite data on fortnightly basis from 2012 onwards (Fig. 8.3). Table 8.1 shows some satellite and sensors operationally used for snow cover mapping and monitoring.

Table 8.1: Some satellite and sensors operationally used for snow cover mapping and monitoring.

S. No.	Satellite / Sensor	Remarks
1	NOAA/AVHRR, Terra, AQUA/MODIS, SUOMI-NPP/ VIIRS	Global and regional level snow cover mapping on daily basis
2	Resourcesat -1/2/2A / AWiFS	Regional and basin level snow cover mapping on five-day basis
3	Resourcesat -1/2/2A / LISS-III, Landsat-TM/ETM/ETM+/OLI, Sentinel-2A/2B / MSI	Basin and sub-basin level snow cover mapping

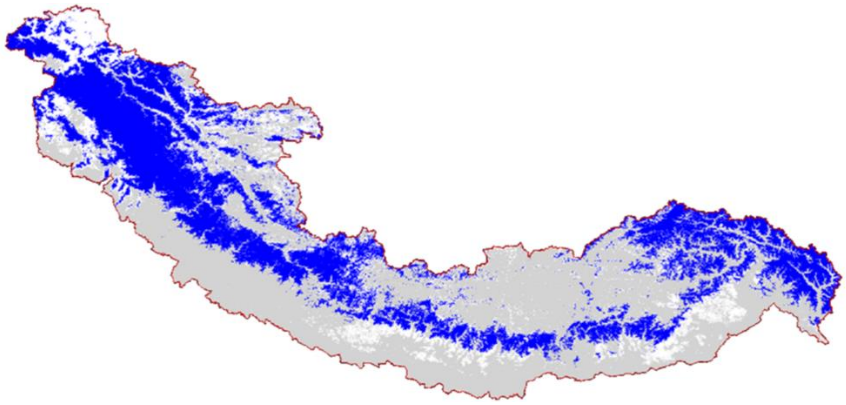


Fig. 8.3 Typical Snow Cover over Himalayas derived from Resourcesat-2 satellite data

ii. Snow parameters retrieval

Data from the visible, near-infrared, shortwave-infrared and microwave portions of the electromagnetic spectrum have been useful for measuring different properties of snow. Visible portion has potential to determine the snow cover extent and albedo of snow cover. Most of the variability in snow reflectance occurs beyond 0.8 µm rather than in the visible spectrum. In these wavelengths, reflectance decreases dramatically as snow grains evolve and grow, whereas in the visible spectrum, snow reflectance is degraded by contaminants such as dust, algae and soot (O'Brien and Munis, 1975; Warren and Wiscombe, 1980). Grain size of snow in the surface layer can be estimated, and thereby derive spectral and broadband albedo.

In the microwave region of the spectrum (300 to 1 GHz, or 1 mm to 30 cm wavelength), remote sensing can be accomplished either by measuring emitted radiation with a radiometer or by measuring the intensity of the return of a signal sent by a radar. Microwave emission from a layer of snow over a ground surface consists of contributions from the snow itself and from the underlying ground. Both contributions are governed by the transmission and reflection properties of the air-snow and snow-ground interfaces, and by the absorption/emission and scattering properties of the snow layer. Passive microwave data available since the 1970 have been utilised for measuring snow extent, snow depth and snow water equivalent though at a coarse spatial resolution while active microwave sensors provide at a higher spatial resolution. Active microwave sensors like scatterometer also provide valuable information on snowpack status (dry/wet).

iii. Inventory of glaciers, glacial mass balance and glacial retreat

Glaciers are one of the most important components of the cryosphere, and they play a critical role in regulating global climate and providing freshwater resources to many regions of the world. Understanding the dynamics of glaciers and their response to changing climate conditions is essential for predicting future freshwater availability. In this context, the inventory of glaciers, glacial mass balance, and glacial retreat are critical components of ongoing climate research, which can be investigated by utilizing remote sensing data. Satellite remote sensing data has proven to be an invaluable tool in monitoring the glaciers. This technology allows researchers to gather crucial information about the glaciers, such as size, location, elevation, glacial retreat, etc. which are mostly inaccessible.

Global Land Ice Measurements from Space (GLIMS) project is a comprehensive effort to inventory world's glaciers using satellite imagery. GLIMS (Kargel et al., 2005) database provides detailed information on glacier extent, volume, and velocity, as well as changes in these parameters over time. Randolph Glacier Inventory (RGI) is another global inventory of glacier outlines. It is supplemental to the GLIMS initiative. As all these data are incorporated into the GLIMS Glacier Database and as download tools are developed to obtain GLIMS data in the RGI data format, the RGI has evolved into a downloadable subset of GLIMS, offering complete one-time coverage, version control, and a standard set of attributes. Another important inventory by the International Centre for Integrated Mountain Development (ICIMOD) is the regional glacier inventory, which provides information on the location, extent, and characteristics of glaciers in the Hindu-Kush-Himalayan region (Maharjan et al. 2018). The glacier inventories are an important resource for researchers, policymakers, and stakeholders who are interested in studying the impacts of climate change on Himalayan glaciers and water resources. Fig. 8.4 shows the Gangotri Glacier, Ganga Basin as seen on RS2-LISS IV satellite pass on October 22, 2016.

Fig. 8.4 Gangotri Glacier, Ganga Basin as seen on RS2-LISS IV satellite pass on October 22, 2016

Glacial mass balance refers to the difference between the amount of snow and ice that accumulates on a glacier each year (accumulation) and the amount of snow and ice that is lost through melting, evaporation, and calving (ablation). Glacial mass balance is a critical indicator of the health of a glacier and its response to changing climate conditions. A negative mass balance is a clear sign that a glacier is shrinking, while a positive mass balance indicates that a glacier is growing. Rising temperatures, changes in precipitation patterns, and their combination can lead to loss of glacial mass and shrinkage in size over time known as a glacial retreat. Glacial retreat is a significant contributor to sea level rise, and it has significant implications for freshwater availability in many regions of the world. One of the most well-known examples of glacial retreat is the ongoing loss of ice in the Arctic and Antarctic regions. Greenland Ice Sheet, for example, has been losing ice at an accelerating rate in recent years, contributing significantly to global sea level rise. Glacial retreat is also having significant impacts on freshwater availability in many regions, including the Himalayas and the Andes.

iv. Mapping and monitoring of glacial lakes

Mapping and monitoring of glacial lakes are a critical component of climate research, as these lakes are often formed as a result of melting glaciers and can pose significant hazards to downstream communities if they breach their natural dams. One of the most well-known examples of the hazards associated with glacial lakes is the potential for glacial lake outburst floods (GLOFs) (NRSC, 2020; NRSC, 2022). GLOFs occur when the natural dam that holds a glacial lake in place suddenly breaches, releasing a large amount of water downstream. These floods can cause significant damage to infrastructure, agriculture, and communities, and they can also have long-term impacts on the ecology and hydrology of the affected regions.

One of the most comprehensive efforts in mapping glacial lakes in the Indian Himalaya is carried out by NRSC under National Hydrology Project (NHP) (Fig 8.5). The effort focused on developing an inventory of glacial lakes using high-resolution satellite imagery. A total of 28,043 glacial lakes have been mapped in the Indian Himalayan River basins using a total of 397 high-resolution multispectral RS-2 LISS-IV images, with a total lake water spread area of 1,31,070 ha. Glacial lakes are predominantly distributed in the Brahmaputra basin (18,001) followed by the Indus basin (5,335) and Ganga basin (4,707). The database contains 22 attributes for each glacial lake and provides detailed information on the geographical, hydrological, geometrical, and topographical characteristics of glacial lakes. Using above glacial lake database, Glacial Atlas of all three river basins (Indus, Ganga and Brahmaputra) and entire Indian Himalayan River Basins has been prepared and web hosted (*https://www.nrsc.gov.in/Atlas_Glacial_Lake*). The atlases present the details of glacial lakes in terms of area, type and elevation and administrative unit wise (Simhadri Rao et al., 2023; Simhadri Rao et al., 2022; Simhadri Rao et al., 2021; Simhadri Rao et al., 2020).

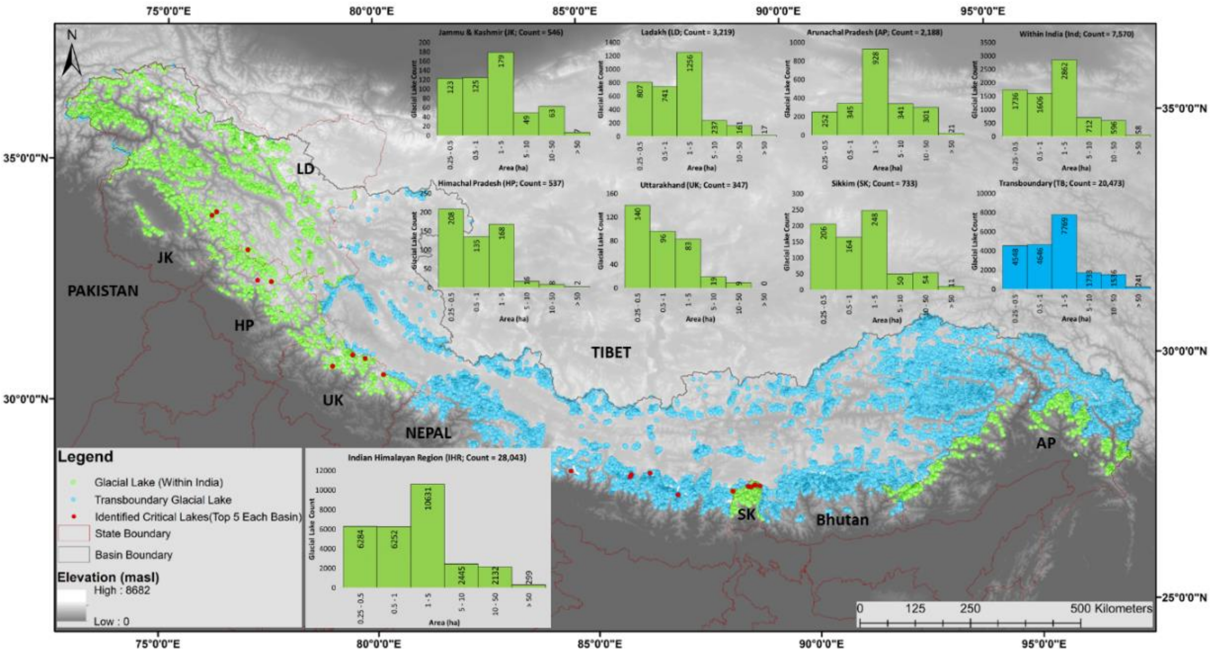


Fig. 8.5 A comprehensive glacial lake inventory prepared for entire Indian Himalayas using high-resolution satellite data

8.2.2 Surface Water

i. Surface Water Bodies

Temporal fluctuations in water resources occur in different seasons of the year, with great variations in water spread area of water bodies during monsoon to summer. Capturing these variations and systematic inventorying on regular basis is operationally difficult task through conventional techniques. However, with the availability of satellite data at multiple spatial resolutions and at regular time intervals, surface water bodies can be mapped and monitored in terms of their occurrence and spatial extent. Generation of such information has many field level applications and provides continuous audit of surface water resources over space and time. The typical spectral response of water facilitates its accurate identification and delineation on remotely sensed images. The time series data provides a record of climate change impact on these storages. In recent years, several advances have been made in this field. For example, new algorithms have been developed to improve the accuracy of water extent mapping using satellite data. Machine learning (Acharya et. al., 2019) and deep learning techniques (Wang et. al., 2020) are also being used to better differentiate between different water types and to identify changes in water levels over time. Additionally, the development of higher-resolution sensors has enabled more detailed mapping of small water bodies (Lu et. al., 2022). NRSC initiated a major effort in mapping surface water bodies at national level through development of automatic feature extraction techniques using multi-spectral data from multi-date IRS LISS-III/AWiFS data sets (Sureshbabu et al., 2008) and other foreign satellites such as Landsat-8, Sentinel-1, 2 (Kadapala et al., 2023) etc. for developing a Water Bodies Information System (Fig. 8.6). This application helps in mapping and monitoring of waterbodies in near real time using multiple satellites.

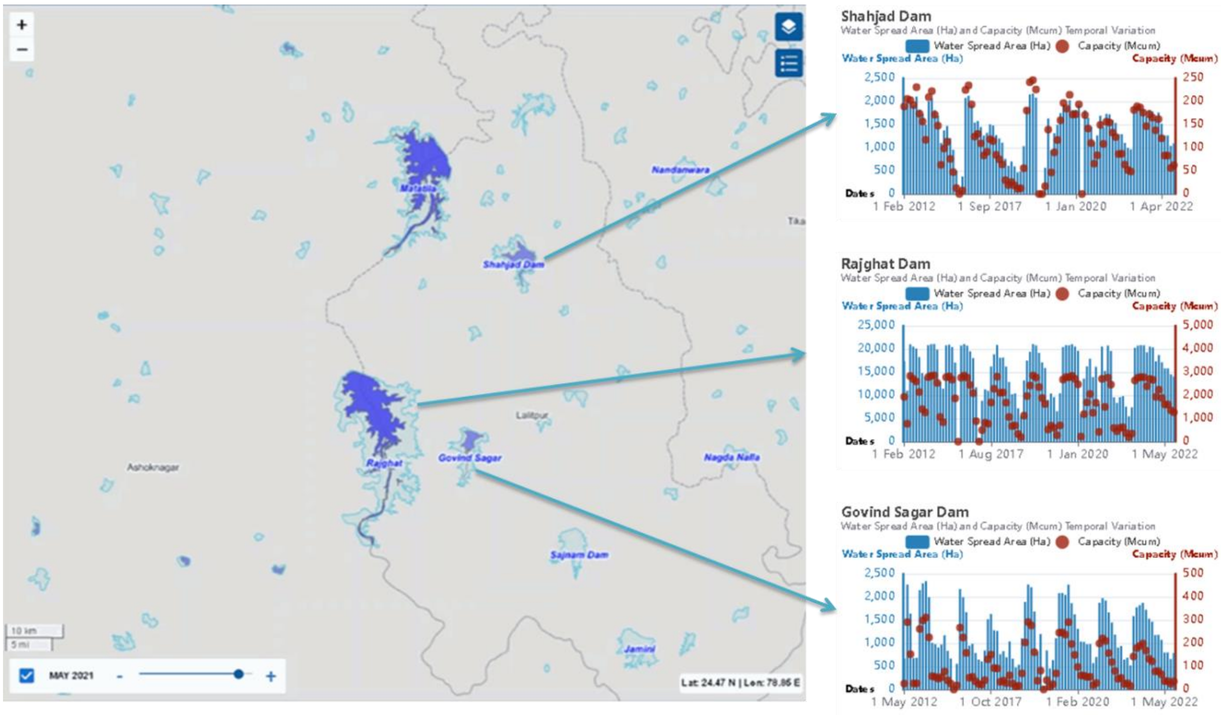


Fig. 8.6 Water Bodies Information System (WBIS)

ii. Wetlands Mapping

Vegetation laden swamps and wetlands form important constituents of natural ecosystems. Remote sensing has been recognized as a powerful, rapid, simple, and practical technique for accurate and exact change detection, mapping, and monitoring of wetland inventories for many years. Both reflective and thermal infrared images are used extensively to map and monitor these water bodies. Different classification methods have been used to determine wetland classes e.g., Kesikoglu et al. (2019) used a multi-temporal ASTER image to classify marsh wetlands and found that the support vector machine (SVM) method was statistically more successful in classification. Mizuochi et al. (2014) determined surface water distribution through the use of modified normalized difference water index and normalized difference polarization indices created using MODIS and AMSR-E data, respectively. Lin et al. (2019) used methods including conditional maximum entropy regression, scaled conjugate gradient multilayer perceptron, SVM, and convolutional neural network (CNN) methods to classify four different wetland areas. Mahdavi et al. (2019) determined five different types of wetlands using synthetic aperture radar and optical images.

8.2.3 Water Availability Assessment

i. Rainfall-runoff

Rainfall-runoff modelling is a type of hydrological modelling that simulates the movement of water from rainfall to streamflow in a river basin. It involves the use of mathematical models and data to estimate how much runoff will be generated by a given rainfall event in a particular location. The goal of this modelling is to provide a better understanding of the hydrological processes that govern the availability and distribution of water resources. These models may be based on a variety of data sources, including meteorological data, land use/ land cover, digital elevation models, etc. of the landscape. Several types of rainfall-runoff models are available e.g., i) Empirical models based on statistical relationships between rainfall and runoff such as SCS-CN (Soil Conservation Service - Curve

Number) (Mishra et al., 2003) model, and the Rational Method; ii) Conceptual models based on simplified representations of the hydrological cycle such as SAC-SMA (Sacramento Soil Moisture Accounting) model; iii) Distributed models which divide catchment into sub-catchments and simulate runoff for each of them separately such as SWAT (Soil and Water Assessment Tool) model and the MIKE SHE (Semi-distributed Hydrological Model) model); and iv) Physically-based models (simulates runoff by representing the physical processes that control the hydrological cycle, such as evapotranspiration, infiltration, and flow routing such as VIC (Variable Infiltration Capacity) and the MODFLOW (Modular Three-Dimensional Ground-Water Flow Model) model).

ii. Snowmelt runoff

Himalaya are the source of huge quantity of fresh water stored in the form of vast tracts of seasonal snow and large number of glaciers. The snow which accumulates during winter months starts melting during summer months providing fresh source of water for multiple purposes for millions of people living in Himalayan region (Immerzeel et al., 2009). The seasonal snowmelt is significantly influenced by changes in atmospheric temperature and it can influence the distribution of stream runoff (Kulkarni et al., 2010). It is critical to know the expected quantity of snowmelt water into the reservoirs for effective planning and management of reservoirs. In general, snowmelt runoff models can be divided into two types of models, namely energy balance models and index models. Index models use one or more variables in an empirical expression to estimate snow cover energy exchange. Air temperature is the most commonly used index. The degree-day index method is more popular because temperature represents reasonably the energy flux and at the same time, it is relatively an easy parameter to measure, extrapolate and probably to forecast. Energy balance models require the information on radiant energy, sensible and latent heat, energy transferred through the rainfall over the snow and heat conduction from ground to the snow pack. Temperature index models are most widely used due to minimal inputs required for estimating the snowmelt runoff. Snowmelt Runoff Model (SRM), HEC-Hydrologic Modelling system (HEC-HMS), HBV, etc. are some of the temperature index-based models used for estimation of snowmelt runoff. Snow cover Energy and Mass Balance Model (ISNOBAL), Precipitation-Runoff Modelling system (PRMS), Utah Energy Balance Snow Accumulation and Melt Model (UEB), etc. are some the energy balance approach-based snowmelt runoff models.

8.2.4 Water Quality Assessment

Water quality is a relative term which is largely defined by physical, chemical, and biological characteristics of the water. Physical parameters such as temperature, colour, odour, taste, turbidity, electrical conductivity, turbidity, total suspended solids (TSS), and total dissolved solids (TDS); chemical parameters such as pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), nitrate, heavy metals; and biological parameters such as coliform bacteria and E coli determine quality of water. Though quality is a relative term, parameters defining quality do not change. It is the desirable range of the parameters as well as their priority which changes depending on the expected use of water.

i. Suspended solids

Suspended solids are primarily responsible for turbidity in a water body and therefore are majorly responsible for increase in backscatter in red and NIR region when present in significant amount. Fig.

18.7 shows the effect of increasing suspended solids in water body on water spectra given by Jensen et al. (2000).

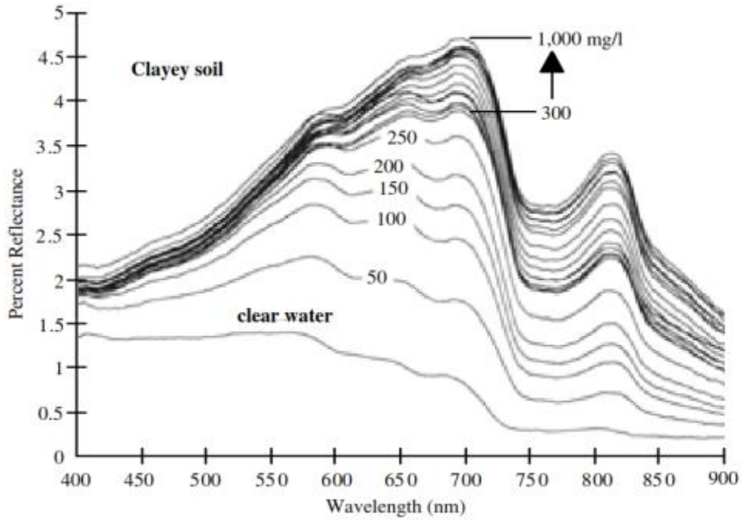


Fig. 18.7 Spectral response from a water sample on increasing sediment concentration (Source: Jensen et al., 2007)

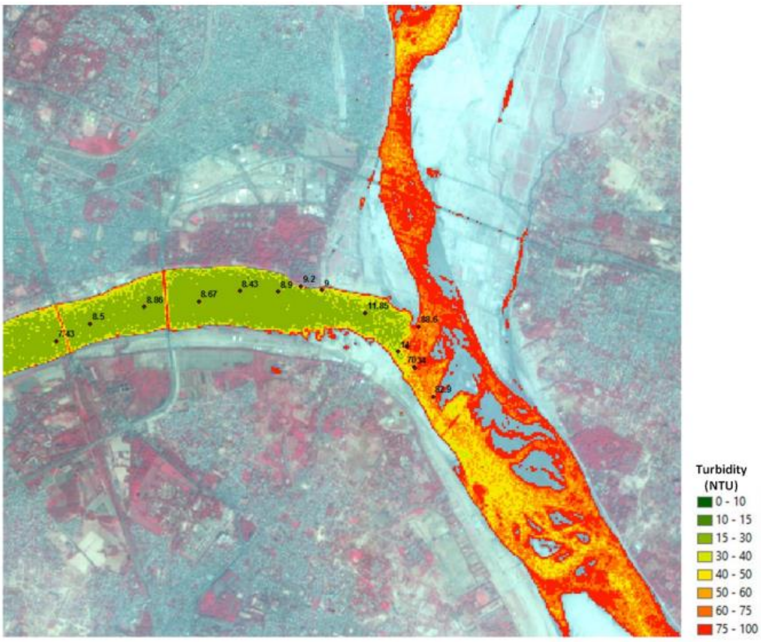


Fig. 8.8 Variation in turbidity in rover Ganga near Paraygraj Sangam on December 05, 2018 mapped using Sentinle-2 data (Source: NRSC Technical Report, 2019)

Suspended solids in a water body include silt and clay particles coming from upland agriculture cropland erosion, weathering of mountainous terrain and shoreline erosion, plankton and other organic particles. Suspended particles are responsible for turbidity of water as they interfere light passage and are responsible for scattering of light (Hajigholizadeh et al., 2016). Turbidity of natural waters tends to increase during runoff events as a result of increased overland flow and erosion. Remote sensing is widely used to estimate and map the turbidity and total suspended solids concentration, and to provide their spatial and temporal variations. An increase in the amount of suspended solid in a water body results in higher reflectance in the red region. Ruddick et al. (2008) showed that most of the algorithms for quantification of total suspended solids from water leaving radiance fall roughly into one of three families, namely, single band, band ratio, and multispectral regression relations. Easiest estimation of TSS is obtained when suspended solids in a region can be correlated with the remote sensing reflectance in any of the available band. Doxaran et al. (2002) suggested use of band ratio for estimation of TSS. Band ratios are less sensitive to uncertainties arising from other factors such as bottom reflectance, absorption/scattering by other impurities in water. Band ratios are less sensitive to illumination conditions. Generally, regression models are developed based on band ratio of reflectance from a particular sensor for estimating TSS concentrations. NRSC Technical Report (2019) demonstrated the use of band difference of Red-edge (704 nm) and green band (560 nm) in mapping turbidity of river Ganga in Prayagraj as shown in Fig. 8.8.

ii. Chlorophyll-a

Chlorophyll-a is an essential pigment for photosynthesis in phytoplankton and other lower plant forms such as algal fungi. Measure of Chlorophyll-a in water body is an indicator of trophic state of a water body (Hajigholizadeh et al., 2016). Trophic state is defined as the total weights of biomass present in a water body. It is the biological response for nutrient additions to the water bodies. Chlorophyll introduced to a pure water body changes its spectral characteristics. If phytoplankton and algae consisting primarily of chlorophyll-a is present, strong absorption of blue light between 400- 500 nm is observed. Strong absorption of radiation is also observed around 675 nm. Local maximum of reflectance is observed around 550 nm and 700 nm which is caused by relatively lower absorption of green light and light in red-edge region. Remote sensing is a useful tool in assessing the trophic state of water body. Often algae present in water body may contain a composition of different pigments. These pigments can also be detected using remote sensing.

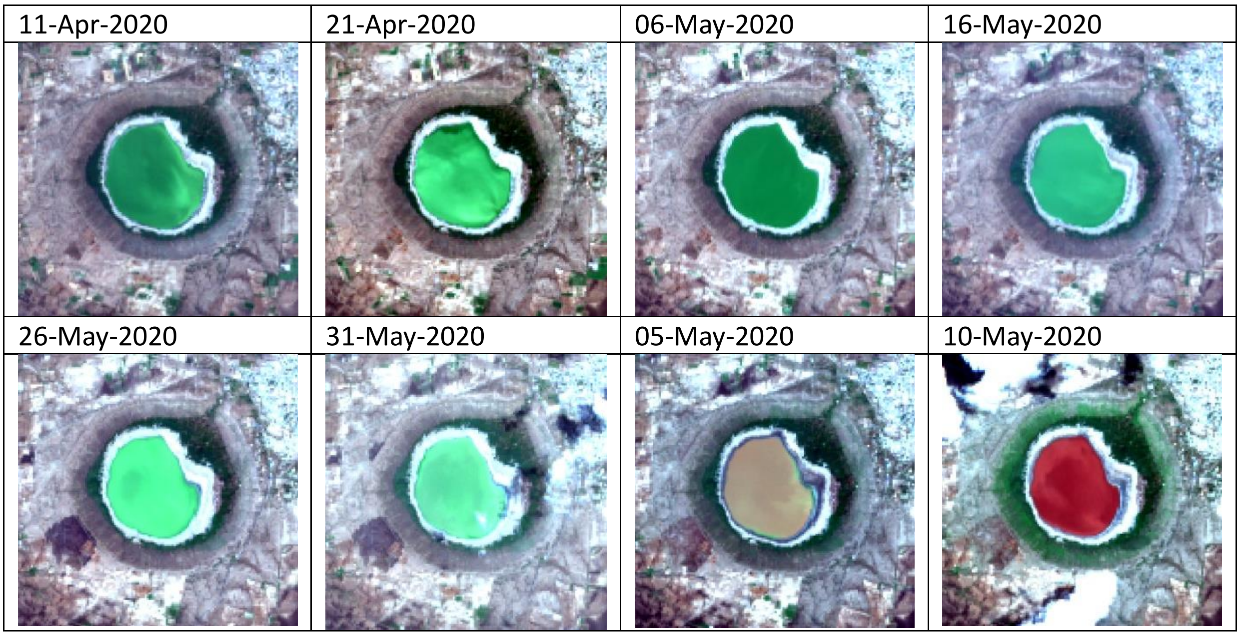


Fig. 8.9 Dynamics of colour change of Lonar Lake shown in MSI/ Sentinel-2 data during April-June 2020.

Mishra et al. (2021) showed utility of remote sensing in capturing various pigments in algae present in Lonar Lake in Maharashtra. Using data of Sentinel-2 and Landsat-8, the dynamics of colour change of

Lonar crater lake was assessed in finding out the days when Lonar lake had changed its colour (Fig. 8.9 and 8.10). The colour change event was attributed to change in dominant pigment of algae from chlorophyll-a (green) to phycoerythrin (pinkish red). A green-red band difference index was used to find out events of colour change during 2014-2020. The positive value of Normalized Difference Red Green Index indicated days when Lonar Lake would have appeared pinking Red and negative value indicate days when lake would have appeared green.

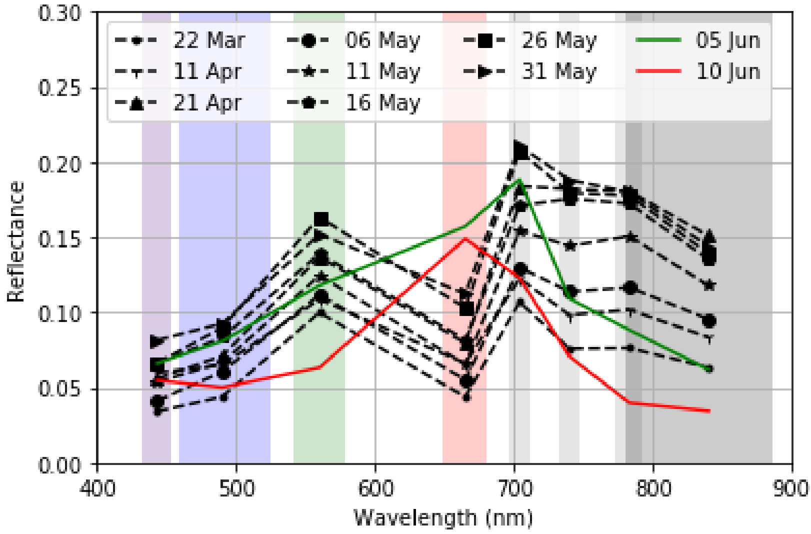


Fig. 8.10 Spectra of Lonar Lake derived using MSI/Sentinel-2 data during April-June 2020

8.2.5 Groundwater Prospecting

Annually replenishable ground water in India is estimated to be 433 billion cubic metres (BCM) and net ground water available for irrigation is 399 BCM and net draft for irrigation is 213 BCM. Ground Water constitutes 55% of irrigation water requirement and 50% of water supplies of urban and industrial areas and 85% of domestic use in rural areas. The above statistics reveal that the ground water management is the key to combat the emerging problems of water scarcity in India. Ground Water Prospects maps were prepared under Rajiv Gandhi National Drinking Water Mission (RGNDWM) project containing information on 1:50,000 scale on different rock types and various landforms that represent the terrain, dykes, linear ridges which form the barriers for ground water movement; weaker zones like fractures/lineaments which act as conduits for ground water movements, etc. The maps also contain hydrological details like all stream courses, canals, water bodies (both seasonal and perennial), tank/canal irrigated areas and ground water irrigated areas, etc. These maps provide comprehensive information on ground water prospects indicating depth to water table, nature of aquifer, type of wells suitable, depth range of well suggested, expected yield range, success rate of wells, quality of water, type of recharge structures suitable and priority for recharge etc. with exhaustive legend. More than 2,00,000 wells have been drilled with a success rate ranging from 90-95% and around 7500 recharge structures have been planned/ implemented by the line departments using hydro-geomorphologic maps prepared using satellite data and collateral information under this Project. Till now 10 states, namely, Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Chhattisgarh, Rajasthan, Jharkhand, Himachal Pradesh, Orissa and Gujarat are covered under Phase-I & II. This project has successfully demonstrated the application of space technology for addressing the grass root level problem in the country and user departments are using these maps for last three years and achieved 90% success rate.

8.3 Water Resources Demand and Utilisation

8.3.1 Irrigation Water Requirement

Irrigation is the controlled artificial application of water to croplands to supplement the natural precipitation. Irrigation not only provides the optimal soil moisture environment for crop growth but also meets the other needs required for growing the crop. Therefore, the Irrigation Water Requirement (IWR) is defined as the total quantity of water required by a crop during a given period of time for its normal growth and development under field conditions. The irrigation water requirement includes irrigation required to meet the losses due to evapotranspiration (ET), the losses during the application of irrigation water (unavoidable losses) and the additional quantity of water required for special operations such as land preparation, transplanting, leaching of salts below the crop root zone, frost control etc. It is expressed in depth per unit time.

$$\mathbf{IWR = ET + \Delta S - ER - GWC + OR} \tag{1}$$

where, IWR is irrigation water requirement, ET is evapotranspiration, ΔS is change in soil moisture, ER is effective rainfall, GWC is ground water contribution and OR is other requirements. The major component of the IWR during the cropping period is the evapotranspiration. Recent advances in remote sensing and geospatial technologies are useful in estimating the evapotranspiration spatially.

8.3.2 Evapotranspiration

Evapotranspiration (ET), defined as the combined loss of water to the atmosphere from the vegetation through transpiration, soil and water bodies through evaporation. Evapotranspiration enables the transfer of moisture and energy from the biosphere and hydrosphere to the atmosphere. Accurate knowledge of spatially distributed ET is essential for a wide range of applications including water resources management, hydro-meteorological predictions and ecological applications (Zhu et al., 2017; Corbari et al., 2015; Anderson et al., 2012). Different types of in-situ instruments are used to measure ET which includes Lysimeter that estimates ET over a spatial scale of few m^2 and eddy covariance flux towers ranging between ~10-1000 m^2. However, for operational estimation of ET at a regional scale, methodologies using remote sensing technology provide a reliable alternative (Price, 1990). Estimation of ET using the remote sensing technique uses the various geophysical and biophysical parameters derived from the satellite data. The remote sensing enables estimation of ET over a large spatial scale, at frequent time interval with reliable accuracy levels acceptable for several applications (Biggs, 2015). As a result, a large number of ET models have been developed from remote sensing observations over the past few decades. Overviews of these models have been provided by a number of authors (Kustas et al., 1996; Kalma et al., 2008; Glen et al., 2007; Li et al., 2009). ET was estimated over India as a function of net available energy and evaporative fraction within a single-source energy balance framework (Bhattacharya et al., 2010; Nigam et al., 2021). Fig. 18.11 shows the mean monthly actual evapotranspiration during March 2022. The main drivers for this process are i) solar energy, ii) vapour pressure gradient between the evaporating surface and the atmosphere and iii) resistance that the land cover offers to the process. The entire process of evapotranspiration can be defined as the residual of the energy balance for the land surfaces.

$$\mathbf{\lambda E = R_n - G - H} \tag{2}$$

Where,

λE is the latent heat flux (W/m^2), R_n is the net radiation (W/m^2), G is the soil heat flux (W/m^2) and H is the sensible heat flux (W/m^2).

ET is derived at 750 m spatial resolution at a daily time interval over the entire Indian sub-continent using NPP-Suomi data (Chandrasekar et al., 2022). The Priestley-Taylor algorithm has been used to estimate the latent heat flux under saturated surface conditions of minimal advection (λE_{PT}).

$$\boldsymbol{\lambda E_{PT} = \alpha \left[\frac{\Delta}{(\Delta+\gamma)}\right] (R_n - G)} \quad \textbf{(3)}$$

Where,

λET_{PT} is the latent heat flux, α is the Priestley-Taylor parameter, Δ is the slope of the saturation vapour pressure curve, γ is the psychrometric constant, R_n is net radiation and G is the surface soil heat flux.

Under the saturated soil moisture conditions, the Priestley-Taylor coefficient (α) takes a value of 1.26 (Ai & Yang, 2016; Priestley & Taylor, 1972; Parlange & Katul, 1992). However, several studies have indicated α varies over the whole growing season for different crops and soil moisture conditions. The Priestley-Taylor coefficient α is replaced by a coefficient α_e which accounts for a wide range of aerodynamic and crop resistance (Jiang & Islam, 2001; Kalma, et al., 2008). Using the scatter of LST and NDVI, under the full ranges of soil moisture availability and varied vegetation cover, α_e is derived. After incorporation of the Priestley-Taylor parameter (α_e) the equation 4 will be

$$\boldsymbol{\lambda ET_{PT} = \alpha_e \left(\frac{\Delta}{(\Delta+\gamma)}\right) (Rn - G)} \quad \textbf{(4)}$$

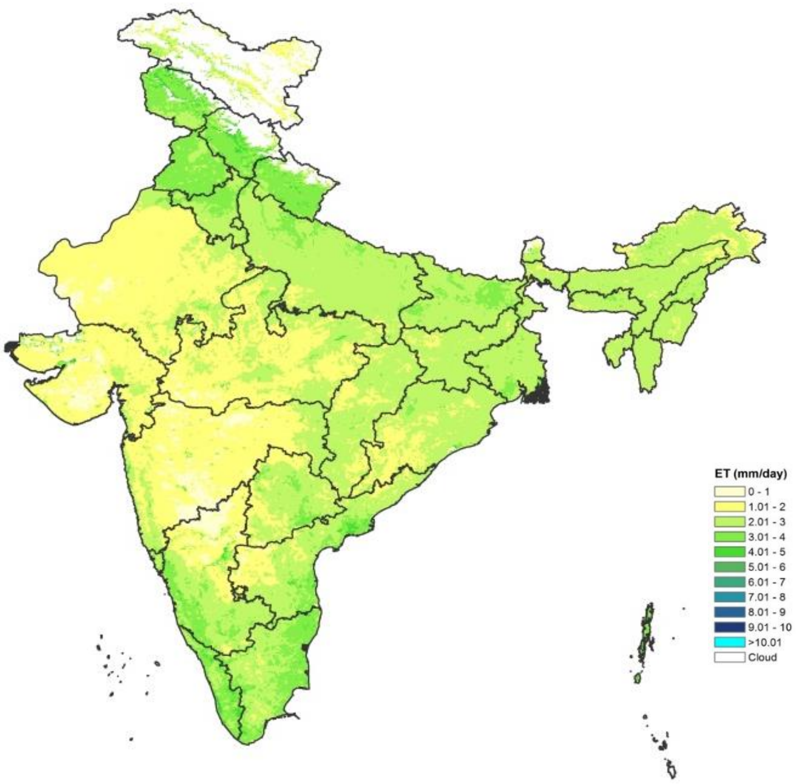


Fig. 18.11 Mean monthly actual evapotranspiration during March 2022

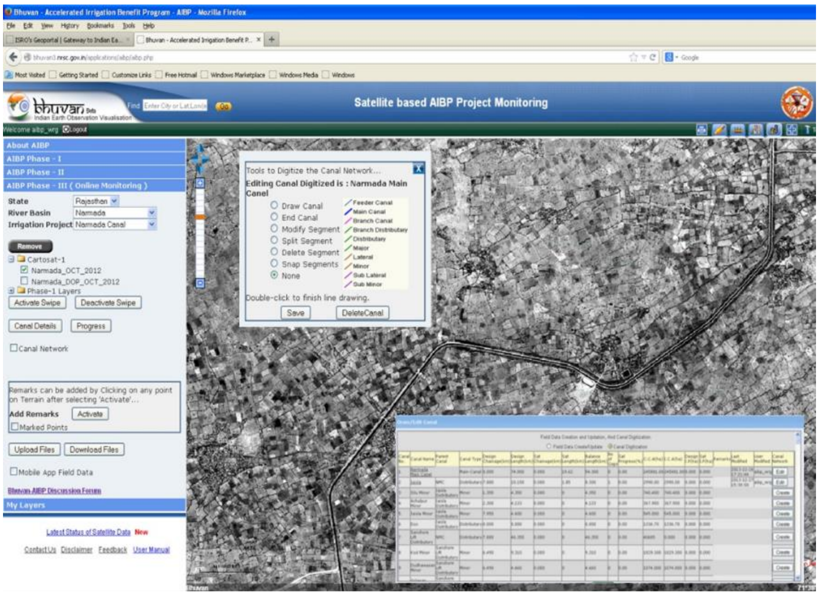
8.4 Water Resources Monitoring and Evaluation

8.4.1 Irrigation Systems

Investment and development of irrigation infrastructure has been long and continued priority in India. In 1950-1951, the net irrigated area in India was 21 million ha and as a result of sustained efforts, this expanded to close to 100 million ha by 2006 (MoWR, GoI). The role of irrigation in India in expanding crop production, reducing output instability and providing protection against periodic drought has been a major factor in the substantial achievement of Indian agriculture over the past four decades.

8.4.2 Irrigation Infrastructure Mapping and Monitoring

Mapping and monitoring of the physical progress of irrigation infrastructure through satellite data is one of the finest examples of application of remote sensing in the field of irrigation engineering. Government of India initiated Accelerated Irrigation Benefit Program (AIBP) under Bharat Nirman during 1996-97, with the aim to provide financial assistance to State Governments for expediting the completion of ongoing irrigation projects and improving the performance of existing irrigation systems by modernisation to bridge the gap between potential created and utilised.



AIBP monitoring web page: http://bhuvan3.nrsc.gov.in/applications/aibp/aibphome/aibp.html

Fig. 18.12 Satellite based AIBP project monitoring through Bhuvan services

NRSC has developed a methodology for mapping and monitoring of irrigation infrastructure using high resolution satellite data by time stamping the completion status of irrigation infrastructure. Spatial information on canal lengths and their offtake chainages along with irrigation and cross-drainage structures were mapped and monitored using satellite data for identification of critical gaps in irrigation infrastructure and prioritisation of works. It supplements the existing monitoring mechanism of Central Water Commission (CWC) by providing authentic and objective data base on existing irrigation infrastructure with a viable cost. NRSC had successfully operationalised the activity of mapping and monitoring of irrigation infrastructure by executing 103 AIBP projects for CWC in two phases during 2007-09 and 2011-2012 (NRSC, 2010). The high-resolution satellite data from Indian satellite sensors (Cartosat-1 & Cartosat-2) were extensively used for this activity. Further, NRSC had demonstrated facility of satellite based online monitoring of AIBP projects using Bhuvan services (Fig. 18.12) (*https://bhuvan-app1.nrsc.gov.in/aibp/aibphome/aibp.html*)

8.4.3 Irrigation Potential Creation and Utilisation Assessment

Government of India launched the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) during 2015 with the motto of 'Har Khet Ko Pani' ensuring access to some means of protective irrigation to all agricultural farms in the country, to produce 'per drop more crop', thus bringing much desired rural prosperity. The ongoing programmes as being implemented by the Government of India, viz., AIBP; Repair, Renovation and Restoration (RRR) of Water bodies and Command Area Development and Water Management (CADWM) have been subsumed in Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR, RD&GR) identified 99 priority projects from amongst the 149 ongoing projects under AIBP for early completion.

8.4.4 Inventory and Monitoring of Command Areas

Mapping of cropping pattern and crop condition assessment using remote sensing data was carried out as early as during early 1990s after the successful launch of first Indian Remote Sensing (IRS) satellite IRS-1A in 1988. Mapping of crops in irrigation command area has since been carried out (Nageswara Rao and Mohankumar, 1990) using multi-spectral optical remote sensing data (Panigrahy and Sharma, 1997; Sai and Narasimha Rao, 2008) and using microwave data (Saindranath et al., 2000, Chakraborty et al., 1997). Murthy et al. (2003) used advanced classifiers like ANN back-propagation technique for classification of irrigated crops. Crop yield has been estimated for cereal crops like paddy (Murthy, et al., 1996) and wheat (Patel, et al., 2006). NDVI was also used for ground sampling of crop cutting experiment in irrigation system (Murthy et al., 1996). NRSC has executed various command area projects under National Water Management Project (NWMP) and Water Resources Consolidation Project (WRCP). In addition to the above, NRSC has also executed several projects (28) for various State Irrigation and Command Area Departments. High resolution satellite images were used in crop inventory of command area of minor irrigation tanks across the country (**Error! Reference source not found.**).

Fig. 8.13 Cropping pattern and LULC of Nanjur tank cascade, Tamil Nadu during 2003

8.4.5 In-Season Inputs for Irrigation Water Distribution

Seasonal irrigation releases in any irrigation system depend on the command area's cropping pattern. In India, cropping patterns and crop calendars are designed for every irrigation system during its planning stage for sustainable system performance. However, due to the variation in the cropping pattern and staggering of the crop calendar, the irrigation system fails to attain the expected productivity due to over-irrigation or shortage of water. With its temporal coverage, satellite data can provide information on the cropping pattern through the season within an irrigation system. The crop type maps for an irrigation system were generated periodically by classification of multispectral data (NRSC, 2022). The dynamic information on the agricultural land cover through the season is used in a distributed soil water balance model developed in the Versatile Soil Moisture Balance (VSMB) framework (Baier, 1969). The VSMB model simulations for Near Real Time (NRT) and forecasted weather are used for estimating the irrigation requirement for the non-paddy crops at a daily time step. For paddy crops, the irrigation requirement was computed by FAO-specified norms (Allen et al., 1998) that include maintenance of fixed standing water depth in the field at a daily scale and provision for deep percolation of 2- 5 mm/day. Deep percolation losses are assumed to depend on the field's standing water depth. Irrigation requirements for the field preparation stage during the transplantation of paddy crops also need to be considered. The irrigation requirement estimates at the pixel level are aggregated spatially to which conveyance and application losses are added to derive the irrigation requirement at the head of branch and main canal as seen in Fig. 8.14.

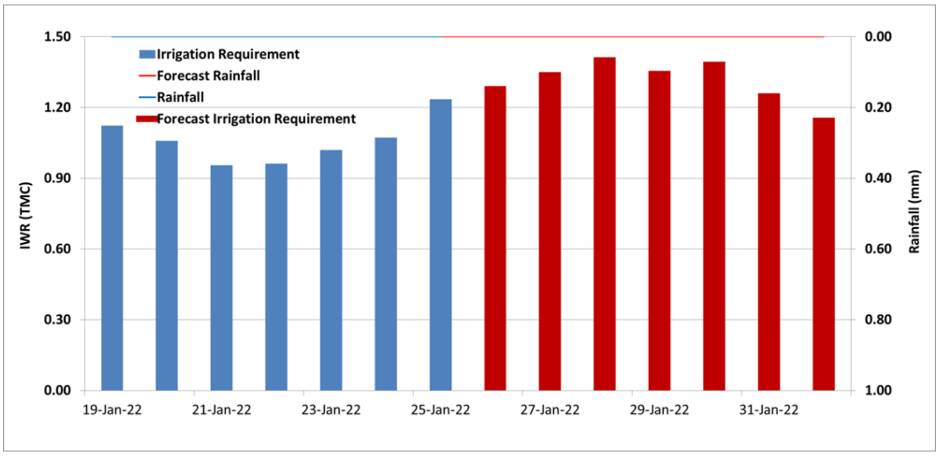


Fig. 8.14 Estimated Daily Irrigation Requirement head of the system (Narayanpur Dam) with NRT and forecast weather data as on January 26, 2022

8.4.6 Irrigation System Performance Assessment

Many Indian irrigation systems perform at a very low level and a number of national efforts has been initiated to improve the performance of existing irrigation schemes. In most of the existing irrigation schemes there is a serious lack of reliable and adequate information on system performance. Large number of irrigation projects generated revenue in far excess of the largest business corporate, however there is virtually no information on the extent of which these projects are achieving the designed performance objectives. It is essential to evaluate the performance of irrigation projects and identify the areas/pockets whose performance is below par. Such exercise would help the irrigation managers to prioritize the improvement measures. Although, information of irrigation system performance can be obtained by conventional techniques, they are often subjective, inconsistent, time consuming and cost-intensive. Satellite Remote Sensing (SRS) has established itself as an effective and accurate tool for providing essential elements for characterizing the irrigation system performance. The accuracy of SRS derived information is significantly higher than the conventional methods. The advantage of SRS data is the opportunity to analyse the data over a period of 15-20 years. It is being operationally used to assess the performance of irrigation systems, bench marking, identifying low performing pockets, effectiveness and sustainability of improvement schemes, etc.

i. Performance Indicators

Performance evaluation of an irrigation system requires the spatial information on crop type, crop calendar, crop condition, crop intensity, water consumed by the crop and crop yield/productivity. Multi-spectral satellite data is found useful to derive primary information on cropping type and crop condition, which can be used to quantify the agricultural performance of the system. This spatial information can be integrated with relevant field data to generate various performance indicators to gauge the performance and compare with targeted, in order to identify and rank the pockets of poor performance. Some of the performance indicators generated from satellite data are: a) Crop Intensity; b) Equivalent crop area intensity; c) Principal crop intensity; d) Proportionate Crop Intensity; e) Crop Condition; f) Coefficient of variation in crop condition; g) Tail-Head ratio of cropping intensity; h) Tail-Head ratio of crop condition and i) Sustainability in crop intensity.

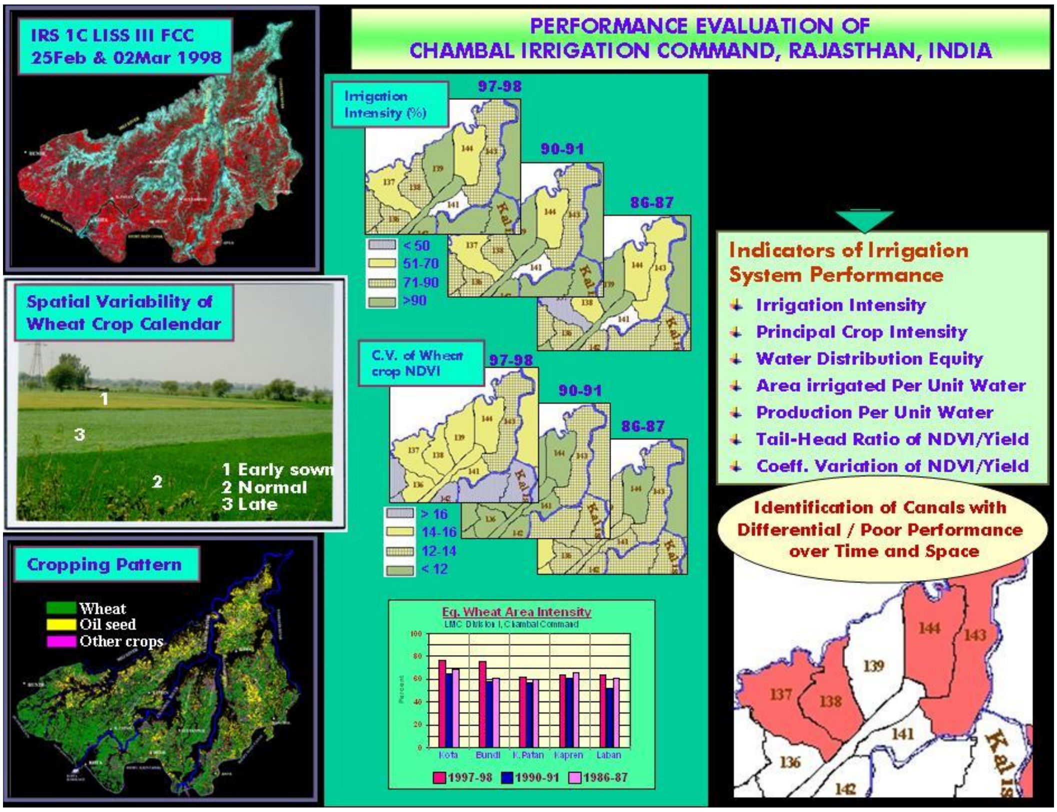


Fig. 8.15 Performance evaluation and problem pockets identification

Satellite data-based monitoring and evaluation of irrigation command areas was initiated by NRSC in 1991-92. Initially base line inventory of irrigated crop areas and their extent was carried out at distributary group in Bhadra project command area in Karnataka state. Thiruvengadachari et al. (1996) used remote sensing-based performance indicators for performance assessment of various irrigation systems in the country. Bastiaanssen (1998) has listed the performance indicators derived from RS algorithms supplemented by ground data. Ray et al. (2002) used RS data to compute three indices namely, adequacy (AI), equity (EI) and water use efficiency (WUE) for the evaluation of performance of distributaries in an irrigation system. Panigrahy et al. (2005) attempted to derive crop indices like Multiple Cropping Index (MCI), Area Diversity Index (ADI) and Cultivated Land Utilization Index (CLUI) using satellite derived parameters such as cropping pattern, crop rotation, and crop calendar, crop type, acreage, rotation and crop duration. NRSC executed, Command Area Development (CAD) project, MOWR for 13 irrigation commands on a pilot basis to evaluate the performance of these irrigation schemes using satellite remote sensing techniques (1997-98 to 1998-99). Fig. 8.15 shows the performance evaluation and problem pockets identification.

ii. Water Productivity and Water Use Efficiency

The increasing world population and the impact of global climate change have increased the demand for water across sectors. The agriculture accounts for nearly 80% of the available fresh water use which is likely to decrease due to the completion arising from urbanisation, power, recreational and environmental demands. It is important to use water judiciously so that the Water Productivity and Water Use Efficiency increases.

iii. Water Productivity

Water productivity (WP), is defined as the as the ratio of the physical yield of a crop or in some case 'economic value' of production and the amount of water consumed, including both rainfall and supplemental irrigation. Yield is expressed as a mass (kg or ton), and the amount of water as a volume (m^3). Water productivity varies spatially depending on factors such as cropping pattern, climate patterns (if rainfall fits crop growth), irrigation technology and field water management, land and infrastructure, and input, including labour, fertilizer and machinery (Biradar et al., 2008). The water productivity can be increased by increasing the crop yield for the given amount of water applied or decreasing the water applied through efficient management of water.

Remote sensing can play an important role in identifying the high and low water productive areas within the irrigation command which will help in analysing the reason for the low water productivity. The WP is assessed at plot or field level and minors/distributaries level for the irrigation command area. Generally, the WP is estimated from the secondary crop statistics and water supply or use data. Remote sensing offers the possibility of both greater coverage, and greater spatial detail in mapping water productivity, through the use of emerging techniques to map and model crop growth and water use, through synoptic coverage over large areas at regular time intervals. The crop yield can be estimated using the relation between crop biophysical parameters and the actual yield. The most commonly used crop variables establishing such relations are leaf area index (LAI), Wet Biomass (WBM), Dry Biomass (DBM), and grain Yield (YLD). Variation in the reflectance was normally associated with chlorophyll and water contents of the plants. The spectro-biophysical models using statistical technique relate the biophysical and yield data. There are several models which uses the remote sensing data to estimate the evapotranspiration (ET) (Kustas et al., 1996; Kalma et al., 2008; Glen et al., 2007; Li et al., 2009) which is the actual water consumed by the crop. This will help is estimating the remote sensing-based water productivity for different spatial scales.

iv. Water Use Efficiency

Water Use Efficiency (WUE) is the ratio of plant biomass (or yield) relative to the water consumed expressed in kilograms/m^3. It can also be defined as the ratio between amount of water used to meet the consumptive use requirement of crop plus that necessary to maintain a favourable salt balance in the crop root zone to the total volume of water diverted, stored or pumped for irrigation. Thus, water applied by the irrigation system and not being made available to be taken up by plant roots is wasted and reduces efficiency. In addition, losses can also occur during storage in case of pond, tank, or reservoirs. The major causes for reduced irrigation efficiency include storage losses, conveyance losses and field application losses. In India, overall irrigation efficiency of major irrigation projects ranges between 35-40%. Remote sensing can be used to estimate the Actual Evapotranspiration (AET) which is the water consumed by the crop. The ratio of AET to the amount of water diverted to the crop will give the water use efficiency of the system.

8.4.7 Salinity and Waterlogged Area Mapping and Monitoring

Waterlogging and subsequent salinisation and/alkalisation are the major land degradation processes operating upon in the irrigation commands of the semiarid regions. The significant occurrence of salt affected soils lies in the arid and semiarid regions reducing considerably (7–8%) the productive capacity of the land surface in the world. Due to improper management of soil and water resources in the command areas, the problems of salinity/alkalinity and water logging are reported to be on the increase. Information on the nature, extent, spatial distribution and temporal behaviour of areas under water logging and salinity/alkalinity is essential for proper management of irrigated lands.

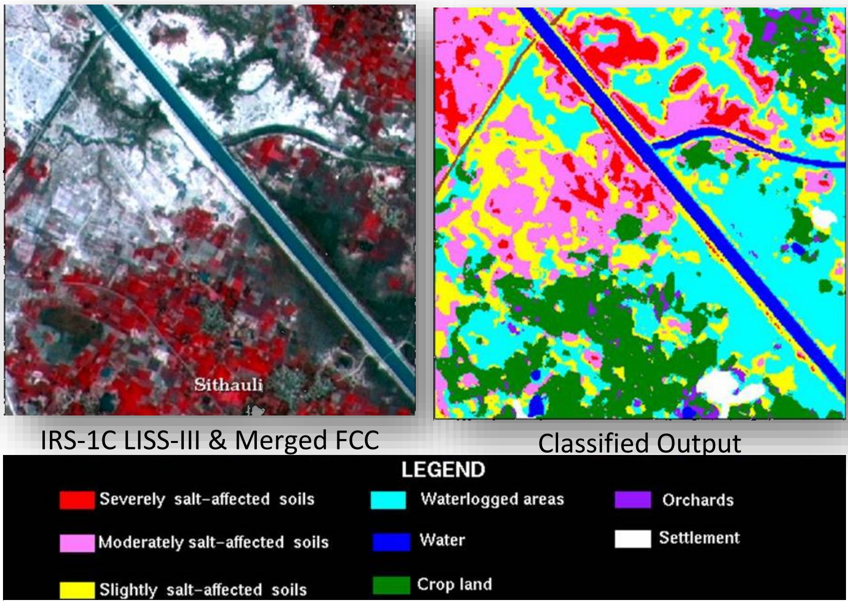


Fig. 18.16 Mapping of salt affected soils and water-logged areas

Until recently, information on the nature, extent, magnitude and spatial distribution which is a pre-requisite for amelioration and management of salt affected soils, has been generated through traditional soil surveys which are tedious and time-consuming apart from being cost-prohibitive. Among the new technologies developed for soil survey, remotely sensed data from space borne sensors like Landsat-MSS, TM, IRS-LISS-I/II/III, Resourcesat-1, SPOT MLA/PLA etc., proved to be valuable to map and monitor salt affected soils and water-logged areas. Satellite data are being used regularly for mapping of salt affected soils (Singh & Dwivedi, 1989) and waterlogged areas (Sharma & Bhargava, 1987; Dwivedi, 1997). Command Area Development (CAD) programme, the Ministry of Water Resources, Government of India, supported a programme to apply satellite remote sensing techniques to generate distributary-wise information on the status of water-logging and salinity and alkalinity periodically during selected years of operation in selected command areas. The information on nature, extent, and spatial distribution of waterlogged area and salt-affected soils was derived through systematic visual interpretation of standard false colour composite (FCC) prints on 1: 50,000 scale. NRSC has prepared state-wise salt affected soils map of India (NRSA 1997) on 1:250,000 scale using remote sensing (LANDSAT) data and ground truth jointly with the Central Soil Salinity Research Institute, Karnal (ICAR), National Bureau of Soil Survey and Land Use Planning, and Nagpur (NBSS & LUP, ICAR). Mandal and Sharma (2006) used GIS derived information on the extent and distribution of salt affected soils for agro-climatic regional and zonal planning for Indo-Gangetic Plain in India.

8.5 Hydrological Extremes

8.5.1 Extreme water events- Flood and Drought

The increasing frequency of occurrence of extreme events of droughts and floods are posing great challenge to human society to absorb the consequent impacts and to get prepared to face such future events with reduced misery. Policies and practices adopted under extreme water conditions are influenced by the causes and characteristics of the extreme conditions. It is also important to consider the nature of activity affected, as the impact varies. Remote sensing data, both historical and near-real time provide objective and authentic information both on the behaviour and response of various activities to extreme water conditions. Over last two decades it has established as a reliable and cost-effective tool for managing extreme water conditions such as flood and drought. The timeliness of satellite data has proved to be very critical in flood management, rescue operations, damage assessment, planning the flood plains and to formulate long term strategies. In conditions of water scarcity, satellite data is useful for monitoring and assessing the drought severity and consequent impact on agricultural production.

8.5.2 Flood Monitoring and Management

Floods are the most common and widespread among all natural disasters in India. Our country is the worst flood-affected in the world after Bangladesh and accounting one fifth of global death count due to floods. About 40 million hectares (Mha) or nearly 1/8th of India's geographical area is flood-prone and the country’s vast coastline of 5700 km is exposed to tropical cyclones originating in the Bay of Bengal and Arabian Sea. The annual average area affected by floods is about 7.57 Mha and the affected crop area is about 3.5 Mha. The average loss in financial terms is about Rs. 13,000 million.

One of the most important elements in flood management is the availability of timely information for taking decisions and actions. To obtain the information by conventional means is virtually ruled out as the areas may not be accessible. In this context, the Earth Observation satellites provide comprehensive, synoptic and multi temporal coverage of large areas in near real time and at frequent intervals which enables to compare the data before and after flood disaster. During monsoon season, a constant watch is kept on the flood situation in the country and all possible satellite data are procured over flood affected areas. The flood inundation maps along with affected area statistics are furnished authorities within the country for timely action. NRSC is contributing towards National Database for Emergency Management (NDEM) which helps in planning suitable flood control measures, relief and rescue management and to formulate long term strategies. Since 1987, all major flood events of the country have been mapped in near real-time and statistics on crop area affected and number of marooned villages are generated.

8.5.3 Hydrological Drought

Hydrological drought refers to a lack of water in the hydrological system, manifesting itself in abnormally low streamflow in rivers and abnormally low levels in lakes, reservoirs, and groundwater. Propagation of drought is characterized by a number of features which are related to the fact that terrestrial part of hydrological cycle acts as a low-pass filter to the meteorological forcing (Van Loon, 2015). Hisdal et al., (2000)**Error! Reference source not found.** shows the propagation of m eteorological drought(s) to hydrological drought. The stages in such propagation are: a) Pooling: meteorological droughts are combined into a prolonged hydrological drought; b) Attenuation: meteorological droughts are attenuated in the stores, causing a smoothing of the maximum negative anomaly; c) Lag: a lag occurs between meteorological, soil moisture, and hydrological drought, i.e., the timing of the onset is later when moving through the hydrological cycle; and d) Lengthening: droughts last longer when moving from meteorological drought via soil moisture drought to hydrological drought.

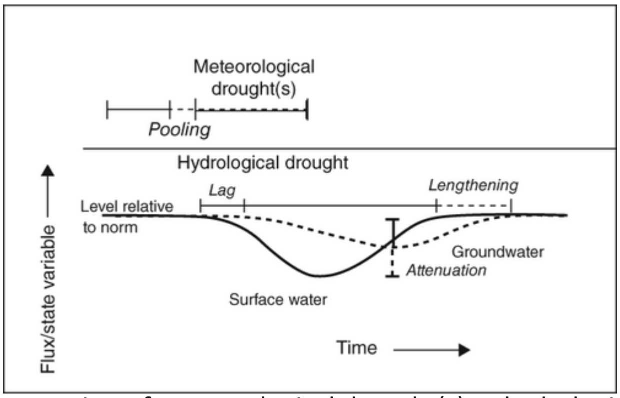


Fig. 18.17 Propagation of meteorological drought(s) to hydrological drought: pooling, lag, attenuation, and lengthening. (Source: Hisdal and Tallaksen, 2000)

Hydrological droughts can have widespread impacts by reducing or eliminating water supplies, deteriorating water quality, restricting water for irrigation and causing crop failure, reducing power generation, disturbing riparian habitats, limiting recreation activities, and affecting a diversity of economic and social activities. Under National Hydrology Project, NRSC is working towards the development of composite hydrological drought index using individual hydrological drought components like runoff derived from hydrological modelling (Shukla and Wood, 2008), surface water spread derived from satellite data and data from ground water well observation network.

8.6 Hydrological and Hydraulic Modelling

8.6.1 National Modelling Framework – VIC & SWAT

i. National Modelling Framework – VIC

Hydrological modelling comprises a set of tools and methods used to simulate the earth's hydrological cycle in predicting water resource availability and quality. Hydrological modelling requires extensive data on soil characteristics, land use, and meteorological data to simulate water balance components such as runoff, evapotranspiration, and soil moisture. The modelling framework can be used to simulate different scenarios and evaluate the impacts of different water management strategies on water resources. The output of the framework can be used to inform decision-making in areas such as water resources management, flood risk management, and environmental management.

Under National Hydrology Project, NRSC has established the National level hydrological modelling framework for India (Fig. 8.18 and 8.19) in Variable Infiltration Capacity (VIC) (Liang et al., 1994) model using various geospatial datasets like digital elevation model, soil map of India, land use/ land cover, leaf area index, and in-season meteorological dataset. Daily water balance components such as surface runoff, soil moisture & evapotranspiration are generated at a 3 min (~5.5 km) grid level for the entire country and are further translated into various value-added products such as: a) Inflows into 125 major reservoirs of India considering reservoir operational rule curves and hydraulic particulars to represent upstream abstraction; b) Drought indicators (Standardized Runoff Index, and Soil Moisture Availability Index) to represent wetness or dryness condition; and c) Crop-specific Irrigation requirement estimation through dynamic root zone soil moisture simulations.

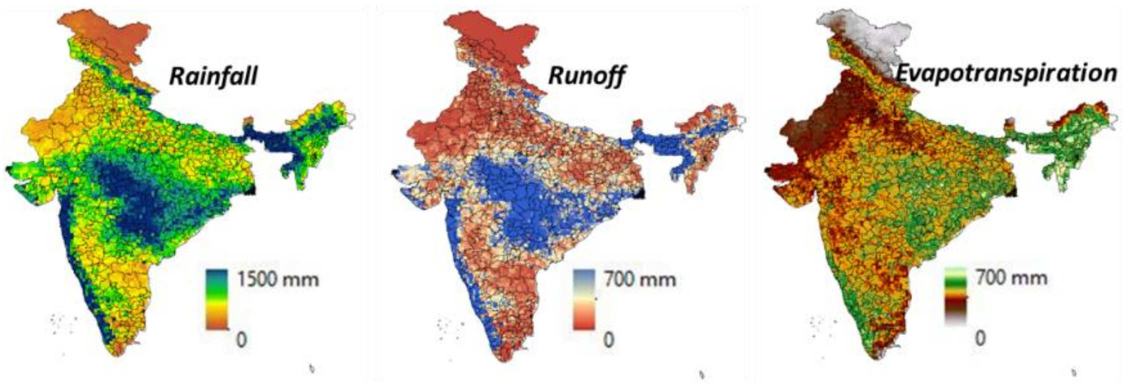


Fig. 8.18 Seasonal Water Balance Components (01st June – 31st October 2022)

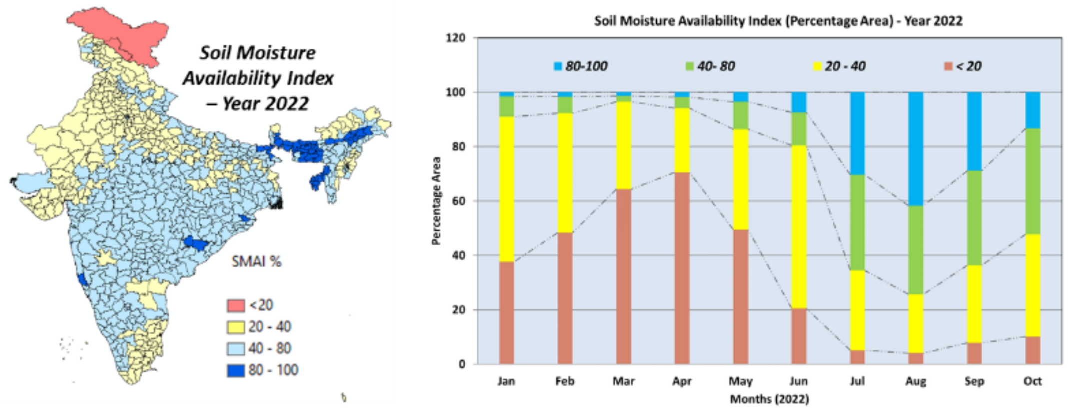


Fig. 8.19 Soil Moisture Availability Index for the Year 2022

ii. Grid based hydrological modelling framework in SWAT

Soil Water Assessment Tool (SWAT) is one of the widely used hydrological models, which can effectively simulate the water balance components spatially in ungauged basins with simplified interaction in the plant-soil-atmosphere continuum in a daily time step (Arnold et al., 1998). The model is semi-distributed physical based, considering all the watershed characteristics (reservoir, ponds, crops, and others) and agricultural practices. Many studies suggest that the SWAT model has been effectively used for multiple applications in the water resources sector, varying from simulation of discharges in un-gauged basins, water availability studies, water productivity in irrigation basins, etc. with minimum available data.

SWAT model setup in grid sub-basin schema was developed for all the river basins in India except for North Ladakh (NRSC-IITM Report, 2020). The following geospatial datasets were used to set up the model: a) GTOPO DEM of 1km (https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-global-30-arc-second-elevation-gtopo30); b) Stream network data from HydroRIVER data (*https://www.hydrosheds.org/products/hydrorivers*); c) Land use/land cover map of 2007-2008 generated by National Remote Sensing Centre (NRSC) at 56 m resolution (https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php); and d) Soil data (1:250,000 scale) from National Bureau for Soil Survey and Land Use Planning (NBSSLUP) (Bhattacharyya et al., 2009). In addition, data were derived from other sources like India Water Resources Information System *(http://indiawris.gov.in/*), Bhuvan (https://bhuvan-app1.nrsc.gov.in/thematic/), and others for deriving information on crop and water management to be defined in the model. The weather inputs used for the model are the gridded precipitation data that is available from 1901-2021 at 0.25-degree resolution (Pai et al., 2014) and the gridded temperature data available from 1951-2021 at 1-degree resolution (Srivastava et al., 2009), from Indian Meteorological department (IMD). SWAT model for all the basins was calibrated with observed streamflow data in SWAT- Calibration and Uncertainty Prediction (SWAT- CUP) (Abbaspour, 2013). The performance of the model during calibration and validation was assessed using the performance indicators, coefficient of determination (R^2), and the Nash and Sutcliffe efficiency between simulated and measured stream flow (Moriasi et al., 2015). The model simulated outputs were integrated to map the spatial variation of the water balance components at daily, monthly, and seasonal time steps as seen in Fig. 8.2020.

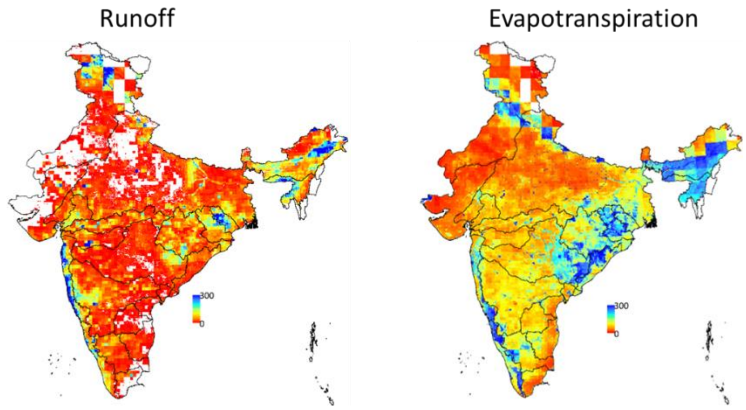


Fig. 8.20 Model Simulated Runoff and Evapotranspiration for the month of June 2019

8.6.2 Snowmelt Runoff Forecasting

In Himalaya, the snowmelt runoff occurring mostly during summer months constitutes a substantial part of the water resources of the major perennial rivers of Northern and Eastern India, namely the Indus, Ganga, Brahmaputra and their tributaries. The snow accumulated in winter months' melts in summer months which are vital during the period of high demand for water and power. A timely forecast of snowmelt water is very useful in planning and managing the multi-purpose projects.

NRSC has provided advance forecast of snowmelt runoff into Bhakra reservoir to Bhakra Beas Management Board (BBMB) for the period 1990 to 2010 using satellite derived snow cover depletion technique. During 2010, Central Water Commission has entrusted NRSC to develop snowmelt runoff models, both seasonal (3 months) and short term (16 days) for forecasting during summer months (April to June) in 5 basins (Chenab, Beas, Sutlej, Yamuna and Ganga) using remote sensing inputs. Independent basin-wise snowmelt runoff forecast models were developed for all the five basins using the energy balance approach.

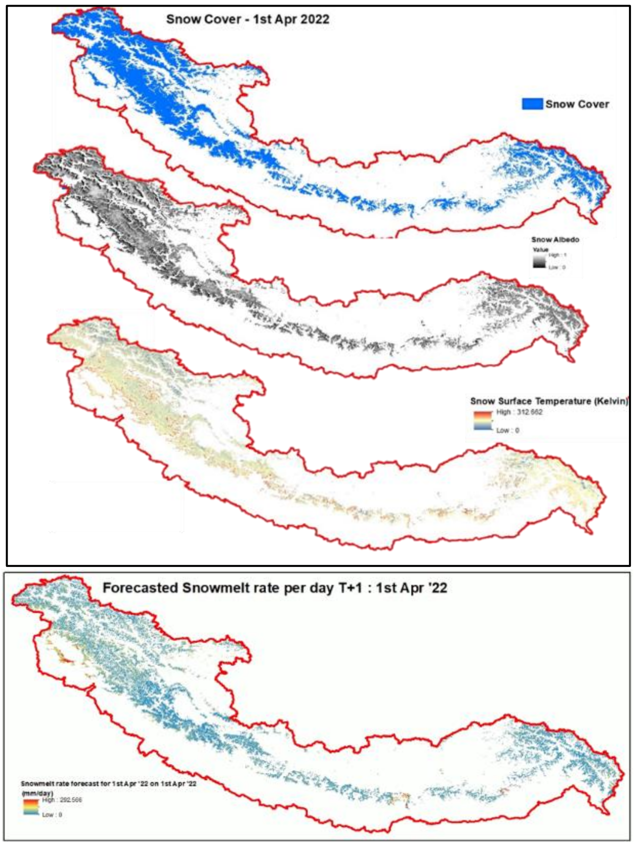


Fig. 18.21 Satellite derived inputs and spatial snowmelt rate forecast for Himalaya

NRSC has further taken up spatial snowmelt runoff product generation for entire Himalayas under NHP in 2017 (Fig. 8.21). Under this activity, energy balance approach previously adopted was improved by incorporating atmosphere transmission effects by considering atmosphere constituents like AOD, water vapour, ozone, clouds, etc. The satellite derived inputs such as snow cover, snow albedo, snow surface temperature and snow emissivity were used in computing net radiation. The net radiation forms the basis in estimating snow melt runoff using energy balance method in spatially distributed approach. The runoff at the river basin outlet comprises of snowmelt, glacier melt, runoff due to rainfall and base flow components. For 16 river basins covering entire Himalayas, 3-days short-term snowmelt runoff forecasts are provided during April to June months on daily basis by using global temperature and rainfall forecasts.

8.6.3 GLOF Modelling

Glacial lake outburst floods (GLOFs) are one of the potential hazards in many mountainous regions around the world, particularly in the Indian Himalaya. GLOFs occur when water stored in glacial lakes is suddenly released, often as a result of glacial retreat, collapse, or due to external factors such as landslides, earthquakes, and avalanches. These floods can cause extensive damage to infrastructure and settlements downstream, and can also result in loss of life.

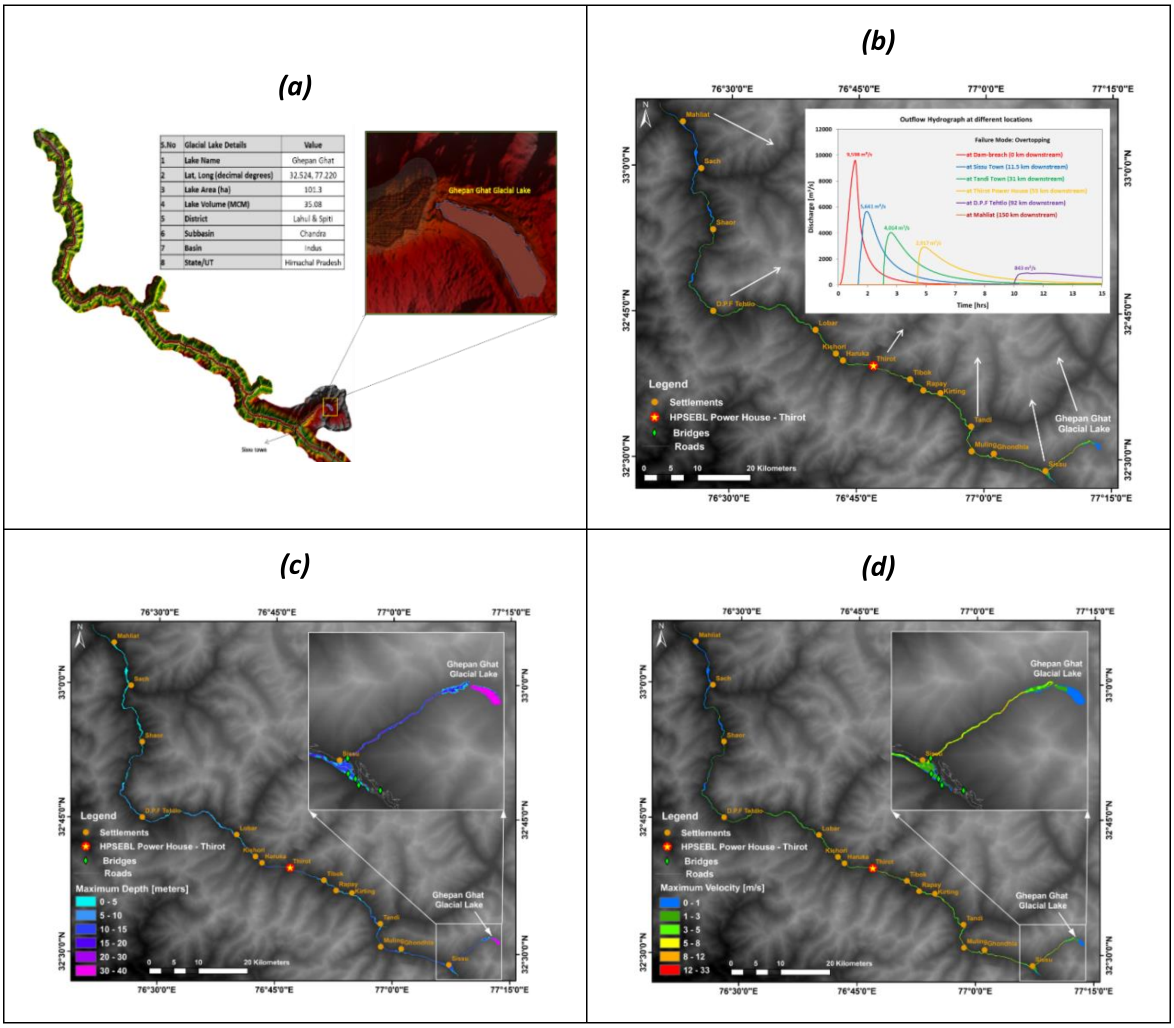


Fig. 8.22 (a) location of Ghepan Ghat glacial Lake situated in the Indus River basin, (b) Routed GLOF hydrographs at different locations along the flow channel for 100% volume discharge, (c) Spatial plot of Maximum Depth [m], and (d) Maximum Velocity [m/s] along.

GLOF modelling involves simulating the potential impact of a glacial lake outburst flood on downstream areas. These models typically incorporate data on the size and location of glacial lakes, as well as information on the topography of the surrounding area, the flow characteristics of the river channel, and the likely behaviour of the flood wave. Software programs like HEC-RAS and MIKE are commonly used for GLOF (Glacial Lake Outburst Flood) modelling. One example of a GLOF modelling tool is the Integrated Flood Analysis System (IFAS), developed by the International Centre for Integrated Mountain Development (ICIMOD). IFAS is designed to provide early warning of GLOFs in Bhutan, a country that is particularly vulnerable to this hazard. Another study carried out by NRSC, contains a comprehensive inventory of Glacial Lakes (28,043) of size ≥ 0.25 ha situated in the entire Himalayas using Resourcesat-2 LISS-IV satellite scenes of 2016 -2017 along with 22 associated attributes. Few prioritized GLs were chosen from each river basin for GLOF hydrodynamic modelling.

Among them, GLOF modelling for Ghepan Ghat Lake situated in Himachal Pradesh in the Indus basin was carried out using HEC-RAS 6.3 and simulated maximum depth and velocity for 100% volume discharge is showcased in Fig. 8.22.

8.6.4 Flood Forecasting and Inundation Simulation

Flood forecasting and early warning to affected areas are among the most important and cost-effective measures for flood management. Central Water Commission has set up a network of flood forecasting and warming stations on most of the inter-State rivers in the country. Currently, 157 flood forecasting stations are in operation and nearly 5500 flood forecasts are issued using gauge correlation techniques and using hydrological models in some basins every year. But many important flood prone rivers/tributaries are yet to be covered. Since the 1930s, numerous rainfall-runoff models have been developed to estimate streamflow on daily, monthly and seasonal basis. Remote sensing outputs are widely accepted by many of the hydrological models to compute surface runoff of the watershed.

8.7 Advanced Applications

8.7.1 Hyperspectral Remote Sensing

Hyperspectral remote sensing has immense potential for applications in the field of water resources management. It can be used to detect and map surface water bodies, groundwater resources, and wetlands. This can be done by analysing the unique spectral signatures of water bodies, which are different from those of surrounding vegetation and soil. Hyperspectral imaging can be used to detect the spectral signatures of different water quality parameters such as chlorophyll-a, total suspended solids, and dissolved organic matter. These parameters are essential in determining the quality of water and identifying any potential contaminants. The main advantage of hyperspectral remote sensing is in generating the continuous spectra of a feature which is not possible with the multispectral sensors. This allows detection of very subtle absorption and reflection characteristics which might not be captured in multispectral data. Chander et al., (2019) carried out a study in Buxar, Bihar to map turbidity of Ganga River. Spectral Angle Mapper technique was used to map water pixels to pre-identified turbidity range classes.

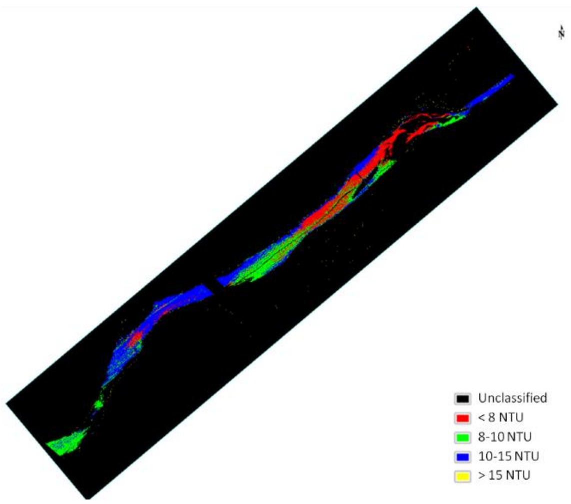


Fig. 18.23 Turbidity map of river Ganga generated using SAM technique on AVIRIS NG data

8.7.2 UAV

Satellite and manned aircraft based remote sensing provides data over a large area, but often at a coarse resolution. Often these platforms are limited in its ability to respond to short-term events to address the near real-time assessment and decision-making especially during and immediately after natural disasters. Unmanned Aerial Vehicles (UAVs) are often more cost-effective than traditional remote sensing and the availability of new advancements in UAV design, power supply, payload capacity, and sensors has been driving rapid innovations in their use in the hydrological sciences.

Some of the UAV's current and potential applications in water resources are: a) Retrieval of field level crop parameter for irrigation water management (Crop phenology, crop height, bio-mass, evapotranspiration, soil moisture); b) Irrigation command water distribution systems leakage detection; c) Glacial lake mapping (e.g., ice front, leads); c) Flood event emergency response (e.g., map extent and damage to properties); d) Pollution event emergency response (e.g., map extent and investigate cause); Turbidity mapping resulting from natural or manmade disturbances; Sewage and industrial outfall detection; e) Dam inspection including condition, leakage and movement; f) Create or update digital elevation models used for flood risk mapping; g) Protected watershed and public water supply surveillance and change detection; and h) Wetland mapping, especially near urban development. The high-resolution data provided by a UAV can also be valuable in estimation of capacities of minor irrigation tanks. The high-resolution DSM (Fig. 8.24) generated by the UAV is used in conjunction with satellite derived water spread area for estimation capacity in near real time for minor irrigation tanks.

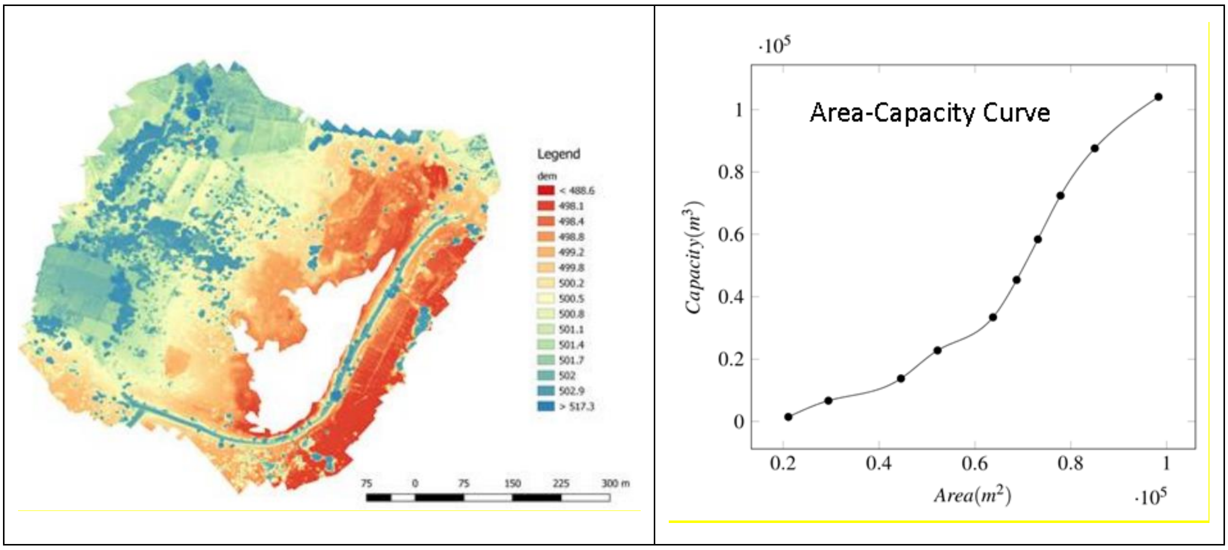


Fig. 8.24 DSM generated using UAV imagery for dry irrigation tank and derived area-capacity relationship

8.7.3 Altimetry

Satellite altimetry is a remote sensing technique that uses radar pulses to measure the height of the Earth's surface from space. This technology has been used for several decades to study the oceans, the polar regions, and the land surface. The principle of satellite altimetry is based on the measurement of the time it takes for a radar pulse to travel from a satellite to the Earth's surface and back. By measuring the time delay between the transmitted pulse and the received echo, the distance between the satellite and the Earth's surface can be calculated using the speed of light. The satellite sends out a radar pulse, which travels through the Earth's atmosphere and reflects off the surface of the Earth. The reflected pulse is then detected by the satellite's radar instrument, which records the time it takes for the pulse to travel back to the satellite. The time delay is used to calculate the distance between the satellite and the surface of the Earth. However, the distance measured is not the actual distance between the satellite and the Earth's surface, but rather the distance between the satellite and a reference ellipsoid, which is an idealized mathematical representation of the Earth's shape. The difference between the measured distance and the distance to the reference ellipsoid is called the geoid height, which represents the deviation of the Earth's shape from the reference ellipsoid. By measuring the geoid height at different points on the Earth's surface, the topography of the Earth's surface can be determined. This information is used to create maps of the Earth's surface, including land elevation, ocean depth, and variations in the Earth's gravity field. Satellite altimetry missions have been conducted by various space agencies such as NASA, ESA, and CNES.

The first satellite altimetry mission was launched in 1978 by NASA, called Seasat. This mission was designed to study the oceans and measure ocean surface topography. The data collected from Seasat provided valuable information on ocean circulation, tides, and sea-level changes. The next missions were joint NASA-French CNES mission, TOPEX/Poseidon, launched in 1992, the follow-on mission in 2001, Jason-1, was launched by NASA and CNES. This mission continued the measurements of TOPEX/Poseidon with improved accuracy and resolution. Jason-2 and Jason-3 were subsequently launched in 2008 and 2016, respectively. These missions continue to measure ocean surface topography and provide valuable data for oceanography, climate research, and marine industries. The European Space Agency's CryoSat mission, launched in 2010, measures the thickness of polar sea ice and ice sheets. NASA Ice, Cloud, and land Elevation Satellite (ICESat) mission, launched in 2003, measures the elevation of ice sheets, glaciers, and sea ice. NASA Terra and Aqua missions, launched in 1999 and 2002, respectively, use satellite altimetry to measure the height of the land surface.

More recently, NASA-CNES joint Surface Water Ocean Topography (SWOT) mission was launched in December 2022 (Fig. 8.25). SWOT's 120-km-wide (~75-mi-wide) swath will result in overlapping measurements over most of the globe with an average revisit time of 11 days. The hydrologic science objectives of the SWOT mission are: a) to provide a global inventory of all terrestrial surface water bodies whose surface area exceeds 250 m^2 (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (requirement) (50 m goal); b) to measure the global storage change in terrestrial surface water bodies (for man-made reservoirs, total storage) at sub-monthly, seasonal, and annual time scales; and c) to estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.

The applications of satellite altimetry for deriving surface water levels and discharge are vast. The measurement of surface water levels using satellite altimetry provides valuable information for managing water resources, flood forecasting, and hydrological modelling. The measurement of surface water discharge using satellite altimetry provides important data for understanding the water cycle, water availability, and water use.

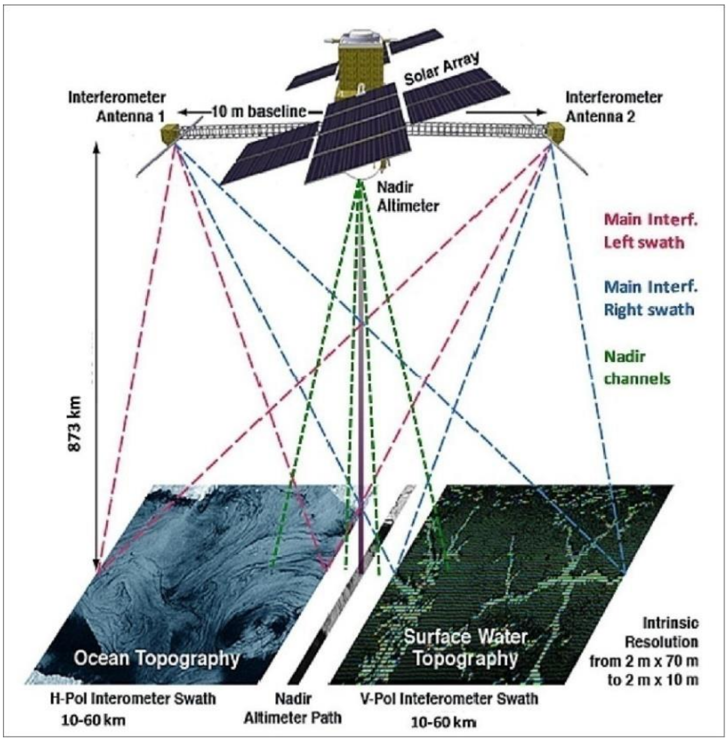


Fig. 18.25 SWOT payload configuration and data acquisition strategy over ocean and land

8.7.4 Gravimetry

Satellite gravimetry is a remote sensing technique that uses measurement of variations in Earth's gravity field to understand changes in mass distribution on the planet. This technology has enabled scientists to study a wide range of phenomena, including the movements of ice sheets, changes in sea level, and variations in the amount of water stored in underground aquifers. One important example of a satellite gravimetry mission is the Gravity Recovery and Climate Experiment (GRACE) mission, launched in 2002 by NASA and the German Aerospace Centre. GRACE mission uses two identical satellites to map variations in Earth's gravity field with unprecedented accuracy. By measuring the distance between the two satellites, which changes in response to variations in the gravity field, the mission is able to create a high-resolution map of changes in the distribution of mass on Earth's surface. GRACE has provided important insights into changes in Earth's water resources e.g., the mission has shown that the Greenland and Antarctic ice sheets are losing mass at an accelerating rate, contributing to rising sea levels. GRACE has also revealed significant changes in the amount of water stored in underground aquifers, particularly in regions of the world where water resources are already under stress. Another important satellite gravimetry mission is the GRACE Follow-On (GRACE-FO) mission, launched in 2018 as a successor to the original GRACE mission. GRACE-FO uses the same technology as GRACE to map variations in Earth's gravity field, but with improved accuracy and resolution. The mission is expected to provide new insights into changes in Earth's water resources, including changes in the amount of water stored in large lakes and rivers. Fig. 8.26 shows trends in Terrestrial Water Storage (TWS; in centimetres per year, cm yr^{-1}) obtained on the basis of GRACE observations from April 2002 to March 2016.

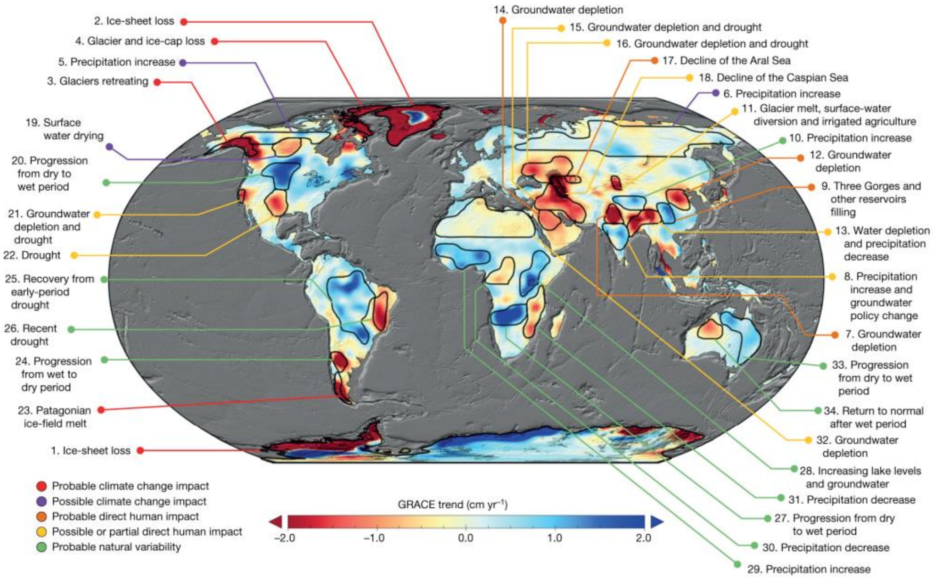


Fig. 8.26 Trends in Terrestrial Water Storage (TWS; in centimetres per year, cm yr^{-1}) obtained on the basis of GRACE observations from April 2002 to March 2016. [Adapted from IPCC 2021 report]

8.8 Water Resources Informatics

Water resources information portals are web-based platforms that provide access to water resources information and data. These portals can serve as a central repository for water data from multiple sources, such as government agencies, research institutions, and citizen science initiatives. This involves collection, processing, analysis, and visualisation of data related to water resources. It also involves the development and use of computer models and simulations to understand and predict the behaviour of water systems and to support decision-making processes. The goal of water resources informatics is to provide reliable and timely information to water resource managers and decision-makers to enable them to make informed decisions about water allocation, use, and conservation. It also helps to identify and mitigate the impacts of natural disasters such as floods and droughts, as well as human-induced activities such as land use changes and climate change. Advances in technology, such as remote sensing and data analytics, are making it easier to collect and analyse data on water resources, which is essential for effective water management.

Multiple water resources informatics products are disseminated to the public using Bhuvan geo-portal of NRSC. Hydro-informatics products as runoff, soil moisture, etc. derived from hydrological models, evapotranspiration, satellite derived surface water extent, hydrological drought status, glacial lakes, turbidity and chlorophyll variations in water bodies, etc. These products help in making informed decisions for management of water resources. Portals such as Bhuvan-NHP (Fig. 8.27), Waterbodies Information System (WBIS), Telangana Water Resources Information System (TWRIS), Urban Water body Information System (UWaIS), National Information System for Climate Sciences (NICES), Andhra Pradesh Water Resources and Information System (APWRIMS), etc. disseminate the water resources informatics products generated by NRSC to the concerned departments and also public.

Fig. 8.27 Hydro-informatics products disseminated under NHP portal

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Chapter 9

REMOTE SENSING APPLICATIONS FOR CLIMATE CHANGE STUDIES

The fundamental laws of physics, chemistry and thermodynamics are assisting us to understand the greenhouse effect and global warming. The Remote Sensing data from Earth Observation satellite sensors are aiding in directly measuring the greenhouse effect and the feedback processes through which the greenhouse effect warms the planet Earth. This chapter document these remote sensing observational evidences for the link between the greenhouse effect and global warming; and subsequent changes in Earth's Climate. This chapter also offers a brief introduction to the observed changes in the climate indicators, Extreme weather events and the Geoengineering approaches that are being proposed to partially offset the impacts of anthropogenic climate change.

9.1 Introduction

Over the last few decades, a change in the Earth's climate was observed. The natural processes (volcanic eruptions, changes in the Earth's orbits, etc.) and human activities (burning of fossil fuels, deforestation, etc.) led to changes in Earth's climate. There is overwhelming scientific evidence confirms that the rapid change in Earth's climate is due to human-induced increase in the amount of atmospheric greenhouse gases.

The Earth's atmosphere is believed to be formed as a result of degassing and volcanic activity during the steamy early life of the Earth. In the beginning, the gaseous molecules present in the Earth's atmosphere (ex: water vapour, carbon dioxide (CO_2) and nitrogen) were the same as those found on Venus or Mars, but the emergence of life processes on Earth drastically changed the Earth's atmosphere composition. Subsequently, the dominant life-form on the Earth (i.e., plants) turned CO_2 into oxygen (O_2) through photosynthesis. With the result that 21% of the atmosphere consists of O_2 molecules by volume and only about 0.028% of CO_2 (or 280 among one-million air molecules). The levels of O_2 and CO_2 in the atmosphere have undergone regular cycles for at least the past million years, due to a balanced interplay between photosynthesis and respiration (which turns O_2 back into CO_2). The Industrial Revolution perturbed the chemical composition of the Earth's atmosphere, which lead to an increase of CO_2 molecules in the atmosphere.

The Industrial Revolution evolved during AD 1750–1850, with the invention of the steam engine by James Watt (and his predecessor Thomas Newcomen) in 1769. Watt's steam engine and subsequent development of fossil fuel using technologies (e.g. the internal combustion engine and gas turbine) have primarily altered the Earth's environment. These fossil fuels (coal, oil, gas) are found in Earth's crust; contain carbon and hydrogen, burned for energy. Today, fossil fuels are the primary source for the world's energy. The deforestation and fossil fuel combustion during the past couple of centuries have been leading to an increase of CO_2 molecules in the atmosphere. The concentration of CO_2 in air has also been steadily increasing from year to year for over 70 years. The current rate of increase is about 0.00025% per year. Indeed, since Watt's steam engine, there have been a series of technological advances and we are now living through the wave of the Digital Revolution.

In general, the Sun's energy drives the biological, chemical and physical processes in the Earths system (which encompasses geosphere, biosphere, cryosphere, hydrosphere, and atmosphere). Besides, on land and oceans it provides energy for plant growth (through photosynthesis) that forms the base of the food chain, and in the atmosphere, it warms air which drives our weather. In short, weather refers to short-term changes (minute-to-minute, hour-to-hour, day-to-day and season-to-season), while climate refers to changes over longer periods of time, usually defined as 30 years or more.

Earth's energy budget determines the climate, i.e., how solar radiation is absorbed by the Earth system, distributed by the motion of the atmosphere and oceans, and eventually re-emitted back into space. The planet warms up if the amount of energy coming in is more than the energy going out. Ultimately, the temperature of the planet will be that at which energy absorbed balances energy lost. When the Sun's energy reaches the Earth, some of it is reflected back into space by clouds, by the gaseous molecules and aerosol (suspended particulate matter) in the atmosphere and by the bright parts of the Earth's surface. The absorption of incoming solar radiation by the atmosphere and the dark parts of the Earth's surface causes the molecules of the object or surface it strikes to vibrate faster, increasing its temperature. The absorbed energy is then re-radiated or re-emitted as invisible infrared radiation, also known as heat. That re-emitted radiation is partly absorbed by molecules like water vapour and carbon dioxide (CO_2), thereby trapping heat and leading to warming. This is called the planet's natural ***greenhouse effect***. This natural process maintains the Earth's temperature warmer than it would otherwise be, allowing life on Earth to exist. These heat-trapping gases are called ***greenhouse gases****.* The global build-up of greenhouse gases (GHGs) amplifying the greenhouse effect, which is resulting in ***global warming***. The cumulative impact of warming is causing the Earth ***climate system to change*** dramatically and irreversibly. The planet has already heated by about 1.0°C in the last century, and temperatures have continued to rise.

9.1.1 Historical Sketch: Greenhouse effect and global warming

The conception of the atmospheric greenhouse effect can be traced back to Jeen-Baptiste Joseph Fourier (1827) work, a French mathematician and physicist. His calculations indicated that Earth's average temperature should actually be much colder (-18°C) instead of the much warmer (+15°C). The name "greenhouse effect" was coined to explain this additional heating (i.e., +15°C -(-18°C) = +33°C) of Earth's surface and atmosphere. He recognised that the atmosphere is relatively transparent to the incoming solar radiation, but highly absorbent to the outgoing terrestrial radiation, thus helping to maintain Earth's surface temperature. The Earth would be a frozen block of ice without this natural greenhouse effect. Later, John Tyndall (1861) carried out laboratory experiments on the radiative properties of various gases (CO_2, H_2O, O_3, Hydrocarbons, O_2, N_2, H, etc.) and measured the heat absorption by gases through carefully designed and developed first ratio spectrophotometer in his laboratory. He deduced that the water vapour and carbonic acid (now known as Carbon Dioxide: CO_2) absorb much more radiant heat than the gases of the atmosphere and inferred the consequent significance of these gases in moderating Earth's climate (i.e., natural greenhouse effect). He concluded that water vapour is the dominant gaseous absorber of radiant heat among the constituents of the atmosphere. The infrared spectroscopy revealed that some of the gases have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation. Gases with two atoms (such as O_2) can only vibrate by stretching (back and forth), and these vibrations are much faster than the infrared radiation frequencies. Gases with poly atoms (such as CO_2) vibrate by stretching as well, but they can also vibrate in other ways, such as by bending. These vibrations are slower and match infrared radiation frequencies. Thus, the most abundant gas molecules in the atmosphere (N_2 and O_2) are not heat-trapping gases at infrared frequencies, while the minor constituents (Carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and certain other gases) absorb infrared radiation from the Earth's surface and re-emit it in all directions. Later, Arrhenius (1896) calculated the thermal effect of rising carbon dioxide (CO_2) levels in the atmosphere and laid the formal foundation linking atmospheric gases to climate change. He was first to calculate the surface temperature increase due to an increase in CO_2 in the atmosphere and predicted that a doubling of CO_2 due to fossil fuel burning alone would lead to a temperature increases of about 3-4°C. This is probably the first study to have provided a model for the effect of industrial activity on global warming (i.e., anthropogenic greenhouse effect). The data essential for monitoring and understanding such changes and its consequences has predominantly utilised remote sensing observations from Earth Observation (EO) missions. Over the past 50 years, a range of satellite platforms carrying many different sensors have been constructed to monitor parameters used in climatological studies, and the information retrieved from satellite-based sensors has greatly enhanced our understanding of global warming and climate change. This chapter discusses the pivotal role of remote sensing observations played in demonstrating that climate change is occurring and understanding the processes of global climate change.

9.1.2 Satellite Era

The remote sensing data from Earth Observation satellites have changed the way that we understand the Earth's climate system. Monitoring of the Earth-atmosphere system evolved with the advent of the satellite era in the early 1960s and subsequently the Earth observation technology has been widely applied in climate change research. In India, development of EO technology for remote sensing applications began in 1970s (Kasturirangan et al., 1991; 1996). In the years and decades that followed, a range of satellite platforms carrying different sensors provided valuable information about the state of the climate system in an area-wide and near-continuous manner, and the retrieved information from satellite-based sensors has allowed enhancing our understanding of the processes and dynamics within the Earth's climate system. Consequently, this large quantity of Earth observation data has facilitated the development of global climate change research.

9.2 Remote Sensing of Earth's Energy Balance

Climate change is related directly to Earth-atmosphere energy balance, thus the measurements of flow of radiation energy within Earth-atmosphere system are at the heart of the climate change discussions. The launch of Earth Radiation Budget Experiment sensors (ERBE) sensor (by NOAA in 1980), Scanner Radiometer for Radiation Balance (ScaRaB) sensor (by France, Germany and USSR in 1994); Clouds and the Earth's Radiant Energy System (CERES) sensor (by NASA in 1997), Scanner for Radiation Budget (ScaRaB) sensor (by ISRO & CNES in 2011) and so on., made it possible to measure the outgoing longwave radiation, incoming solar radiation, and reflected solar radiation at top-of-atmosphere; thus assisted to understand the drivers of the changes. Further, ISRO launched ScaRaB sensor (abroad Megha-Tropiques satellite) in a circular orbit with low inclination has greatly enhanced the latitudinal sampling of the tropical regions by up to 4-5 observations per day of the same footprint over the tropics compared to typical low earth observing platforms. This unique approach provided the improved diurnal sampling of the Earth's radiation budget. This unique Megha-Tropiques satellite mission has two more payloads viz., Microwave Analysis and Detection of Rain and Atmospheric Structures (MADRAS) and Sounder for Atmospheric Profiling of Humidity in the Inter-tropics by Radiometry (SAPHIR) that provided additional data for understanding hydrological cycle simultaneously. These satellite measurements facilitated the depictions of energy flows in the global climate system and the global annual mean energy budget of Earth date to the beginning of the twentieth century, is depicted in Figure 9.1. This initial iconic picture of global annual mean energy budget of Earth (Kiehl and Trenberth, 1997) are prominently featured in climate change assessment reports as well as in many publications and text books.

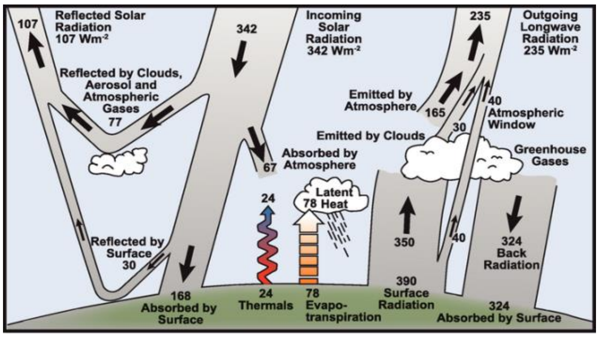


Fig. 9.1 The global annual mean energy budget of planet Earth beginning of the twentieth century with the new and recent satellite missions. Numbers indicate magnitudes of the flows in Wm^{-2}. (Source: IPCC, 2021)

In addition, the remote sensing data assisted in directly measuring the greenhouse effect and global warming.

Measuring the Greenhouse Effect*:* The infrared energy from the surface was 390Wm^{-2} while the energy escaping to space was only 235 Wm^{-2} (whereas under cloud-free conditions was only 205 Wm^{-2}). The trapping of the infrared energy by the intervening atmosphere led to the reduction of infrared energy by 155 Wm^{-2} (i.e., 390-235). Thus, the greenhouse effect was determined to be 155 Wm^{-2} under all sky conditions; whereas it is 125 Wm^{-2} under cloud-free conditions. This greenhouse effect of 125 Wm^{-2} is the sum of natural and anthropogenic effects under cloud-free conditions.

Quantification of Natural versus Anthropogenic Greenhouse Effect: The climate change assessment reports (IPCC, 2021) that the increase in the infrared energy trapped by the greenhouse gases emitted by human activities is estimated to be around 3.8 Wm^{-2}; after incorporating observed increase in the concentrations of greenhouse gases since the 1750s and integrating them with the quantum mechanical parameters for absorption of infrared radiation. By comparing this number with the 125 Wm^{-2} inferred from the satellite data for natural and anthropogenic greenhouse effect, it can be inferred that the Natural Greenhouse Effect by the atmospheric gases is 121.2 Wm^{-2} and the Anthropogenic Effect is 3.8 Wm^{-2}. Thus, human activities have thickened the atmospheric greenhouse blanket by 3% since 1750s.

Greenhouse Effect to Global Warming link: In response to the anthropogenic contribution of 3.8 Wm^{-2} to the infrared energy to the planet, the planet will warm and radiate this energy in order to restore the energy balance. For an easy explanation, assume that the surface and the atmosphere behave like black body, in which case it will radiate energy to space as a black body, which is given by σT^4, where σ is a Stefan-Boltzmann constant and T^4 denotes the fourth power of temperature T. From the Stefan-Boltzmann law, the surface and the atmosphere will radiate 3.3 Wm^{-2} per 1°C of warming. It means that the planet can dispose of 3.3 Wm^{-2} for every degree warming. So to dispose of the anthropogenic (3.8 Wm^{-2}) energy trapped by manmade greenhouse gases, the planet will warm by (3.8/3.3=) 1.2°C. However, this simple explanation ignored some major feedbacks between warming and atmospheric greenhouse effect and planetary albedo. [The greenhouse effect of water vapour increases by about 1.4 Wm^{-2} for each degree of warming. Thus, the inclusion of the water vapour feedback would increase the projected warming from 1.2°C to 2.6°C].

Planetary Albedo: The percentage of incoming solar radiation that is reflected to space is referred as the planetary albedo, which is around (107/342 =) 31%. This was one of the major achievements obtained from early satellite remote sensing of Earth.

Thus, the remote sensing of energy fluxes greatly assisted to measure how Earth's climate responds to increasing concentrations of greenhouse gases.

9.3 Remote sensing of atmospheric composition

The advances in Earth Observation technology and retrieval techniques have offered new opportunities for measuring carbon dioxide (CO_2), methane (CH_4), Ozone (O_3) and other GHGs from the space-based high-resolution spectra of reflected solar radiation from, and/or thermal radiation emitted by, the Earth's surface and atmosphere.

9.3.1 Ozone

One among the several greenhouse gases is Ozone, which is the most important gas for the photochemistry of the atmosphere. The chemistry and chemical composition of the atmosphere would be very different without Ozone. Atmospheric Ozone in the stratosphere plays a critical role in limiting the penetration of biologically harmful solar ultraviolet radiation to the Earth's surface. The average concentration of total columnar Ozone in the atmosphere amounts to only about 0.3 per million air molecules (or 300 Dobson units which is equivalent to a layer 3 millimeters), but it nevertheless suffices to absorb the main part of the dangerous solar ultraviolet radiation. In the 1970s concern about the effect of man-made chemicals, especially chlorofluorocarbons (CFCs), on the Antarctic stratospheric ozone layer were raised by Paul Crutzen, Mario Molina and Sherwood Rowland (received Nobel Prize in 1995 for the same). Through industrialisation, another class of compounds, namely species such as the chlorofluorocarbons (CFCs, Freons), methyl chloroform (trichloroethane), and halogenated chlorofluorocarbons (HCFCs) were produced as safer chemicals for refrigerators used in large commercial applications. Thomas Midgley of General Motors first synthesized CFCs in 1928. CFCs are one of the most popular refrigerants used then. These are exclusively human-made artificial compounds and have no natural sources in the Earth system. These compounds have no significant biological sinks in the Earth system since they are produced industrially and the only major sink is photochemical breakdown in the atmosphere. Molina and Rowland (1974) hypothesized that Cl and ClO_3 released to the atmosphere from the photochemical decay of CFC gases, could deplete Ozone by a similar chain of catalytic reactions as repotred earlier with NO and NO_2 by Crutzen (1971). Nitrogen oxides (NOx), emitted from the large fleets of supersonic transport aircrafts, react catalytically with ozone (O_3), breaking it down into molecular oxygen (O_2). Thus, these gases NOx and ClOx are called as "Ozone killers".

By 1985, the presence of an annually occurring Ozone hole over Antarctica was observed using ground-based measurements. The Antarctic ozone hole is a thinning or depletion of ozone in the stratosphere over the Antarctic each spring (as shown in Figure 19.2). Under certain low-temperature conditions the CFC have the additional property of destroying stratospheric ozone, which is dramatically demonstrated every spring over Antarctica. Atmospheric researchers have since reported thinning of stratospheric ozone layer (i.e., Ozone hole) is driven in part by the special meteorological conditions over Antarctica during spring time, which cause CFCs above the continent to be particularly effective in depleting ozone.

Since the detection of ozone depletion in the Antarctic stratosphere, the Antarctic stratospheric ozone has been continuously monitored using remote sensing satellites. Since Ozone has emerged as a global environmental problem, several remote sensing satellite sensors data, for instance Ozone Monitoring Instrument (OMI), Total Ozone Monitoring Spectrometer (TOMS), Global Ozone Monitoring Experiment (GOME), Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY), Microwave Limb Sounder (MLS), and Global Ozone Monitoring Experiment (GOME) are used to measure the Total Columnar Ozone. The remote sensing data from the Ozone Mapping and Profiler Suite (OMPS) instrument onboard the Suomi-NPP satellite indicates the presence of lower concentrations of Ozone over Antarctica on Sept 25, 2022, as depicted in Figure 9.2.

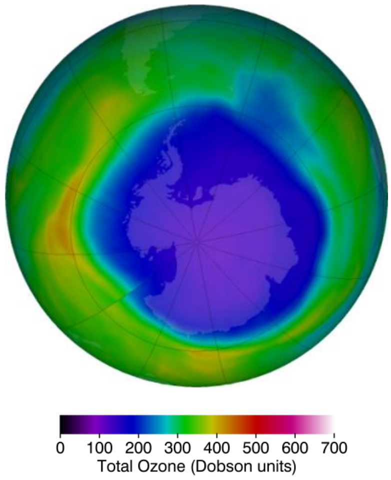


Fig 9.2 The Ozone hole is the region over Antarctica with total Ozone of 220 Dobson Units or lower. The false-color view of the total ozone over the Antarctic pole for Sept 25, 2022. The blue and purple colors are where there is the least ozone, and the yellows and reds are where there is more ozone. The data is from the Ozone Mapping and Profiler Suite (OMPS) instrument onboard the Suomi-NPP satellite. (Courtesy: Image are from NASA Ozone Watch: https://ozonewatch.gsfc.nasa.gov/monthly/monthly_1979-09_SH.html)

Following the discovery of the Antarctic ozone hole, scientists raised the alarm to the international community, which came together to set out an ambitious set of measures to phase out ozone depleting substances, under the Montreal Protocol. The Montreal protocol that came into effect in 1989 was updated in 2016 with the Kigali Amendment to address the emerging threat of ozone depleting gases. The adoption of the Montreal Protocol proved to be a crucial turning point, drastically reducing the release of CFCs into the atmosphere. However, reversing ozone depletion is a slow process and the ozone layer is expected to take several decades to recover. Through the invention and emissions of CFCs, humankind has created a chemical instability, leading to rapid loss of Ozone in the stratosphere.

In the troposphere there is very little ozone. Until about 1980s, it was thought that the troposphere contained only ozone that had been transported down from the stratosphere. Tropospheric ozone makes up only about 10% of all ozone in the atmosphere. At that time tropospheric ozone was considered to be interesting only in the study of atmospheric transport, and its enormous importance for the chemistry of the troposphere was not recognised. Subsequently, it was realised that the Tropospheric ozone (O_3) is the third most important anthropogenic greenhouse gas after carbon dioxide (CO_2) and methane (CH_4). Ozone is formed from other pollutants such as volatile organic compounds (VOCs) and nitrogen oxides that are emitted from industrial sources, power plants, cars, and trucks. These chemicals are transformed by sunlight in a chemical reaction that breaks down oxygen in the air and results in ozone formation. Ozone absorbs infrared radiation (heat) from the Earth's surface, reducing the amount of radiation that escapes to space; thus, contributing to the warming. Ozone in the stratosphere is beneficial because it protects us from the damaging ultraviolet rays of the sun. But the near-surface ozone is extremely toxic to our lungs. Ozone in the lower troposphere is also known as smog because it creates a gray-brown haze that looks like a combination of smoke and fog. ISRO's geostationary Indian National Satellite (INSAT-3D) sounder is providing spatial and temporal distribution of Ozone at regional level since 2013. Figure 9.3 shows the spatiotemporal distribution of Ozone over the Indian sub-continent for 2014. The Ozone measurements from INSAT-3D sounder gained prominence in air quality, model validation and climate studies.

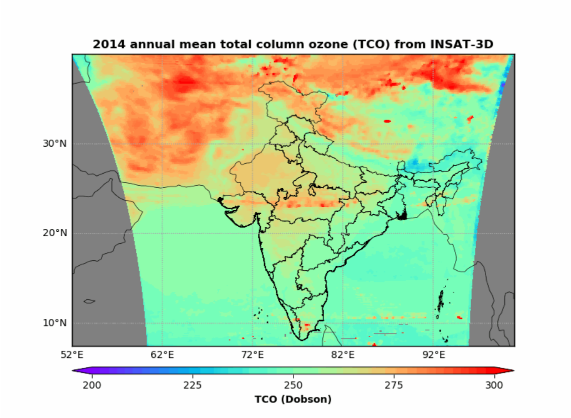


Fig 9.3 Total Columnar Ozone from INSAT-3D sounder data for 2014 (Source: ISRO)

9.3.2 Remote sensing of CO_2 and CH_4

Initial efforts to retrieve GHGs from space-based measurements used thermal infrared (TIR) observations that were routinely collected by meteorological sounders. For example, CO_2 and CH_4 were retrieved using the satellite observations from NOAA's High resolution Infrared Radiation Sounder (HIRS-2), the NASA's Atmospheric Infrared Sounder (AIRS) the Infrared Atmospheric Sounding Interferometer (IASI) and the Tropospheric Emission Spectrometer (TES). In addition to the above near-nadir looking instruments, the observations of limb emission data from Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) sensor abroad ESA's ENVISAT satellite were utilised to retrieve the vertical profiles of CH_4 and N_2O in the stratosphere and mesosphere. These measurements helped to estimate GHG fluxes at monthly intervals at regional to hemispheric scales, and assisted the data assimilation experiments of the Atmospheric Monitoring Services to provide GHG forecasts. In addition, the solar occultation measurements available from two satellite sensors, namely SCIMACHY and ACE sensors have also been utilised to estimate the CO_2 and CH_4 profiles. The GHG datasets from these sensors assisted various studies ranging from greenhouse gas transport, trends and processes in the upper troposphere or above. In 2018, ISRO launched HySIS, a hyperspectral imaging observation satellite to study the Earth's surface in visible, near-infrared and shortwave-infrared regions. The next generation Earth observation satellite sensors, including the ESAs SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY), the Japanese GOSAT (Greenhouse Gases Observing Satellite), and NASA's OCO-2 (Orbiting Carbon Observatory-2), European Commission Copernicus Sentinel 5 Precursor (S5P) TROPOspheric Monitoring Instrument (TROPOMI), have used high-resolution spectroscopic measurements of reflected sunlight within CO_2 and CH_4 bands at short wavelength infrared (SWIR) wavelengths. The global mean atmospheric CO_2 and CH_4 concentrations since 2009 using GOSAT observations are shown in Figure 9.4. The magnitude and the growth of the trend line are assisting to understanding global warming issues.

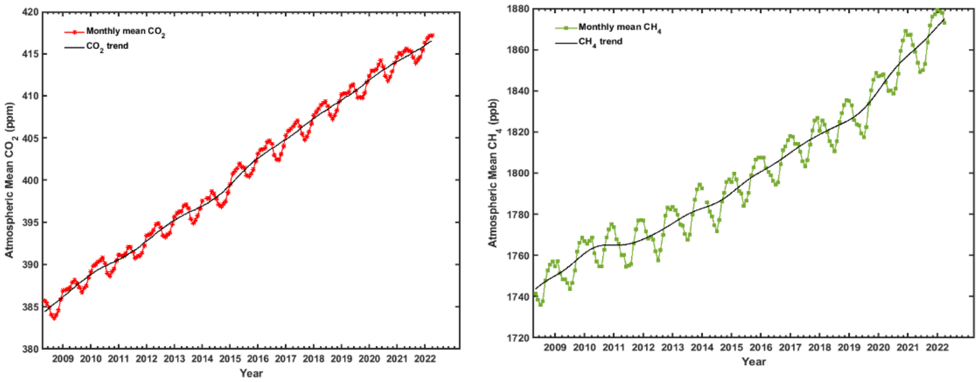


Fig 9.4 The global mean atmospheric (a) CO2 and (b) CH_4 concentration using the observational data collected by the Greenhouse Gases Observing Satellite (GOSAT) since April 2009. The respective seasonal changes and yearly rise are also depicted in the figure. The magnitude and the growth of the trend line are important to discuss global warming issues. (Source: Data from GOSAT project).

These advancements in space technology assisted the scientific community to document the enhancement in GHGs in the atmosphere. The concentration of CO_2 in the atmosphere before 1850 was around 275ppm (based on measurements of ancient air bubbles trapped in ice and other data), meaning that humans have now increased the overall concentration of CO_2 by nearly 50% since the pre-industrial era. More than half of this increase has occurred since 1980. Over the same period of time, the globally averaged atmospheric CH_4 concentration increased by more than 2.5 times, from 720 parts per billion (i.e., 0.72 ppm in 1750) to more than 1.9 ppm today. Other GHG concentrations in 2019 were: nitrous oxide (N_2O) in 332ppb; perfluorocarbons (PFCs) in 109 parts per trillion (ppt) CF4 equivalent; sulphur hexafluoride (SF6) in 10 ppt; nitrogen trifluoride (NF_3) in 2 ppt; hydrofluorocarbons (HFCs) in 237ppt HFC-134a equivalent and other Montreal Protocol gases (mainly chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)) in1032 ppt CFC-12 equivalent. These observed changes in the atmospheric composition have raised the concerns about anthropogenic climate change since these GHGs are efficient in trapping thermal radiation and thereby warming the surface.

9.3.3 Remote sensing of Aerosols

The human activities, particularly from coal combustion, diesel combustion and biomass burning, have also resulted in addition of particles to the atmosphere, called aerosols. Aerosols, through scattering and/or absorbing incoming solar radiation and emitting and/or absorbing infrared radiation, alter the radiation budget at the surface and the top of the atmosphere. These aerosol-induced changes in the radiation budget are referred to as direct effect. On top of aerosol direct effects on climate, aerosols also impact atmospheric radiation indirectly by affecting cloud properties. Aerosols act as cloud condensation nuclei, and thus exert significant indirect climate effect through interactions with clouds. It is reported that aerosols increases cloud reflectivity due to more and smaller cloud droplets forming on the aerosol (Twomey, 1977) and by increasing the lifetime of clouds due to reduced precipitation in clouds with more and smaller droplets (Albrecht, 1989). Further, aerosols may increase or decrease cloud cover based on cloud type and relative position of aerosol layers. This indirect effect is acknowledged to be the largest source of uncertainty in understanding the human impact on the global climate (IPCC, 2021).

Since 1990s, satellite remote sensing observations of aerosols assisted in enhancing the knowledge on the impact aerosols. The launch of MODIS-Terra satellite in 2001 (by NASA), have revealed that, due to fast long-range transport, aerosols are transported across continents and ocean basins, resulting in trans-oceanic and trans-continental plumes. ISRO's Ocean Colour Monitor (OCM) sensor (on-board Oceansat-1 (1999-2010), Oceansat-2 (2010-2022) and EOS-6 (2023 onwards) satellites) is providing aerosol optical property, namely aerosol optical depth (AOD) at 865nm (Chauhan et al., 2009). AOD is a good index for column-averaged scattering and absorption. Further, the imager on-board geostationary satellite, INSAT-3D, providing AOD at broad visible channel (i.e., 0.55-0.75μm) over South Asian Region (Mishra 2018), as shown in Figure 9.5. The AOD data from low Earth Orbiting satellites (ex: Oceansat) are providing daily global coverage, whereas the geostationary meteorological satellites (INSAT) are offering observations on diurnal evolution of pollution fields over part of the globe with a fast revisit time. The satellite remotely sensed aerosol products are being utilised in various applications, such as deriving surface-level $PM_{2.5}$, air quality assessment and forecasting, monitoring urban and industrial pollution, improving model first guesses, and deriving fire emission amounts. More importantly, the satellite remote sensing of high-quality aerosols parameters enabled the scientific community to quantify the aerosol radiation forcing at regional and global levels.

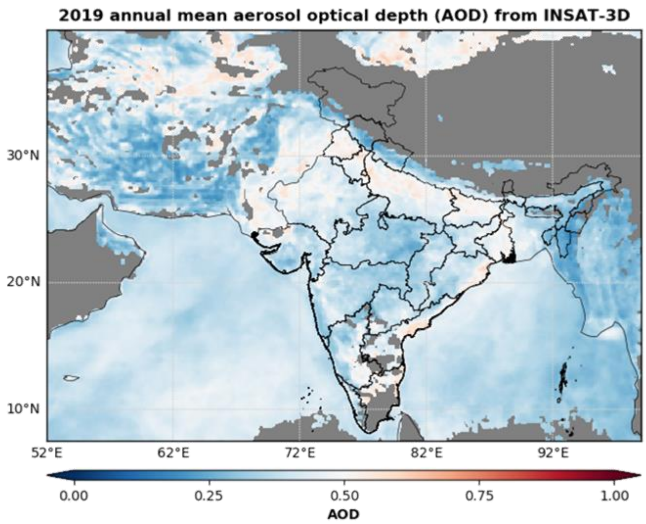


Fig 9.5: Annual mean aerosol optical depths (AOD) for 2019 derived from imager sensor on ISRO's INSAT-3D satellite. The color shading is dark blue for AODs smaller than 0.05 (clean marine), light blue for 0.2 (moderately polluted), white for 0.4 to 0.5 (very hazy) and red for AODs>0.6 (heavily polluted) (Source: ISRO).

The aerosols over various parts of the globe (E. Asia, S. Asia, the Atlantic, Western Pacific, Mediterranean, in Europe, N. and S. America and Africa) indicate a large reduction of the seasonal averaged solar radiation of the order of 5% to 10%. The worldwide distributed surface radiometers data also showed a general decrease of surface reaching solar radiation over land surfaces on the order of 4% to 6% over 30 years from about 1960 until 1990 (Stanhill and Cohen, 2001). Black Carbon (BC) aerosols observed to play a significant role in the aerosol forcing by partially shielding the surface reaching solar radiation and enhancing the atmospheric solar radiative heating. While scattering aerosols (sulfates, nitrates, etc.) reported to have a negative forcing (i.e., surface cooling effect). The climate assessment reports estimated that aerosols are contributing to near surface warming of $-1.1\ W\ m^{-2}$ with much wider range in uncertainty (-1.7 to $-0.4\ Wm^{-2}$). This suggests that the magnitude of this aerosol-induced cooling effect remains highly uncertain due to the complexity of the composition and lifecycles of aerosols.

9.3.4 Surface warming due to GHGs and cooling due to Aerosols

The greenhouse gases, including ozone and stratospheric water vapour from methane oxidation, are estimated to contribute to warming of 3.84 Wm^{-2} from pre-industrial period to the present (i.e., over 1750–2019 time period). CO_2 alone is estimated to contribute around 2.16 Wm^{-2} and non-CO_2 gases estimated to contribute around 1.68 Wm^{-2} (IPCC, 2021). The estimated contribution due to the increase in aerosols is −1.1 Wm^{-2} over 1750–2019. Overall, the aerosol climate forcing tends to partly offset the global warming impacts associated with greenhouse gases (GHGs). However, GHG forcing is distributed globally and is cumulative with time, while the aerosol forcing is concentrated regionally. On top of this, aerosols act as cloud condensation nuclei, and thus can have significant indirect climate effect through interactions with clouds. Finally, without improved quantification of the masking effect of aerosols, it is difficult to assess the warming in the coming decades.

9.4 Remote sensing of Arctic Sea Ice

In recent decades, several studies have reported that the Arctic is warming faster than the rest of the planet, a phenomenon known as "Arctic amplification". The recent technological advancements and the launch of satellite altimeters and scatterometers are able to measure the Arctic cryosphere climate parameters (since 2003 and 1999 respectively). Also, satellite-based passive microwave images of the Arctic Sea ice reached its minimum extent on Sept 18, 2022, as shown in Figure 19.6 September Arctic Sea ice is now reported to be shrinking at a rate of 12.6% per decade, compared to its average extent during the period from 1981 to 2010 (from sonar-based measurements). It is suggested that surface warming by GHGs would lead to an increase in the melting of snow and ice and the exposure of the underlying darker surface would lead to more absorption of solar radiation. The albedo (percent reflection of solar radiation) of fresh snow is about 80% or more, whereas land surface albedo is typically about 10% to 40%, while that of the underlying ocean water is about 5% to 20%. In general, warming tends to decrease ice cover and hence decrease the albedo (i.e., ice albedo value to water albedo value if over ocean or ice albedo value to land surface albedo value if over land surface), which thus increases the amount of solar energy absorbed and leading to more warming. Thus, the retreat of sea-ice and snow would lead to amplification of global warming. The annual mean sea ice retreat from 63% to 53% is observed to darkening the Arctic region by 0.04, from 0.52 to 0.48 of Arctic planetary albedo, between 1979 and 2011. The increased solar energy absorbed by the Arctic Ocean was about the same as the added energy trapped by thickening the CO_2 greenhouse blanket by 25%. In addition to the above contributing factor, deposition of dark soot over bright sea-ice and snow surfaces increases the absorption of solar radiation by ice and snow which is another source of warming.

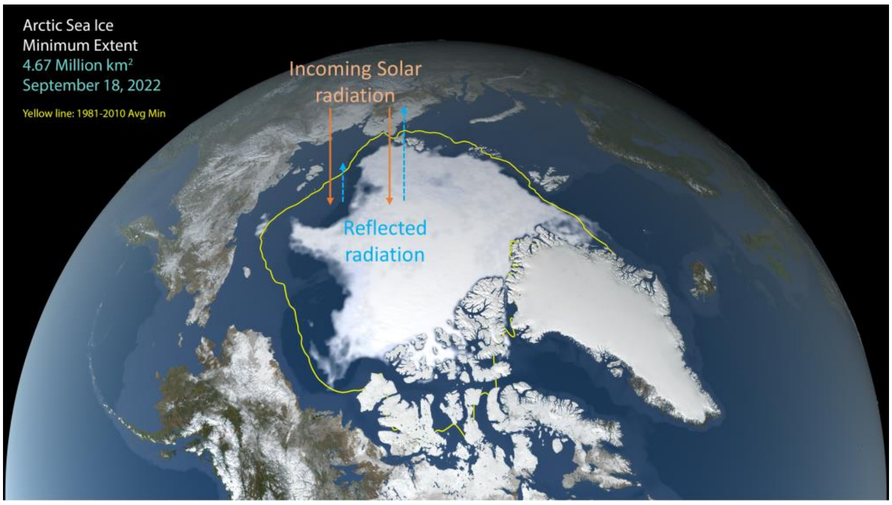


Fig 9.6 This image visualizes sea ice change in the Arctic using data provided by the Japan Aerospace Exploration Agency's Global Change Observation Mission 1st-Water "SHIZUKU" satellite, which is part of a NASA-led partnership to operate several Earth-observing satellites. (Credit: NASA's Scientific Visualization Studio).

9.5 Remote sensing of Land Use Land Cover

Human-induced changes in Earth's natural landscapes is resulting an alteration in surface albedo, which in turn contributing to an imbalance in the Earth System's energy, water and emission fluxes via land-use and land-cover (LULC) changes. The anthropogenic LULC changes are crucial to many diverse applications such as environment, forestry, hydrology, agriculture and geology. Furthermore, climate change models are built on LULC data and thus require long-term LULC data at various spatiotemporal scales for modelling exercises. As a result, LULC research has gained increased attention over recent decades.

The generation of global LULC maps originated from the AVHRR sensor on board the NOAA satellites launched in 1978 and the VEGETATION sensor, installed in the SPOT satellite in 1998. The Landsat satellite program, with its continual global coverage since 1972, provided the moderate to high resolution LULC maps at regional and local scales. Nowadays, there are many sources of annual maps of global LULC data, which include NASA's MODIS sensor (500 m resolution) datasets, ESA's Climate Change Initiative (CCI) at 300m resolution datasets, Copernicus Global Land Service (CGLS) Land Cover 100 m dataset and ISRO's Land use Land cover dataset. The LULC classification schema proposed by USGS in 1976 (Anderson et. al., 1976) was the first standard classification. Later, several classifications schemes evolved over the period of time, such as the International Geosphere Biosphere Programme (IGBP with 17 classes), the Land Cover Classification Scheme (LCCS with 22 classes), MapBiomas classification (5 major classes), and GlobeLand30 land cover types (10 classes).

In India, ISRO is generating and disseminating LULC data at around 56-m grid resolution at annual interval from 2004 onwards, using the Advanced Wide Field Sensor (AWiFS) of Resourcesat satellite series. Roy et al., (2015) generated LULC data for India at medium resolution (~30 m) for three decades (1985–1995–2005), using the earlier inventory LULC datasets from different sources (i.e., Landsat, IRS 1C- Linear Imaging Self-Scanner (LISSS)) along with the LULC datasets developed from remote sensing datasets available from Resourcesat satellite series. The generated time-series maps for three decades adopting IGBP classification scheme is shown is Figure 9.7.

Around 0.1% of the total geographic area of India has undergone changes during this time period. Majorly, a loss of forest cover in central and northeast India, increase of mangroves area, increase of cropland area in Western India, growth of peri-urban area, and relative increase in plantations were observed (Roy et al., 2015). However, at global level, the contribution of land-use change to albedo changes was investigated using MODIS and AVHRR to attribute surface albedo to geographically specific land-cover types. The contribution from land-use change is –0.20 ± 0.10 Wm–2 for the period 1750-2019, thus making it the fourth most important anthropogenic driver of climate change.

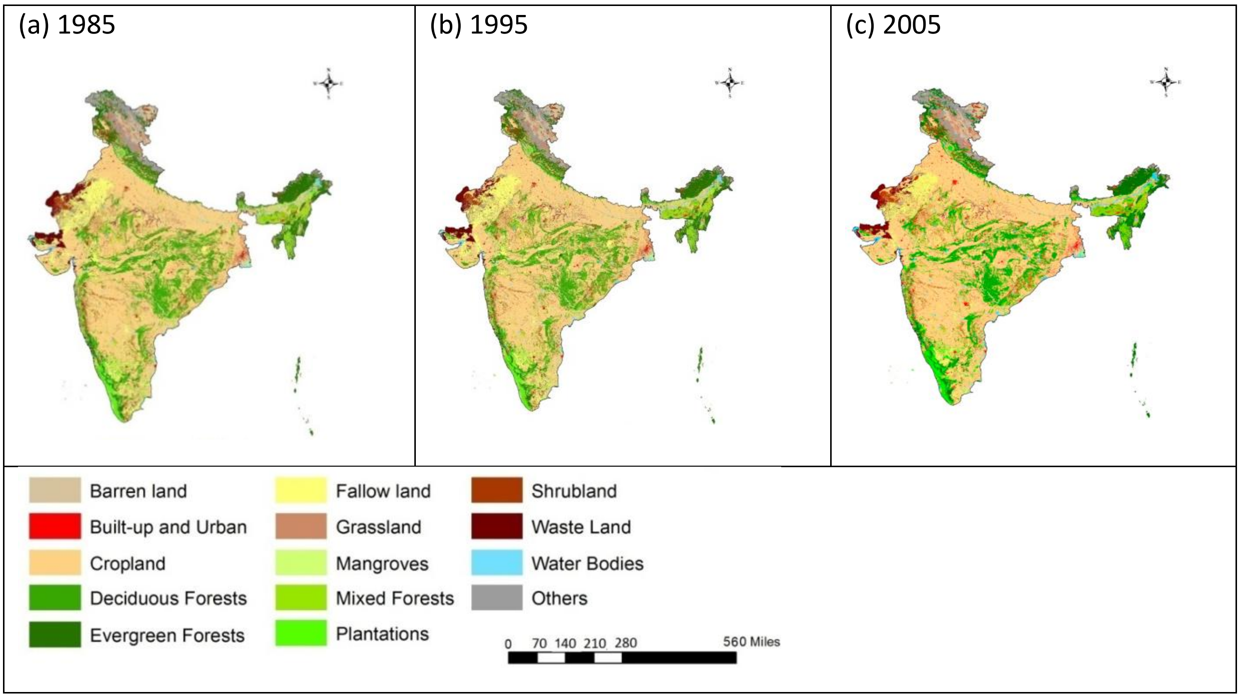


Fig 9.7 Land cover and land use (LULC) map of India prepared using satellite remote sensing data sets for the years (a) 1985, (b) 1995, and (c) 2005. (Courtesy: Openly Sourced from Roy et al., 2015).

9.6 Stratospheric Water vapor

Stratospheric water vapour is recognized as one of the potentially important drivers of global climate change. However, the distributions of water vapour in the upper troposphere and the stratosphere are not very well known due to limitations of high vertical resolution observations in this region of the atmosphere. The advent of remote sensing of atmospheric sounding techniques assisted to document the water vapour changes in the upper troposphere and lower stratosphere. For example, SAPHIR sensor on-board Megha-tropiques mission providing relative humidity data for different layers (1000–850 mb, 850–700 mb, 700–550 mb, 550–400 mb, 400–250 mb and 250–100 mb) of the atmosphere. Figure 9.8 shows the annual average upper tropospheric relative humidity for 400-250mb layer over the tropics in 2014. Water vapour is also a greenhouse gas and its interannual variations in stratosphere are reported to have important climatic consequences. Due to enhancement in stratospheric water vapour is reported to be contributing the warming around 0.05 ± 0.05 Wm^{-2} (IPCC, 2021).

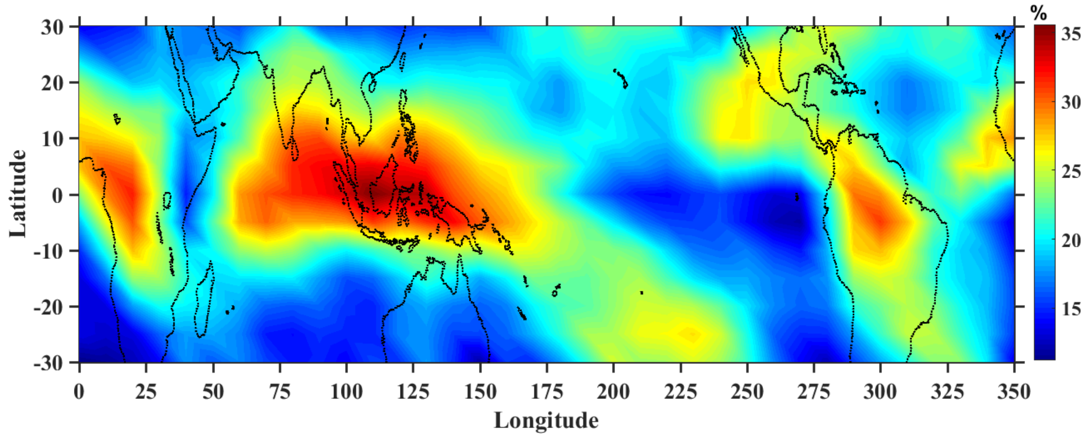


Fig. 9.8 Annually Relative Humidity fields derived from a microwave humidity sounder 400–250 mb layer for 2014 (Source: data from SAPHIR sensor on-board Megha-tropiques, ISRO).

9.7 Observed changes in climate indicators

The global warming is already having a measurable effect on the planet in the form of rising sea levels, Arctic Sea ice, retreating glaciers, increased frequency and intensity of extreme weather events, and a change in animal and plant ranges. It is also now clear that the temperature of the planet is increasing and the rate of increase is becoming greater. Land is heating faster than the oceans but both are warming. The increasing of night time temperatures is greater than day time temperatures. The troposphere is becoming warmer as the stratosphere cools. Below are some of the indicators.

9.7.1 Sea Level Change

Global sea level change is a key indicator for understanding how Earth's climate is changing. Long-term changes in global mean sea level rise are caused primarily by two factors related to global warming: the added water from melting ice sheets and glaciers, and the expansion of seawater as it warms. Further, water that is either removed from land (ex: through groundwater pumping) or stored on land (ex: through dam building) can cause a net change in the total water found in the ocean.

The use of satellite radar altimeters to measure global sea surface height (SSH) has come a long way since the brief Seasat mission of 1978. Early missions measured SSH with an accuracy of tens of metres. More recent high quality satellite altimeter missions such as TOPEX/Poseidon (launched August 1992) and Jason-1 (launched December 2001) measure SSH to an accuracy of a few centimetres. These satellites were specifically designed to measure SSH to the highest possible accuracy. ISRO launched the Satellite with ARGOS and ALTIKA (SARAL) in 2013, a joint Indo-French satellite mission for oceanographic studies. SARAL performs altimetric measurements designed to study ocean circulation and sea surface elevation. Recently, the Sentinel-6 Michael Freilich, a radar altimeter satellite developed in partnership between several European and American organizations, was lunched in Nov 2020 as a part of the Jason satellite series. These satellite radar altimeters assisting to measure the changes in global mean sea level for the past 27 years and providing information on how the ocean is warming and how much land ice is melting. The change in sea surface height across the globe from 1993 to 2019 is shown in Figure 9.9, as observed by satellite altimeters. The annual rate of global mean sea level rise is 0.20 cm per year in 1993 to the current yearly rate of 0.44 cm per year. In total, the rate of global mean sea level rise from 1993 to present has been measured at 0.34 cm per year. This data is also assisting the planners in understanding the trajectory of future sea level rise. Further, the GRACE and GRACE-FO satellites measure mass-driven changes in global mean sea level associated with ice melt and changes in land water storage. The Argo profiling floats measure temperature and salinity changes in the global ocean, and provide an estimate of thermosteric global mean sea level change. Combining the estimates from GRACE/GRACE-FO and Argo and then comparing to satellite altimeters data allows us to quantify the contributors to global mean sea level.

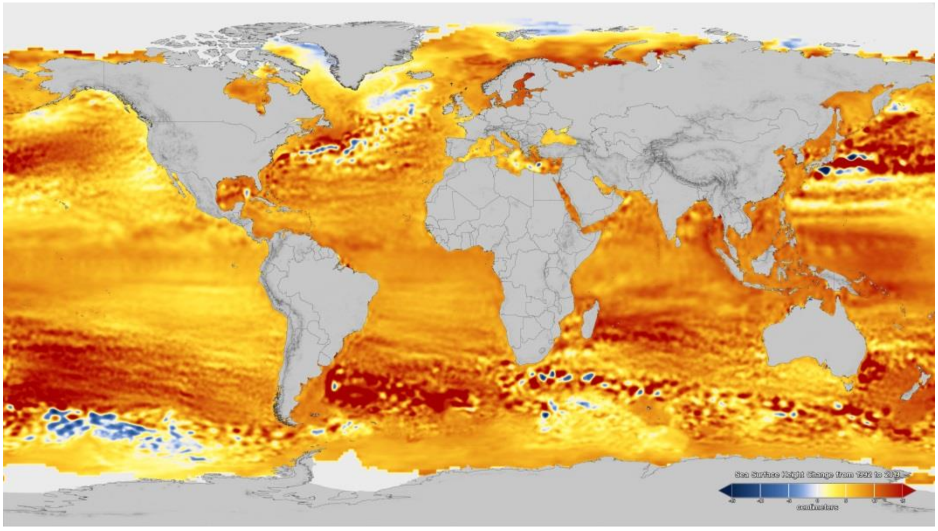


Fig. 9.9 Satellite altimeter measured sea surface height (SSH) of our ever-changing oceans. This image shows the change in sea surface height across the globe from 1993 to 2019 (Credit: NASA).

9.7.2 Greenland Ice Mass Loss

The satellite observations indicate that the mass of the Greenland ice sheet has been rapidly declining during the last several years due to surface melting and the breaking of ice chunks from the edge of a glacier (called iceberg calving). The measurements from Gravity Recovery and Climate Experiment (GRACE) satellites (2002-2017) and GRACE Follow-On (since 2018 onwards) indicates that between 2002 and 2023, Greenland lost approximately 270 gigatons of ice per year, causing global sea level to rise by 0.8 millimeters per year. Figure 9.10 shows the Greenland image and Greenland ice mass data since 2002, generated using GRACE and GRACE-FO data. In the figure, orange and red colour shades indicate areas that lost ice mass, while light blue colour shades indicate areas that gained ice mass. White indicates areas where there has been very little or no change in ice mass since 2002. In general, higher-elevation areas near the centre of Greenland experienced little to no change, while lower-elevation and coastal areas experienced over 6 meters of ice mass loss over this 21-year period. The largest mass decreases occurred along the West Greenland coast.

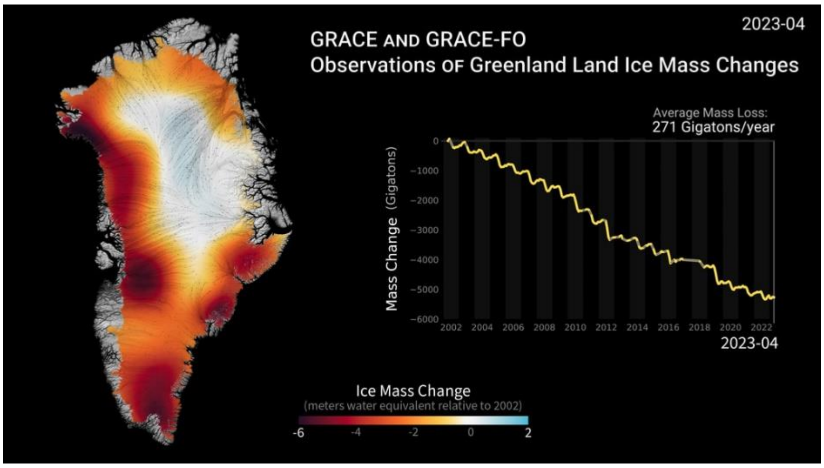


Fig. 9.10: These images, created from GRACE and GRACE-FO data, show changes in Greenland ice mass since 2002 (Credit: NASA and JPL/Caltech)

Further, Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere are observed. Following are the list of those indicators

Atmosphere and Water cycle:

- *Warming of global mean surface air temperature since 1850-1900*: From 1850–1900 to 2011–2020, the temperature increase over land (1.59 [1.34 to 1.83] °C) has been faster than over the oceans (0.88 [0.68 to 1.01] °C).
- *Warming of the lower troposphere since 1979*: Observed change in atmospheric temperature for the lower troposphere is 1.08°C over 1960-2019.
- *Cooling of the lower stratosphere since the mid-20th century*: Observed change in atmospheric temperature for the lower stratosphere is -1.36°C over 1960-2019. The total change during 1980-2019 is -1.03°C and 0.10°C during 2000-2019. Stratospheric ozone depletion was the main driver of stratospheric cooling between 1979 and the mid-1990s.
- *Expansion of the zonal mean Hadley circulation since the 1980*: annual mean Hadley circulation has shifted poleward at an approximate rate of 0.1°–0.5° latitude per decade over the last about 40 years (Allen and Kovilakam, 2017; Davis and Birner, 2017; Grise et al., 2018; Staten et al., 2018, 2020; Studholme and Gulev, 2018; Grise and Davis, 2020).
- *Large-scale precipitation and upper troposphere humidity changes since 1979*

Ocean

- *Ocean heat content increase since the 1970s*: At the ocean surface, temperature has, on average, increased by 0.88 [0.68 to 1.01] °C between 1850–1900 and 2011–2020, with 0.60 [0.44 to 0.74] °C of this warming having occurred since 1980. Ocean heat content has increased from 1971 to 2018 by 0.396 [0.329 to 0.463] yottajoules.
- *Salinity changes since the mid-20th century*: Globally the mean salinity contrast at near-surface between high- and low-salinity regions increased 0.14 [0.07 to 0.20] from 1950 to 2019 (i.e., near-surface high salinity regions have become more saline, while low salinity regions have become fresher since 1950).
- *Global mean sea level rise since 1970:* The average rate of sea level rise was 1.3 [0.6 to 2.1] mm.yr^{-1} between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm.yr^{-1} between 1971 and 2006, and further increasing to 3.7 [3.2 to –4.2] mm.yr^{-1} between 2006 and 2018

(IPCC, 2021). Since 1901, Global Mean Sea Level has risen by 0.20 [0.15 to 0.25] m at an accelerating rate.

Cryosphere

- *Arctic sea ice loss since 1979:* Over 1979–2019 Arctic Sea ice area has decreased for all months, with the strongest decrease in summer. Decadal means for SIA decreased from the first to the last decade in that period from 6.23 to 3.76 million km2 for September, and from 14.52 to 13.42 million km2 for March.
- *Reduction in Northern Hemisphere springtime snow cover since 1950*: The trend in April snow cover extent for the Northern Hemisphere over 1922–2018 period is –0.29 (± 0.07) million km^2 per decade.
- *Greenland ice sheet mass loss since 1990s*: The Greenland Ice Sheet lost 4890 [4140 to 5640] Gt (Sea Level Equivalent 13.5 [11.4 to 15.6] mm) of ice between 1992 and 2020. The rate of ice-sheet (including peripheral glaciers) mass loss rose from 120 [70 to 170] Gt yr–1 (Sea Level Equivalent 0.33 [0.18 to 0.47] mm yr–1) in 1901–1990 to 330 [290 to 370] Gt yr^{-1} (Sea Level Equivalent 0.91 [0.79 to 1.02] mm yr^{-1}) for 2006–2018.
- *Antarctic ice sheet mass loss since 1990s*: The Antarctic Ice Sheet lost 2670 [1800 to 3540] Gt (Sea Level Equivalent 7.4 [5.0 to 9.8] mm) of ice between 1992 and 2020. The rate of ice-sheet (including peripheral glaciers) mass loss rose from 0 [–36 to +40] Gt yr^{-1} (SLE 0.0 [–0.10 to 0.11] mm yr^{-1}) in 1901–1990 to 192 [145 to 239] Gt yr^{-1} (SLE 0.54 [0.47 to 0.61] mm yr^{-1}) for 2006–2018.
- *Retreat of glaciers*: Glaciers lost 6200 [4600 to 7800] Gt of mass (17.1 [12.7 to 21.5] mm global mean sea level equivalent) over the period 1993–2019.

Land

- *Mean surface air temperature over land* (about 40% larger than global mean warming)
- *Decline in Coastal wetlands:* Nearly 50% of coastal wetlands have been lost over the last 100 years, as a result of the combined effects of localised human pressures, sea level rise, warming and extreme climate events

Carbon cycle

- *Increased amplitude of the seasonal cycle of atmospheric CO2 since the early 1960s*: an amplitude increase of 6 ± 2.6% per decade has been observed at the Barrow surface observatory in Alaska over 1961–2011 (Graven et al., 2013)
- *Acidification of the global surface ocean:* the pH of the ocean surface had decreased since preindustrial times, primarily as a result of ocean uptake of CO_2 (global ocean absorbed 20–30% of total CO2 emissions since the 1980s). The surface open ocean pH has declined globally over the last 40 years by 0.003–0.026 pH per decade, and a decline in the ocean interior has been observed in all ocean basins over the past 2–3 decades.

Furthermore, climate change is already affecting many weather and climate extremes in every region across the globe (IPCC, 2021). The heatwaves have become more intense across most land regions and marine heatwaves have become more frequent in recent times. In addition, frequency and intensity of heavy precipitation events have increased over most land areas. Further, warming has contributed to increases in droughts in some regions, thus putting more stress on water supplies. It is likely that the sea level rise has increased the impacts of coastal storms. Currently, the economic impact of these extreme weather-related disasters is mounting.

9.8 Weather and Climate Extremes

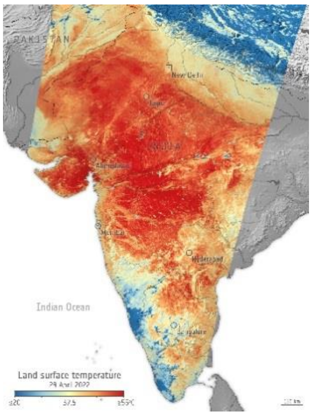
The global warming could exceed 2°C by 2050 with the unrestricted GHG emissions beyond 2030, which is expected to worsen the frequency, intensity, and impacts of some types of extreme weather events (IPCC, 2021). The advancement in satellite technology is enabling the monitoring of extreme weather events.

9.8.1 Heatwave and Marine heatwave

In general, a hot weather condition that persists for several consecutive days is defined as heatwave (Perkins, 2015). Consequently, identification of heatwave events depends upon two parameters, viz., high temperature threshold and the duration of threshold. The satellites retrievals of land surface temperatures (LST) and sea surface temperatures (SST) are assisting to identify the extreme high temperature regions over land and marine regions respectively. For example, the LST data, over India on April 29, 2022 from Sea and Land Surface Temperature Radiometer (SLSTR) sensor on-board Sentinel-3; exceeded 60°C in several areas, as depicted in Figure 19.11a. This data further assists in forecasting the near surface air temperature for furthering heatwave forecast. Further, such heat conditions can intensify hot and dry conditions, which can in turn contribute to wildfire conditions. Remote sensing data from Sentinel-3 mission is assisting to monitor wildfires as well as vegetation state.

In addition, some of the regions are experiencing severe marine heatwaves, especially in the seas surrounding the UK and Ireland. The figure 9.11b shows, the SLSTR retrieved sea surface temperatures over Atlantic Ocean and surrounding seas on 18 June 2023 compared with the long-term (1981-2016) average, indicating extremely warm conditions. Further, satellite data is assisting to document the impact of marine heatwave on the marine ecosystem, local wind patterns, and the impact on industries such as aquaculture and fisheries

(a)



(b)

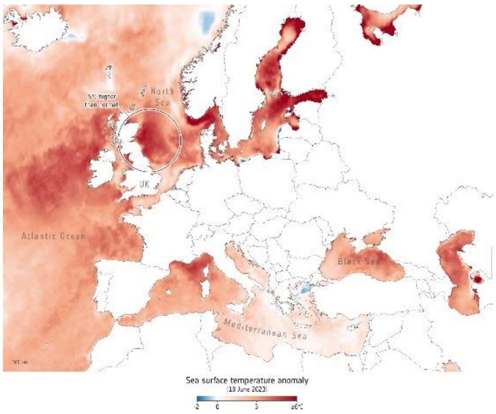


Fig. 9.11 Satellite measured (a) land surface temperature distribution over India on April 29, 2022 at 10.30 local time; and (b) sea surface temperature anomalies over Atlantic Ocean on July 18, 2023 (Source: images are from ESA website https://www.esa.int/ESA_Multimedia/Images/2022/04/Heatwave_across_India#:~:text=India%20is%20currently%20facing%20a,records%20over%20120%20years%20ago. Credit: ESA).

9.8.2 Cyclones and Floods

Tools for forecasting extreme weather events, like cyclones and floods, have advanced in recent decades due to the advancement in microwave-based radars such as SAR and scatterometer technologies. For example, ISRO's recently launched EOS-06 mission detected the Typhoon Mawar (also called Betty), the first typhoon of the season 2023, as depicted in Figure 9.12. It was the strongest northern hemisphere tropical cyclone on record in the month of May, and the strongest tropical cyclone worldwide in May 2023. This image captured by EOS-06 Scatterometer on 29th May 2023 and 31st May 2023 are showing the cyclonic wind vector patterns superimposed on Ocean Color Monitor (OCM-3) RGB image captured from the same satellite platform. The challenging issue with the cyclones is how to observe/measure the high intensity winds accurately under such extreme weather conditions. The remote sensing measurements are assisting short-term forecasting of these events, rapid intensification of extremely sever cyclone storms as well as understand climatological trends in tropical cyclone frequency, intensity, and spatial extent and the impact of these storms. In general, floods are among the most common and damaging of all natural hazards. Similarly, remote sensing technology is assisting in characterising the spatial extent of the flood affected region.

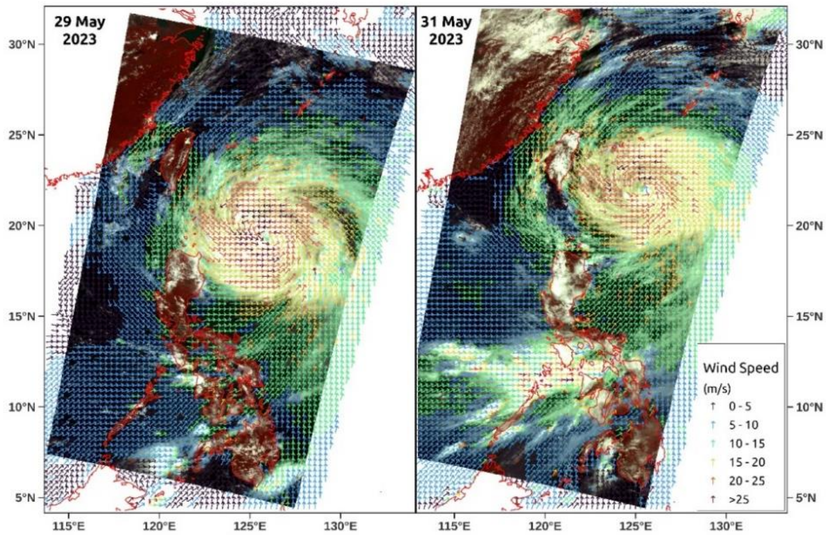


Fig. 9.12 ISRO's EOS-06 mission detected Cyclone Mawar on May 29, 2023 and May 31, 2023. EOS-06 Scatterometer on 29th May 2023 and 31st May 2023 are showing the cyclonic wind vector patterns superimposed on Ocean Color Monitor (OCM-3) RGB image captured from the same satellite platform. (Source: NRSC, ISRO)

Finally, more intense and frequent weather extremes will likely occur under changing climate scenario. In addition to the advancement in satellite technology as well as high spatiotemporal data, improved weather prediction models are vital to provide forecast for longer lead times for minimizing the damage and for effective planning.

9.9 Satellite Earth Observations in support of Climate Information on ECVs

The developments in Earth observation technology helped to acquire highly useful information in global climate change over the past few decades, especially through providing physical, chemical and biological parameters on a global scale. Considering the urgency and critical nature of climate change in recent years, space agencies have established space programmes dedicated to monitor and to track climate change. The Global Climate Observing System (GCOS) has set out requirements for satellite data to meet the needs of climate science, designating key variables that are currently feasible for observation and important to the United Nations Framework Convention on Climate

Change (UNFCCC) as “Essential Climate Variables” (ECVs) (GCOS 2011). Dedicated climate information services from a variety of space agencies now provide data on ECVs to characterize the state of the global climate system and enable long-term climate monitoring.

In order to meet CEOS commitments, the European Space Agency (ESA) has launched the Climate Change Initiative (CCI) to meet the challenging requirements of the climate community. The National Oceanic and Atmospheric Administration (NOAA) initiated Climate Data Record Program to develop and implement a robust, sustainable, and scientifically defensible approach to producing and preserving climate records from satellite data. The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) also had a program to provide certain climate data records in a sustained mode both within its own operational facility and its Climate Monitoring Satellite Application Facility. With the rapid expansion of Earth observation big data, on July 9, 2010, China launched a major national scientific research project on global change research. Likewise, ISRO has initiated a program called ***National Information system for Climate and Environment Studies (NICES)*** under the framework of the National Action Plan on Climate Change (NAPCC). The NICES program, a joint undertaking of ISRO and other Ministries and Institutions, was established in Sept 2012 to ensure that the climate data and information needed to address climate related issues are obtained and made available to all potential users. Since its inception, efforts have accelerated to generate and disseminate satellite-retrieved geophysical products and ECVs through NICES web-portal, as well as training and capacity building. The number of geophysical products that are currently available in the NICES/Bhuvan portal and the time span of the products are listed in the below table.

Time span (products)	**NICES Geophysical products**
20 - 30 years (5)	Ocean Heat Content, Ocean Mean Temperature, Tropical Cyclone Heat Potential, Eddy Kinetic Energy, Surface Soil Moisture
15-20 years (3)	Forest Fire, Snow Melt and Freeze, Mean Sea Level Anomaly
10-15 years (8)	Chlorophyll, Diffuse Attenuation at 490 (Kd_490), Land Use Land Cover (LULC), Land degradation, Tropospheric Ozone, Net sown area (Agriculture), Cloud Cover and Cloud Fraction, Vegetation Fraction, Normalized Difference Vegetation Index (NDVI)
5-10 years (20)	Albedo, Surface Water Body Fraction, Snow Cover Fraction, Himalaya Glaciers, Snow albedo, Model-TCHP, Model-D26, Ocean Surface Currents, Total Alkalinity – Dissolved Inorganic Carbon, PBLH, Ocean Surface Winds, Wind Stress, Wind Curl, Sea Level Pressure, Ekman Currents, Geostrophic Currents, Total Currents, Sea Surface Height, Cloud Top Temperature.
< 5 years (4)	Forest fraction cover, Indian Soil datasets, Co-Tidal Map (K1O1), Co-Tidal Map (M2S2).
Model derived products	
>30 years (5)	Net Ecosystem Productivity, Net Primary Productivity, Variable Infiltration Capacity (VIC) Model -Surface Soil Moisture, VIC Model-Evapotranspiration, VIC Model-Surface Runoff
5-10 years (2)	Model-Tropical Cyclone Heat Potential, Model-Depth of 26° Isotherm

More recently, ESA initiated new climate program called CLIMATE-SPACE to support climate science and service development across member space agencies from 2023 to 2029. All this data contributes to a more precise estimation of climate change required by decision makers in Governments who demand such information to make commitments of various kinds along the lines of mitigation and adaptation.

9.9.1 Utilization of Products in support of climate challenges: The available NICES data have generated a large amount of analysis studies ranging from the documentation of the tropical inter-annual variability, climatic trends estimation and process studies (Refer NICES/Bhuvan webportal for further details).

9.9.2 Counting the Carbon: Carbon is an element that is essential to all life on Earth, especially very important in biology. Carbon, in the form of carbon dioxide, is very for photosynthesize. The carbon cycle describes the flow of carbon with in the Earth's climate system. Some processes release more carbon dioxide into the atmosphere than they absorb (example: burning of fossil fuels releases more carbon into the atmosphere, etc.). Such processes that release carbon into the atmosphere are known as carbon sources. Whereas some processes absorb more carbon than they release (example: Forests and oceans absorbs large amount of carbon dioxide from the atmosphere), which are called carbon sinks. In general, the carbon cycle would keep Earth's carbon concentrations in balance, moving the carbon from place to place and keeping atmospheric carbon dioxide levels steady. However, the carbon cycle is changing because of human activity. Human beings are releasing more carbon into the atmosphere by burning fossil fuels and deforestation activities. Deforestation is depleting Earth's supply of carbon sinks. As a result, the amount of carbon in the atmosphere is rising. Thus, in climate change perspective; monitoring the global carbon cycle is vital to predict, mitigate and adapt to the related climate changes. The Carbon Cycle Modeling and Simulations (CCMS) has also been initiated in ISRO, with the aim to setup an integrated model for biogeochemical cycle for Indian region to assimilate the regional data for improved understanding of the carbon cycle regionally (over India) and globally. The model simulated atmospheric CO_2 at surface level is depicted in Figure 9.13; which shows the locations of high CO2 concretions. Also, the figure indicates that the CO_2 levels are relatively high in northern hemisphere compared to southern hemisphere. This could be because the northern hemisphere contains much more land than the southern hemisphere, whereas the southern hemisphere is mostly covered by ocean.

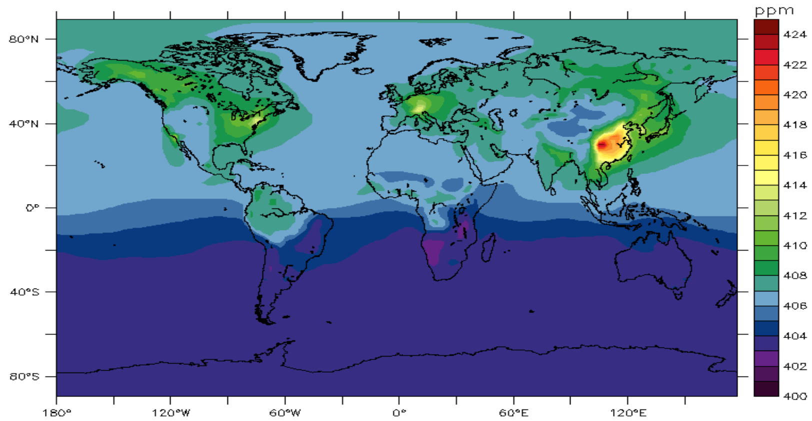


Fig. 9.13 Model simulated annual mean atmospheric CO_2 concentrations at surface level for the year 2020 (Source: NICES data from GEOS-Chem Atmospheric Chemical Transport model).

9.10 Protecting the Planet

Even though the greenhouse effect was first discovered in the 1800s, but it was not until 1988 that the global community galvanized to form the Intergovernmental Panel on Climate Change (IPCC). Subsequently, the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1994 to stabilize "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference in the climate system". To limit the increase in the globally average temperatures to less than 2°C above pre-industrial levels, the 21st session of the Conference of the Parties (COP21) of the UNFCCC implemented the Paris Agreement in 2015, an ambitious global effort to reduce GHG emissions. Parties to the Paris Agreement defined nationally determined contributions (NDCs) to a global GHG emissions reduction effort. Each party agreed to report their anthropogenic GHG emissions and removals to the UNFCCC, which would evaluate their progress toward their NDCs at 5-year intervals through a "global stocktake", the first of which is scheduled for 2023. In 2015, all United Nations member states agreed to the 17 Sustainable Development Goals (SDGs) designed to "provide a shared blueprint for peace and prosperity for people and the planet, now and into the future." SDG 13 in particular commands member states to "take urgent action to combat climate change and its impacts."

9.11 Geoengineering

In order to mitigate adverse climate changes, not only through higher emissions reduction targets and enhanced sinks of GHGs, but also proposed Geoengineering (also called Climate engineering) approaches as a last and desperate measure. Geoengineering refers to a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change. Most of the approaches that have been proposed fall into 2 categories, namely solar radiation management and CO_2 removal. The climate engineering of solar radiation management technique aims to offset the global effects of radiative forcing agents by either decreasing absorption of solar energy within the Earth-atmosphere system and/or increasing the fraction of incoming solar energy scattered by Earth back to space. They are like stratospheric aerosol injections aimed at decreasing net incoming solar radiation at the top-of-atmosphere, brightening marine clouds to increase planetary albedo and surface albedo modification methods to increase reflected energy back to space. The geoengineering of CO_2 removal technique aims to bring GHGs (mainly atmospheric CO_2 concentrations) back to safe levels. They are like extraction of significant amount of CO_2 from the atmosphere and sequester it in reservoirs, and/or acceleration of some of the natural processes for reduction of atmospheric CO_2.

9.11.1 Reduction of atmospheric CO_2

Ocean fertilisation approach is one of the most investigated methods among the proposed Geoengineering techniques; which focuses on manipulating the ocean's iron content to increase the long-term oceanic storage of carbon by the enhancement of Ocean's biological pump (i.e., biological CO_2 uptake). The ocean biological pump is described as a single combined process, wherein organic matter produced by phytoplankton during photosynthesis in surface waters is transported to intermediate and/or deep waters, leading to carbon export to the deep ocean or sediments. In general, the biological pump is primarily controlled by the supply of macronutrients (i.e., nitrate, phosphate, and silicate) from the deep ocean into the ocean mixed layer, leading to new production However, iron acts as an essential micronutrient to stimulate the uptake of macronutrients for phytoplankton growth. To investigate ocean iron fertilisation geoengineering hypothesis; 13 artificial iron fertilization experiments have been performed since 1993 over different oceanic regions covering subtropical North Atlantic, Equatorial Pacific, subarctic North Pacific, and Southern Ocean (Yoon et al., 2018).

The latest and one of the first large experiments was the Indo-German iron fertilisation experiment, called LOHAFEX (Loha means iron in Hindi, and FEX stands for fertilization experiment) in 2009 over the South Atlantic Ocean, together with scientists from Europe and Chile (Smetacek and Naqvi, 2010; Martin et al., 2013).. This experiment aimed at filling the gaps of knowledge mentioned by international conventions to classify the potential role of ocean fertilization as a means of reducing CO_2 concentrations in the atmosphere. LOHAFEX was carried out from 7 January to 17 March 2009 in an ocean eddy at 48°S 15°W characterized by a moderate Chlorophyll-a concentration (0.4–0.5 mg Chl-a m^{-3}) and low silicate concentrations (<1 µM) in the mixed layer. During this experiment, 2-tons of iron in the form of dissolved iron sulphate was released in the closed core of a cyclonic eddy (48°S, 15°W) located south of the Antarctic Polar Front in the southwestern Atlantic sector of the Southern Ocean. Remote sensing data confirms the enhancement in the Phytoplankton bloom following an iron-fertilization experiment in the Southern Ocean as depicted in Figure 9.14. In general, these experiments have shown that primary production can be enhanced by the artificial addition of iron.

However, the findings of these experiments and the potential side effects (i.e., production of climate-relevant gases, Fuhrman and Capone, 1991) have been scientifically debated among those who support and oppose iron fertilisation conducting investigations (Lawrence, 2002; Buesseler and Boyd, 2003). In general, Geoengineering approaches and techniques remain in its infancy that requires improved assessment of the strategies, benefits and risks.

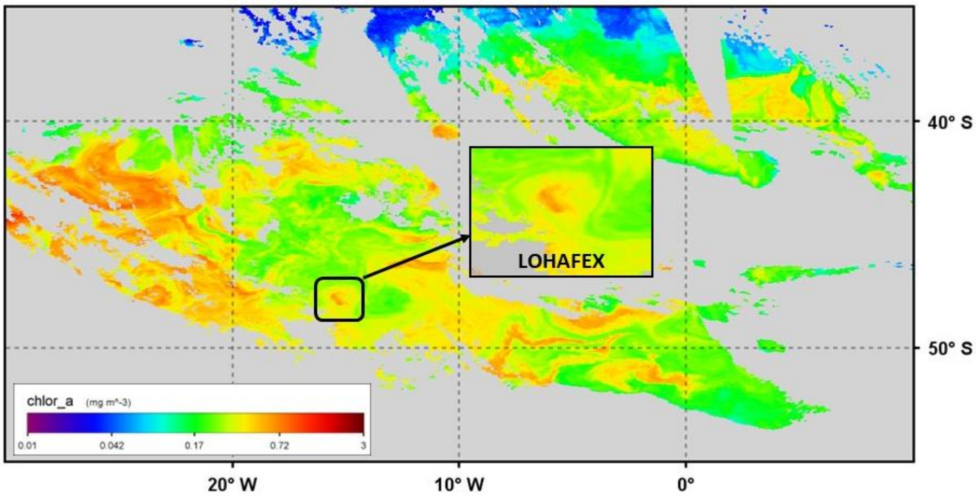


Fig. 9.14 Chlorophyll-a (Chl-a) bloom (square box) following an iron-fertilization experiment during LOHAFEX (composite image: 12 - 14 Feb 2009). Color scale indicates the mass of chlorophyll per cubic meter of seawater (Source: Chl-a data were downloaded from the NASA website).

9.12 Conclusions

The advent of Earth Observation satellite technology has eased pathways to measure different climate change indicators, understanding the Earth system science and the evolution of the planet's climate. Satellites are critical to monitoring, but emerging and novel methods for analysing and visualizing all the data in one place are vital to help the global community deal with climate change and need to be further developed.

The global warming is further contributing to changes in the frequency, intensity, duration, spatial extent and timing of weather and climate extremes, which can lead to unprecedented extremes. Awareness on climate extremes has increased in recent years due to its social-economic importance and impacts. As a consequence, reliable predictions of extremes are needed on short and long-time scales to reduce potential risks and damages that result from weather and climate extremes.

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Chapter 10

REMOTE SENSING FOR RURAL DEVELOPMENT

10.1 Introduction

Decentralised nature of distribution of rural habitations always needs a synoptic observation opportunity of monitoring, especially due to contrasting levels of development in Indian context. Village is an important habitat in the entire spectrum of human settlements. An insight of the rural development scenario reveals that, although we are in an era of urbanization, two third of country's population is still living in rural areas. In 2016, total villages in the country were 6.38 lakhs of which 5.93 lakhs are inhabited. Earth observation using remote sensing technology on board platforms, operating at various altitudes, offers vast scope of watching details of villages in space and time. Rural landscapes present scenarios of varied complexity with respect to dynamics of Earth as a system, since interaction of man and nature has resulted in to diverse land cover patterns. Indian villages, such as Ralegaon Siddhi, Hivre Bazar, Sukhomajiri, Piplantri, Kadawanchi, have demonstrated high degree of rejuvenation and resilience in the face of socio-ecological adversity, solely due to the tenacity and commitment of individuals steering communities often to adopt science driven standards of resource management in disciplined manner. Since earliest initiation of remote sensing applications at rural level, technology paradigm has evolved and currently it presents a highly promising framework to furnish information to decision makers and stakeholder at grassroots level alike. Current deliberation is about illustrating wide range of applications, solutions and tools developed over last five decades using space technology with more focus on remote sensing coupled with geographic information.

Keeping in focus the need to articulate various themes related to rural development, current discourse aims to trace the earliest experiments in remote sensing applications followed by incremental development witnessed in involving this technology for decision support at higher levels of governance. Era of employing coarse resolution, low radiometric quality images to prepare spatial output in hardcopy maps that gradually developed in to medium resolution, better radiometry-based images, has galloped in to a stage of amalgamation of wide-ranging technologies juxtaposed with remote sensing technology. Often the edges of technology domain are so seamless, that information derived has multiple sources at a given instance and serves so well to the grassroot users as a set of sustainable choices. Advances in technology related to visualisation, rapid analysis, communication, wearable devices, 3-D immersion and many more domains make it handy for the stakeholder either to avail or contribute in to the relevant grain of information.

Indian villages that witnessed sluggish growth in early years of development, in terms of economic development due to outdated policies and implementation often, have caught up with information explosion accessible through low-cost mobile telephony and enhanced awareness. Success stories of agrarian economy and ecology, especially as products of increased cooperation and faster communication have set new benchmarks of development, which need to be demonstrated in virtual ambience for uninitiated rural societies, which in turn can catapult development due to upscaled knowhow. Spatial representation resulting from remote sensing-based approach has distinct and strong scope of taking such learning to target communities so that signals of true development as seen in Earth Observation data are conveyed for building conviction among the uninformed. Attempt is also made herewith to dwell on the role of technology for supporting policy planning and implementation especially in the light of digital economy which in turn may be swayed by climate change related extremities. Role of technology institution such as ISRO in reducing the gap between technology-based information and the communities with socio-economic disadvantage is paramount since geospatial technology is increasingly recognised as true horizontal across various sectors of growth and development.

10.2 Early Applications in Remote Sensing for rural development

10.2.1 Integrated Mission for Sustainable Development (IMSD)

Sustainability in rural development has been the core issue in addressing the need of holism in improving life and its quality in remote hinterlands of this nation, that dates back in to initiatives as early as 1950s. Formulation of interdisciplinary team in 1949 to address soil and water conservation works in Damodar Valley Corporation followed by FAO and Govt of India joint meeting at Hazaribagh marked the first set of initiatives. Earliest efforts to address rural development as an integrated approach is evident by treatment of 42 micro-hydrological units by CSWCRTI, Dehradun, that gradually evolved in World Bank funded wide area initiative addressing 5 lakh ha. The understanding about limitations of conventional process in development of watersheds lead to adaptation of remote sensing-based approaches in enhancing the integration of diverse information as well as understands the impact in improved functioning of watershed evident through signals from space-based sensors.

In response to a critical query of Prime Minister in 1987 about use of technology in managing severe droughts of the nation, NRSC initiated a study 'Integrated Study to Combat Drought'. Country had faced strings of drought between 1985-87 and needed a truly scientific and sustained solution to overcome this. First experimental solution was attempted using remote sensing-based solutions in Kolar District of Karnataka, at a coarse resolution of 1:250000 scale. Upon the learning from study in Kolar, which is a drought stressed district, First Phase of this Drought Study was upscaled in 21 districts in 13 states at a finer scale of 1:50000 in lieu of 250,000. Early results on this study were reviewed by Planning Commission in 1992, which in turn lead to launching of a mission 'Integrated Mission on Sustainable Development' covering watersheds/study areas in 126 districts across the nation (NRSA, 2002). Subsequently in 1994, upon deliberations between Secretaries of Dept of Space and Rural Development, next initiative of 'IMSD Special' was launched which aimed exclusively on preparation of land and water resource management action plans for 92 priority blocks (including 12 of Phase I) (Table 10.1). From a scope of pilot project in Kolar it extended in seven years in to national mission covering 175 districts having 247 sites addressing 25% (84 M Ha) of the country's rural landscapes. First set of action plans using RS & GIS tools were prepared for extremely backward Kalahandi-Bolangir-Koraput region of Orissa by State Centre of Orissa addressing 800 micro-watersheds, in 1998. Mandate of IMSD comprised of preparation of natural resource database in cost and time effective manner followed by generation of location specific action plans addressing alternate land use, soil/water conservation, ground water recharge. First set of action plans across India were taken up in six watersheds of Ahmednagar, Anantpur, Bhiwani, Dharampuri, Jhabua and Kalahandi districts.

Table 10.1 Coverage /criteria for different IMSD phases

1	Integrated Survey to combat Drought	21 drought prone districts of the country (Full districts)	Drought prone districts identified by respective state govts.
2	IMSD Phase II	One third of the district/block/watershed	Problematic districts/areas identified by respective district administrations/state remote sensing centers (also, specific problems like floods, hilly terrain, tribal areas etc,)
3	IMSD-Special (for MRD)	Priority bocks of DDP/DPAP districts	Extent of wastelands (over 15%) and as identified by MRD

10.2.2 Action Plans and their implementation

Action plans were prepared using Geospatial approach involving contributions of State and Central institutions as well as entrepreneurs. Preparation for a pilot in Peddavagu micro-watershed (Fig. 10. 1a) was executed in Andhra Pradesh to demonstrate the scale of spatial data as well as the relevant field information essential to build a meaningful database for planning and monitoring. Methodology included preparation of database on natural resources related to soil (Fig. 10.1b), water, geomorphology, land use/cover, drainage, slope, aspect, contours and transport network, followed by allied technology database related to agriculture, water management, harvesting, GW recharge, animal husbandry, land degradation, land capability. Profiles for social, demographic, cultural and economic orientation were prepared and PRA conducted so as to help prioritisation as per people's needs. Decision rules were formulated and implemented through GIS tools. Action plans for water and land resource development (Fig. 10.1: c & d) were provided to respective district administration for demonstration, implementation and evaluative feedback. Under National Natural Resources Information System (NRIS) six query shells were designed and developed to access the information from GIS database, so that users would find information easy to handle and go beyond the issues related to hardcopy maps. A spatial decision support system hence was realised to arrive at a set of optimum land development prescriptions for planning purpose.

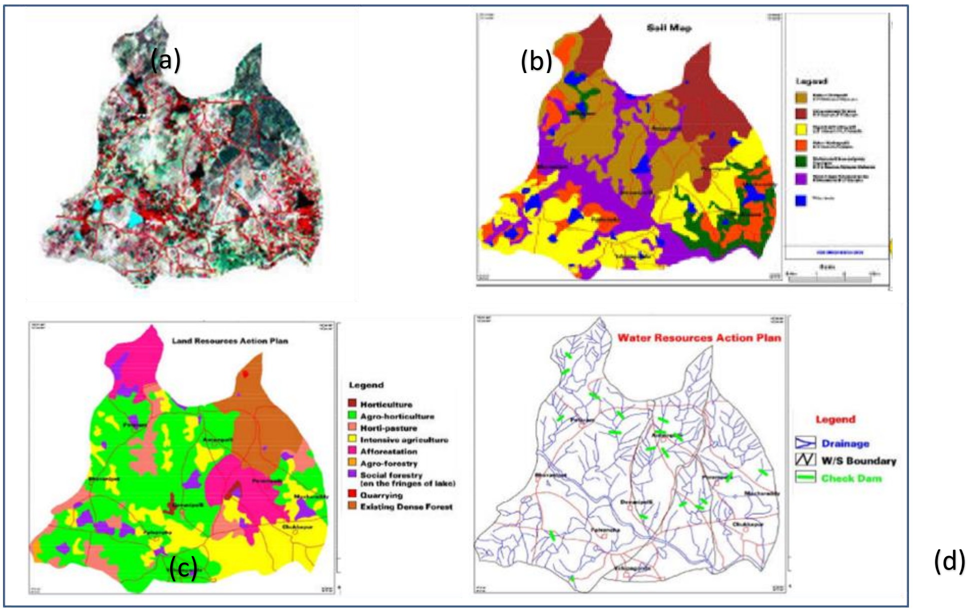


Fig. 10.1 Study of Peddavagu Watershed, Nizamabad district, A.P showing satellite imagery, thematic and ancillary layers to generate land and water resource action plans

One of the strongest challenges in IMSD initiative was the implementation of action plans on the ground. As compared to conventional approach remote sensing-based approach eased the approach of integrating multiple themes and reducing the cost of integrated resource mapping by almost half, with average unit area cost of Rs 5.10/Ha in conventional method turning in to Rs. 2.43/Ha. Implementation got a substantial support from voluntary agencies in establishing contact with people for their active participation. Technical, managerial and financial elements are quite essential for development of watersheds ranging from role of government institutions in terms of technical solution development, funding, capacity building to people participation in terms of awareness campaigns, plan execution and feedback. Implementation resulted in to activities such as creation structures (checks, water harvesting, farm bunds etc) and greening up interventions (pasture, plantations, afforestation, Agro-horticulture). Impacts of interventions resulted in increase in cropping intensity (120-150 percent), average crop yields (0.5 – 2 times), ground water level (1-3 m), cultivated area (~30 per cent), plantations (50-60 percent), forest cover (45 percent) and decrease in wastelands (~40 percent). Vegetation index derived from remote sensing data showed upto 40 percent increase, indicating better irrigated conditions (Cheyyedu Watershed, AP). Approach demonstrated the core strength of remote sensing derived information bringing in paradigmatic change in integrated rural development, while paving the way for taking information of this nature to stakeholders with higher intensity and better plan of skill building.

10.3 Remote Sensing Information for Rural Development as Natural Resource Database

10.3.1 NR Census: Land Cover Database

Rural development applications are continuously focussing on water and land conservation through systematic planning, implementation of development plans in rural sector. Applications of geospatial solutions and their implementation in rural development sector provide customized near real time natural resources databases, tools for the analytics and drawing the water and land resources plans.

Under NR-CENSUS program, mapping of Land use / Land cover (LULC) using multi-temporal satellite data on entire India is carried out every year on 1:250,000 scale with 18 classes. The project utilizes multi temporal AWiFS sensor data from Resourcesat satellite series to provide Kharif cropped area estimates along with additional two in-season assessments for August & September months depending on cloud-free data availability, Rabi cropped area estimates along with additional 2 in-season assessments for December and February months and reprocessed LULC inputs required for NICES and weather forecast models. For faster and effective processing, entire India is divided into 137 tiles of size 200km x 200km. The entire approach of LULC preparation and the seasonal sown area estimation use automation and tile-based approach in a systematic manner by processing monthly composites of NDVI. This is further subjected to rule-based thresholding using R Programming, to extract sown area during a season (kharif/ rabi/ zaid). The other classes are prepared using various indices and thresholding techniques using AWiFS and Open-source data available using Google Earth Engine and other programming scripts. Final integration to prepare integrated LULC is carried out using rule-based approach.

As a part of NR-Census programme of ISRO to carry out developmental planning and research activities at state / district / watershed level, a more detailed LULC data compatible for use at 1:50,000 scale (NRSC,2012) is required and to meet such requirement NRSC has undertaken national LULC database creation using IRS LISS-III MX datasets. This exercise is taken up by NRSC by involving State Remote Sensing Centre spread over the country. First Land Use Land Cover mapping under this project was undertaken for the year 2005-06 and was repeated for the year 2011-12 and 2015-16. Before undertaking this project, a pilot study was carried to arrive at classification system and mapping methodology. After completing the pilot study, a 79-fold classification system was designed to create LULC layer using visual interpretation approach. Before undertaking 2nd cycle of National LULC mapping, revision in the classification system was felt. Revision of existing 79-fold classification system to new compatible 54-fold classification system is developed and adopted. Output under this project is GIS Vector data for 2005-06, 2011-12 and 2015-16.

The users of this database include the Niti Ayog, State planning departments, Ministries of Rural Development, Environment and Forests, Earth Sciences, Central Water Commissions, Urban Development, Science and Technology, Agriculture, ICAR Institutions, Pollution Control Boards, State Land Use Boards, State Land Use Boards etc. from government side. Whereas this is also required by many industries, researchers, climate modeler, weather forecaster for analyzing it along with many other parameters for the benefit of the human society.

Effective utilization of natural resources and their management is essential for development of any country. In order to achieve this, there is a need to catalyze the planning process at grass root level which is based on the informed decisions taken by using scientific inputs. In India, Planning aims at inclusive, participatory and coordinated approach for local area development to ensure that each Panchayat or local body is treated as a planning unit. Reliable and timely information on resources is pre-requisite for the development on large scale and with detailed classification suitable to meet village or Panchayat level planning requirement. To support this activity NRSC has taken up with ISRO supported project Space based information support for Decentralized Planning (SISDP) which includes land cover information at 1:10,000 scale for creating 28 LULC classes for more precisely at village level planning

National Land Use / Land Cover Mapping: 2021-22 Land Use / Land Cover (LULC) database created at 56m resolution for the country as 16th cycle (2021-22) (Fig. 10.2.1). Season wise cropped area under Kharif, Rabi, Zaid and monthly cropped area for August, September, December, February (2021-22) is prepared (Fig. 10.2.2 & 2.3). Analysis shows that there is increase in cropped area under Rabi and Double/triple crop with 6.51 and 1.39 lakh ha respectively as compared to 15th cycle. However, Kharif crop shows (Fig. 10.2.2) decrease in area with 10.3 lakh ha as compared with the previous cycle. This analysis also shows overall decrease in total net sown area due to the less rainfall.

In addition to changes in cropped areas, the analysis also highlights shifts in other land use and land cover categories. The area designated as current fallow has increased, indicating land that is temporarily uncultivated but has potential for future cropping. Built-up areas have expanded with a growth of 0.41 lakh ha as compared to previous cycle. Moreover, both minimum and maximum waterbody areas have decreased with 2.93 and 3.27 lakh ha in area respectively (Fig. 10.3). Minimum and maximum waterbody extents are mapped from respective season's satellite data indicating the dynamics of each waterbody.

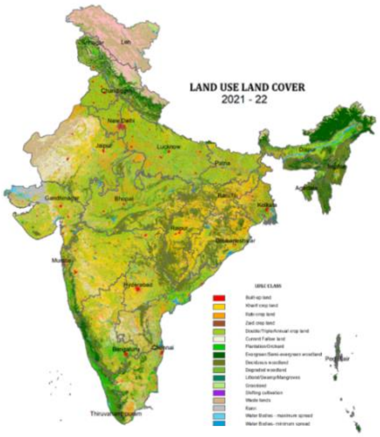


Fig. 20.2.1 Land use land cover map

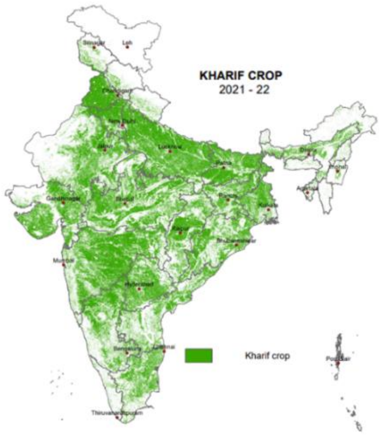


Fig. 20.2.2 Annual Kharif Crop map

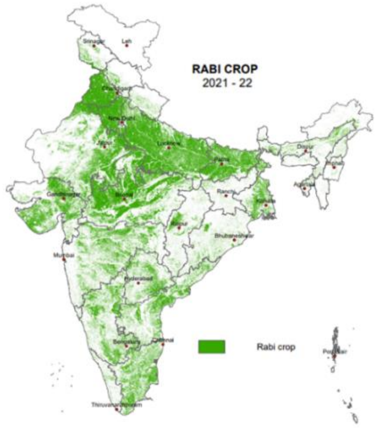


Fig. 20.2.3 Annual Rabi Crop Map

10.3.2 Assessment and Monitoring of Agriculture

Remote sensing technology offers efficient, timely and cost-effective method for mapping, monitoring and management of agricultural resources. India is one of the few countries in the world that uses space and Geo-ICT technologies as well as land-based observations for generating regular updates on crops and providing inputs to achieve sustainable agriculture. Space data is used in addressing many critical aspects such as crop area estimation, crop yield & production estimation, crop condition, cropping system studies, experimental crop insurance, etc.

Remote sensing-based acreage and production forecasts based on weather parameters and spectral indices was conceptualized by ISRO in early eighties. This led to the Ministry of Agriculture sponsored CAPE (Crop Acreage and Production Estimation) project, wherein district-level pre-harvest acreage and production estimation was carried out for six major crops covering large areas viz. paddy, wheat, sorghum, groundnut, rapeseed-mustard and cotton. These remote sensing-based acreage estimates were made available about one month prior to the harvest of the crop so as to enable strategic decision making.

The scope of this project was further enhanced with FASAL (Forecasting Agricultural output using Space, Agro-meteorology and Land based Observations) programme. Under FASAL, methodology was developed for multiple in-season forecasts of nine field crops at national scale. The Mahalanobis National Crop Forecast Centre (MNCFC) was established by MoA&FW in New Delhi in April 2012.

Technology for crop acreage and estimation was transferred to MNCFC for upscaling and operationalisation. Besides field crops, national level assessment of horticultural crops is also being carried out as part of the CHAMAN (Coordinated programme on Horticulture Assessment and Management using Geoinformatics) programme.

Agriculture value chain has been strengthened with data, information and knowledge for informed decision making to meet the current challenges of income security, food security and climate resilience. Smart agriculture through digital innovations using data centric geospatial technologies is leading to technology enabled farming, governance and policy making.

a) Towards Digital Agriculture

ISRO is the knowledge partner with several state governments for space-based technology and know-how, to provide quantitative in-season measures related to crop growth and productivity. In particular, technology support is being provided to the states of M.P and Maharashtra (Fig. 10.4) for effective utilization of data-centric technologies for informed decision making, planning and risk mitigation in agriculture and allied sectors. Innovative mapping and data analysis techniques are being implemented to provide quantitative in-season information/metrics/parameters related to agriculture, viz. crop sowing intelligence, crop health monitor, crop management, pest/disease advisory, horticulture, soil health card, etc. The project supports both farmer-centric and planning-centric activities in agriculture decision-making as well as the major on-going programmes – crop insurance, drought management, agro-advisory etc.

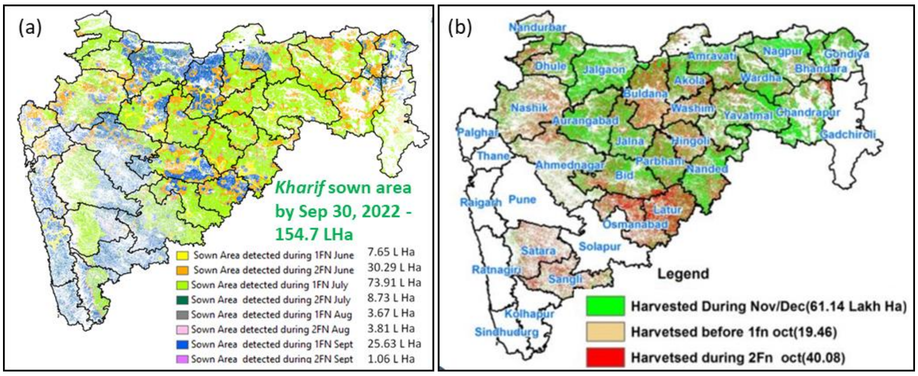


Fig. 10.4 Crop monitoring using satellite and meteorological data for Maharashtra state (a) Kharif sown area progression, (b) Crop exposed to unseasonal rains in 2019-20

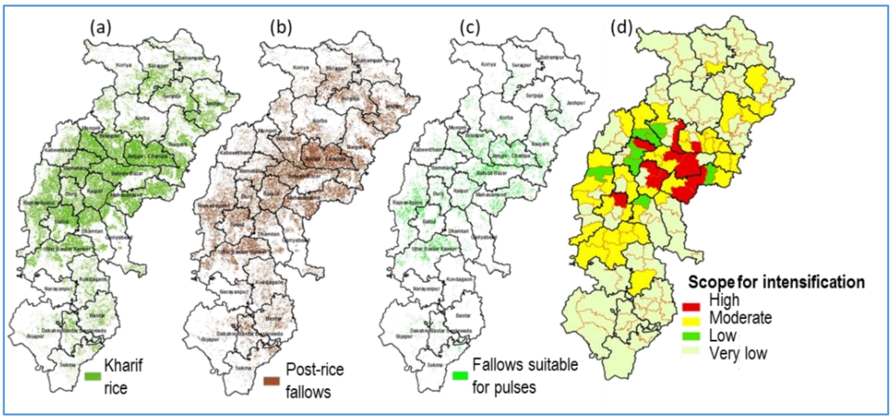


Fig. 10.5 Crop intensification studies for Chhattisgarh state (a) *Kharif* rice area (b) Post *Kharif* rice

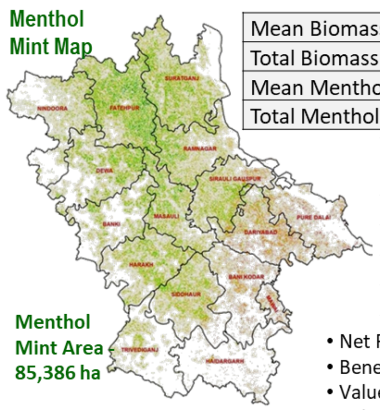
fallow areas (c) Areas suitable for growing pulses (d) Scope for intensification

b) Crop Intensification towards National Food Security

Rice is the principal food crop of India, grown over 36 Mha in *kharif* season, where nearly 30% of agricultural area is left fallow after the harvest of rice crop. The residual soil moisture at the time of rice harvest is often sufficient to raise short-duration Rabi crops. Remote sensing provides ideal framework for generation of geospatial database on spatial extent of post *kharif* rice fallows, and to ascertain the suitability of such fallows to cultivate short duration pulses (Fig. 19. 5c). Such a database offers simple, fast, efficient and cost-effective method to make appropriate recommendations for implementation at district/village level. The post-*kharif* rice fallow lands have been mapped for major rice-growing states (Odisha, Chhattisgarh, Bihar, Jharkhand, and West Bengal, Assam) and its spatial extent for Chhattisgarh state is given in Fig. 19.5. Inventory of fallow areas using earth observation data at national, state, district, block and village level and subsequent prioritization at village level helps policy makers to plan for implementation of effective measures towards crop intensification thereby helping to meet the food security challenges.

c) Horticulture (Supporting Mission for Integrated Development of Horticulture)

Horticulture has a very significant share in the country's economy, and it provides better alternative for diversification in view of higher returns, as well as plays a key role in nutritional security. Earth observation data based technique development was carried out for area estimation of major horticulture crops at sub-district level using high and medium resolution satellite data for mango, banana, citrus, menthol mint, turmeric and chillies under the national level project Coordinated programme on Horticulture Assessment and Management using Geoinformatics (CHAMAN),. Mapping and economic analysis was carried out in Barabanki District, Uttar Pradesh for menthol mint, an essential oil-bearing plant, which indicated a high profitability from mint crop during lean zaid season of May-June (Fig. 10.6). These inputs are useful for policy planning and area expansion, while also contributing towards increasing farmers' income.



Mean Biomass estimate (t ha^{-1})	18.59
Total Biomass production estimate (000' tonnes)	1587.74
Mean Menthol Oil estimate (Kg ha^{-1})	111.57
Total Menthol oil production estimate (Tonnes)	**9526.00**

NDVI Classes	Crop status group	Mean Biomass estimate (t ha^{-1})	Mint crop area (ha)
	Poor	9.6	5,609
	Medium	17.4	44,610
	Good	21.0	31,412
	Very good	26.1	3,755

- Net Return to farmer: 52,546 Rs./ha
- Benefit-cost ratio: 2.05
- Value of menthol oil per Cu.M of water: 168 – 224
- Value of employment: Rs. 128 Crores (for entire district)

Fig. 10.6 Mapping and economic analysis for menthol mint crop for Barabanki District UP

d) Crop Insurance

Crop insurance has become an indispensable risk management tool in the agriculture sector, especially in the agrarian monsoon-dependent country like India. NRSC (ISRO) is closely working with Ministry of Agriculture, State Depts. of Agriculture and Insurance Industry to develop and implement technology interventions in the Pradhan Mantri Fasal Bima Yojana (PMFBY). The successful use-cases include development of an agriculture risk index for clustering of districts, coverage discrepancies/compliance, smart sampling of CCEs, impact assessment of weather extremes and alternate crop risk assessment model. These use cases of technology interventions have resulted in improving crop risk assessment system, moderating the exaggerated crop loss assessments and eventually reducing the premium rates, benefitting farmers and other stakeholders of crop insurance.

An innovative index-based insurance scheme has been developed and implemented, linking pay-outs to the measured crop performance instead of crop yield estimates. The scheme - first of its kind in the country - is being implemented from 2020 crop season in West Bengal. It is a transformative crop insurance solution wherein a composite index - Crop Health Factor (CHF) represents the crop performance by incorporating multiple physical and biophysical parameters related to crop health. End-of-the-crop season risks like hailstorms, floods, cyclones have also been accounted for in the crop performance. Advantages of such technology-based crop insurance solutions are many folds viz. elimination of moral hazard, a substantial reduction in the cost of insurance, transparency and objectivity in the process, faster payment of claims etc.

e) Bioenergy (renewable energy solutions)

Agriculture residues are an important source of renewable energy. With gross cropped area of 195 Mha covering multiple crops, a huge pool of residue biomass is available across India. Effective utilization of such biomass aids in providing clean energy and reduction in fossil fuel, besides creating employment opportunities in rural India. For efficient utilization of energy from crop residues, information gaps on its availability need to be bridged so as to have a smooth supply chain. NRSC in collaboration with DST has generated a systematic geospatial database on biomass residues from four major crops. A unique spatial information system - BHUVAN-JAIVOORJA - offers data and information support to different stakeholders in terms of maps of gross and surplus biomass residues and its bioenergy potential towards informed decision making (Fig. 10.7).

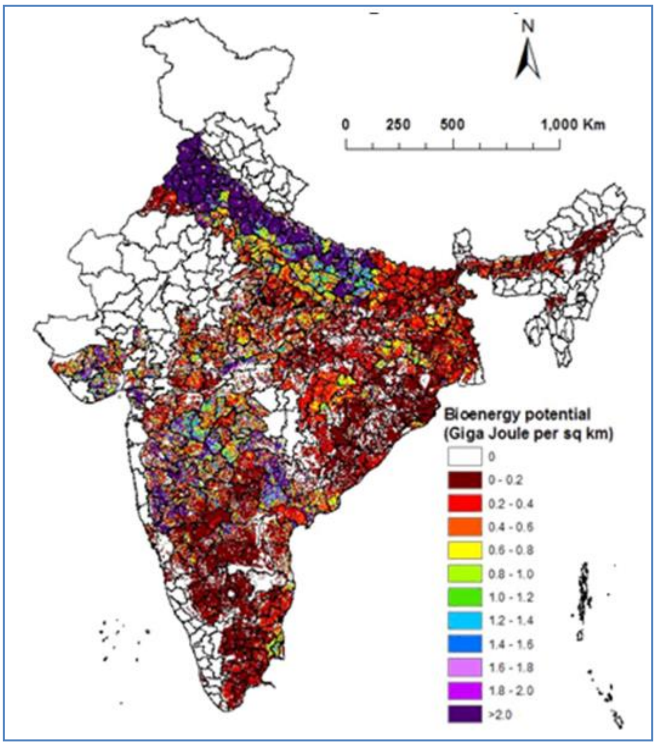


Fig. 10.7 Spatial distribution of bioenergy potential over India from surplus residues of rice, wheat, sugarcane & cotton

10.3.3 Ground Water Prospects & quality using Remote Sensing

a) Ground water prospects mapping under National Rural Drinking Water Programme (NRDWP Project)

Ground water forms the backbone of Indian Agrarian Economy in non-irrigated tracts and hence was required to be studied using state of the art technology in the light of unplanned exploitation and concomitant collapse this pristine resource. Project aimed to prepare groundwater prospects maps corresponding to Survey of India toposheets in 1:50,000 scale. The map shows a) prospective zones for groundwater occurrence, b) tentative locations for constructing recharge structures. The information provided in the groundwater prospects maps forms a suitable database for narrowing down the target zones and systematic selection of sites for drilling, after conducting follow-up ground surveys. The GWP maps helped in establishing drinking water sources to all the habitations, besides providing information for selection of suitable sites for construction of recharge structures to improve the sustainability of drinking water sources, wherever required (NRSC, 2015).

A systematic procedure has been adopted to prepare the groundwater prospects map using satellite data and GIS techniques in conjunction with limited field work. Various thematic maps had been prepared on lithology, geomorphology, structures, hydrology and base map details based on the digital interpretation of standard FCC of satellite data in conjunction with limited field / existing data with reference to SOI toposheets in 1:50,000 scale. Hydrogeomorphic units have been derived by integration of these thematic layers. Groundwater prospects for each of the hydrogeomorphic units has been evaluated considering the well observation data on these hydrogeomorphic units and other supportive ancillary data collected from CGWB, RWSS, PHED and private individuals. According to the prospects and condition of the hydrogeomorphic units, suitable recharge structures and locations have been suggested for sustainable groundwater management.

The entire project was carried out in four phases as per the priority set by the Ministry of DWS. Initially, in January, 1999, under Phase – I programme, six (6) States namely - Rajasthan, Madhya Pradesh, Chhattisgarh, Andhra Pradesh (part), Karnataka and Kerala were taken up involving preparation of 1654 maps. The mapping has been completed as per the schedule in the year 2002. Subsequently, during Phase – II, Jharkhand State was taken up in October 2001 followed by Himachal Pradesh, Orissa and Gujarat States in October 2002, totally covering 724 maps. The ground water prospects maps pertaining to these states have also been completed during December, 2004 and submitted to the user department. After successful completion of Phase-I and Phase-II, six (6) more states viz. Jammu and Kashmir, Punjab, Uttarakhand, Assam, Maharashtra and parts of Andhra Pradesh covering 1290 maps were taken up in Phase-III A and completed by 2009. Four (4) more states were taken up in Phase-IIIB viz. Haryana, Arunachal Pradesh, parts of Uttar Pradesh and parts of West Bengal covering 339 maps and completed by 2011. Under Phase-IV of the project, rest of the country was covered for preparing 891 ground water prospects maps (Fig. 10.8). Numbers of Central and State Govt. agencies including State Remote Sensing Centers, Universities were involved in this mapping project along with selected private entrepreneurs.

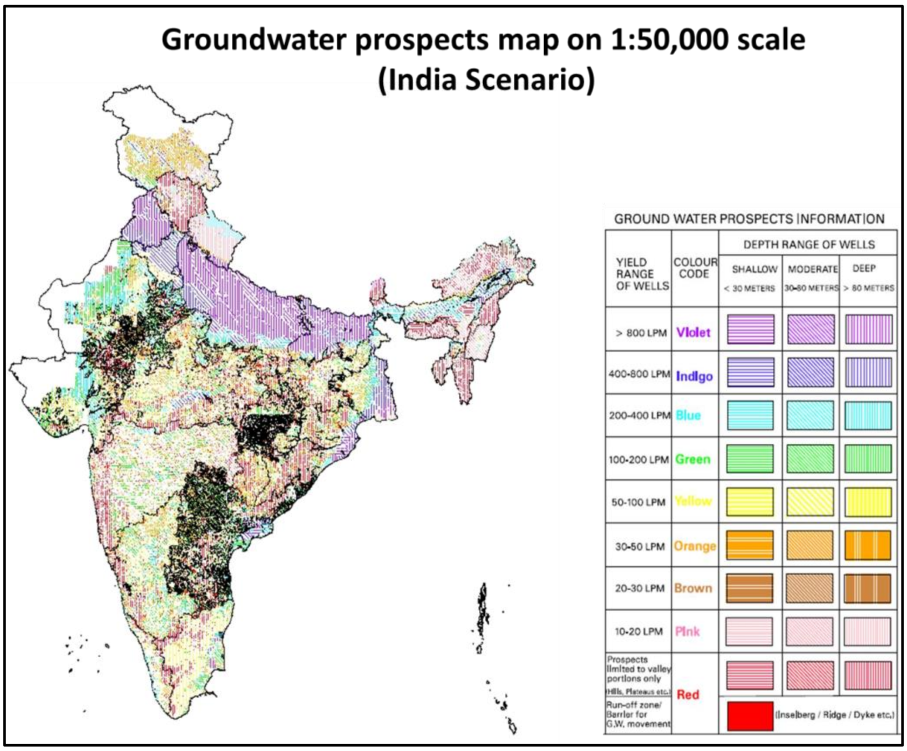


Fig. 10.8 Seamless Country mosaic Groundwater Prospects Map of India prepared under NRDWP

b) Ground Water Quality Mapping for the country on 1:50,000 scale

Geogenic and anthropogenic factors are extensively changing the potability of the ground water scenario in India. National Remote Sensing Centre (NRSC), in collaboration with the Ministry of Drinking Water and Sanitation (MDWS), is preparing a comprehensive geo-spatial database of groundwater quality for the country. To understand the quality of ground water is one of the prime/key factors for solving the need of safe drinking water for the rural population. Geo-spatial technology has been used for understanding the variability of geochemical parameters obtained from the habitation wise ground water quality observations, provided by state line departments, both in spatial and temporal domain. The main objective of the groundwater quality mapping is to provide information of the habitation wise groundwater quality information for the country, which may greatly help the decision makers for planning and implementation of sustainable development of groundwater management plans towards the ministry's goal of providing safe drinking water to each of the rural population. Habitation wise groundwater quality database, consisting of seasonal observations of 12 essential geo-genic elements (e.g. Arsenic Fluoride, Nitrate, Sulphate, Chloride, Hardness, Total Dissolve Solids, Alkalinity, Calcium, Magnesium & Iron) has been prepared for the entire county with 7.6 lakh observations.

The Groundwater Quality (GWQ) database is available through Bhuvan –Bhujal portal www. https://bhuvan-app1.nrsc.gov.in/gwis .

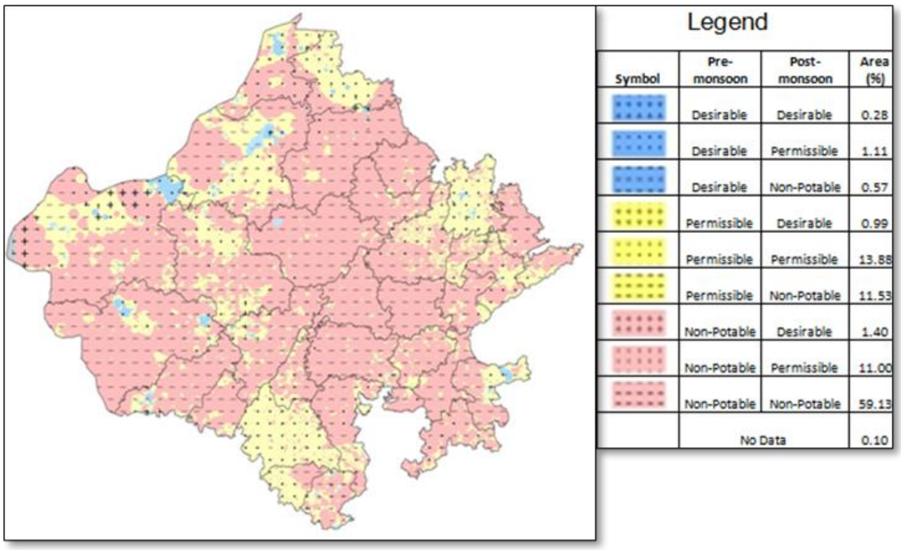


Fig. 10.9 Seamless State mosaic Groundwater Quality Map of Rajasthan state prepared under NRDWP of MDWS using Geo-statistical interpolations of habitation wise groundwater quality point observations for 2013-2016 time period

10.3.4 Mapping the Degraded Land using remote sensing

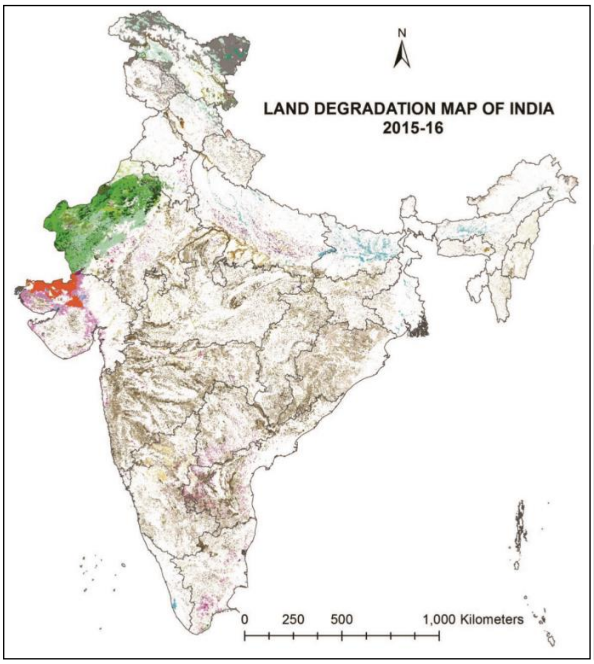
Land is the most valuable natural resource for production of food, fiber, fuel and many other essential goods required to meet human and animal needs and determines the quality of life. However, it is facing serious threats of deterioration due to unrelenting human pressure and utilisation incompatible with its capacity leading to degradation of land. Land degradation is temporary or permanent lowering productivity of land due to physical, chemical and biological processes. The information on land degradation is needed for a variety of purposes like planning reclamation programs, rational land use planning, bringing additional areas into cultivation and also to improve productivity levels in degraded lands.

Geospatial database of decadal changes in land degradation in the country is an important input to address the various components of rural development. It will also enable planners, administrators and policy makers to initiate appropriate measures for developmental and reclamation activities in rural India.

India is on track to achieve its national commitment on Land Degradation Neutrality (LDN) which is Sustainable Development Goal target 15.3 to restore 26 million hectares of degraded land by 2030. This would contribute to India’s commitment to achieving an additional carbon sink of 2.5 to 3 billion tonnes of carbon dioxide equivalent (a part of the Nationally Determined Contribution (NDC) target under the 2015 Paris Agreement). Realizing the need for reliable information on degraded land, and the potential of space-borne multispectral and multi-temporal data inventory and monitoring, a national level land degradation mapping was taken up Under Natural Resource Census program of ISRO, on 1:50,000 scale for entire Country. Land degradation was mapped using multi-temporal Linear Imaging Self Scanning Sensor (LISS-III) data acquired from Resourcesat-1/2 during 2005–2006 and 2015–2016.

Major Land degradation processes addressed are water erosion, wind erosion, waterlogging, salinisation / alkalization, acidification, glacial, anthropogenic and others. Geo-rectified Resourcesat LISS-III data covering Kharif (Aug–Nov), Rabi (Jan- Mar), Zaid (April- May) seasons was used to address spatial and temporal variability in land degradation and information generated (Fig. 10.10)adapting procedure as briefed below.

Satellite data was inferred for land degradation classes following standard visual interpretation techniques using the interpretation cues / classification scheme . Stratification available was used to identifiy sample location for to verify ground information followed by sampling of soil. Soil samples collected were analysed for chemical properties, wherever required. Preliminarily land degradation database was finalised in correspondence with ground truth and soil analytical data (wherever done). Existing legacy spatial data of on forest cover, wastelands, salt affected soils, biodiversity, land use / land cover etc. were also used in delineation of types of land degradation.



Process	Code	Land degradation class	Symbol
Water erosion	A1	Sheet erosion – slight	
	A2	Sheet erosion – moderate	
	A3	Sheet erosion – severe	
	A4	Rills	
	A5	Gullies	
	A6	Ravines – shallow	
	A7	Ravines – deep	
Wind erosion	B1	Sheet erosion – slight	
	B2	Sheet erosion – moderate	
	B3	Sheet erosion – severe	
	B4	Stabilized dunes	
	B5	Partially stabilized dunes	
	B6	Unstabilized dunes	
Waterlogging	C1/C2	Surface ponding – seasonal/permanent	
	C3	Subsurface waterlogged	
Salinization/alkalization	D1-D3	Saline – slight/moderate/severe	
	D4-D6	Sodic – slight/moderate/severe	
	D7-D9	Saline sodic – slight/moderate/severe	
	D10	Rann	
Acidification	E1/E2	Acidic – moderate/severe	
Glacial	F1	Frost heaving	
	F2	Frost shattering	
Anthropogenic	G1	Industrial effluent-affected areas	
	G2	Mining and dump areas	
	G3	Brick kiln	
Others	H1	Mass movement/mass wastage	
	H2	Barren rocky/stony waste	
	H3	Riverine sands/sea Ingress, etc.	

Fig. 10.10 National Land Degradation Database at 1:50000 Scale with class details

Quality evaluation plays a key role in building reliable datasets. Two tier quality checking (QC) mechanism was adopted in this project viz., Internal QC (IQC)(exhaustive wall to wall accuracy) and External QC (EQC)(randomised 10 per cent samples). Following quality verification entire data was organized as geo-database to help retrieval using appropriate metadata. District-wise land degradation area statistics were generated.

a) Land degradation Mapping:

Analysis of the database revealed that about 91.21 M ha of land is under various processes of land degradation exists in India, accounting to 27.68% of TGA. Water erosion is the major category of land degradation in India accounting to 55.91 % of total land degradation(15.53% of TGA). This process is dominant in the central and southern regions of India. This is followed by wind erosion accounting to 15.66% of total degraded land (4.35% of TGA). The salinization / alkalization spread over 6.46 M ha (7.09% of degraded total). It is maximum in Gujarat, owing to inclusion of rann area. Acidification was found to occur in 3.04 M ha accounting to 3.33% of total land degradation. Acidification occurring in paddy lands, dense forest areas and plantations is excluded in this study.

Water logging was found to occur in 1.82 M ha accounting to 2.00 % of total land degradation. The natural wetlands were excluded in this study. Glacial activity like frost heaving and shattering was found to occur in 2.88 M ha accounting to 3.16 % of land degradation area.

Out of all the states, Rajasthan was found to be with maximum extent of land degradation extending over 1.80 M ha (19.77% of total Indian degraded land). It is followed by Maharashtra with 1.09 M ha land degradation. The major process operating in Rajasthan was wind erosion where as in Maharashtra water erosion was dominant. When extent of land degradation is seen as a fraction of its total geographical area, Uttar Pradesh has maximum fraction accounting to 53.44% of its TGA followed by Rajasthan with 52.69%.

Entire set of spatial information on Land degradation serves as a key input for prioritization of watersheds for treatment., planning soil conservation and reclamation programmes in the watershed and Monitoring the reclamation efforts. It is also pivotal in preparation of action plan maps for land degradation neutrality.

10.4 Decentralised Planning Approach

10.4.1 Concept and Design

Effective utilization of natural resources and their management is essential and the need is to catalyze the planning process at grassroots level. Planning aims at inclusive, participatory and coordinated approach for local area development to ensure that each Panchayat or local body is treated as a planning unit. Reliable and timely information on resources is pre-requisite for the development of a plan. Decentralized district planning comprises of what different planning units within a district can achieve by envisioning collectively, operating their budgets, exercising their skills and leveraging their initiatives. Typically, in an ideal decentralized district planning exercise, each planning unit, namely, Panchayat, villages, municipalities and line departments would prepare the plan for execution of each of their functions and responsibilities after consultations with the people. Spatial planning needs to be part of the district planning process at all levels and in this regard, country has rich experience in using space technology for supporting decentralized planning and benefiting the grassroots level (Fig. 10.15), since inception of IMSD. Comprehensive database comprising information on natural resources, socio-economic data, infrastructure and other collateral information is a prime requisite for proper and optimal planning, implementation and impact assessment.

The concept of decentralized planning at gross root level has been enabled by 73rd Constitutional Amendment under Eleventh Schedule (Article-243G). Up-to-date and reliable spatial information on various resources themes, along with the field level attributes and the participation of local people are the fundamental components for planning and implementation of various developmental programmes.

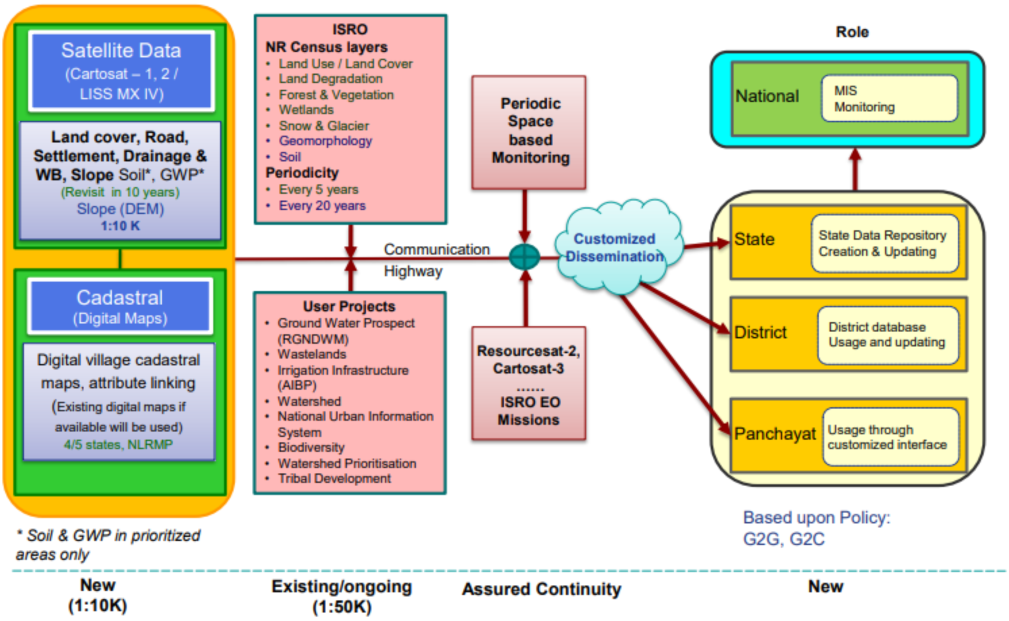


Fig. 10.15 Concept of SIS DP

Though, a few attempts were made to create such spatial information, yet they are limited to the specific area, project/schemes, resulting in ad-hoc nature of spatial information without following common standards. In order to provide spatial information in transparent, timely and cost-effective manner, development of scientific planning process can be effectively met by remote sensing based natural resource spatial layers. Spatial layers were created from tabular stakeholder department data linked to spatial framework, as Geographic Information and Communication Technology (GeoICT) tools. For this endeavour, resource data on 1:10,000 scale was felt essential for scientifically depicting village level spatial information. High resolution satellite imagery from Cartosat1/2 (PAN) and Resourcesat-1 LISS-IV was proven as reliable source for generating resource's themes on 1:10,000 scale for the entire country in a seamless digital manner. At the instance of Planning Commission, Government of India, ISRO/DOS has taken up this task of supporting state centers in creating, updating, development of GeoICT tools and its dissemination for planning at grassroots level as "Space Based Information Support for Decentralized Planning (SIS-DP)".

10.4.2 Standards & Implementation of Geospatial Database

Primary aim of the study was to provide technical guidelines and standards to be followed while generating required resource's themes on 1:10,000 scale with uniform standards in GIS environment and consummate the effort in to a comprehensive database. Standards and procedures defined for this mission were kept in compliance with erstwhile National Map policy (open series maps), to enable smooth distribution and sharing of spatial GIS layers. The resources' theme layers such as settlements, infrastructure, land cover, soil, ground water prospects were generated from the Cartosat-1 PAN and LISS-IV MX fused imagery of 2.5 m spatial resolution. Digital Elevation Models (DEM) such as CartoDEM resulting from photogrammetric solution of Cartosat stereo pairs, as well as DEM from Survey of India source, SRTM or ASTER were used for generating the slope layer. Digital geo-referenced village cadastral maps were taken up for overlaying and performing various analyses. Many states during that period were already having village cadastral maps digitized and georeferenced to a projection system which in turn facilitated multi-thematic integration. For the rest of the states process of digitization of cadastres and subsequent registration with satellite data was accomplished.

Under SIS-DP(NRSC , 2011), orthorectified state wise seamless Cartosat-1 PAN and LISS-IV Mx fused imagery as basic common input for all resource themes preparation has been accomplished(Fig. 10.16). This as an unprecedented database of its kind, enabled to retain the common spatial reference and geometric integrity across and seamlessness along all SIS-DP GIS themes. Open standard GIS schema for all the layers incorporating spatial reference, theme classification, codes, and nomenclature and GIS rules to ensure common standards were provided.

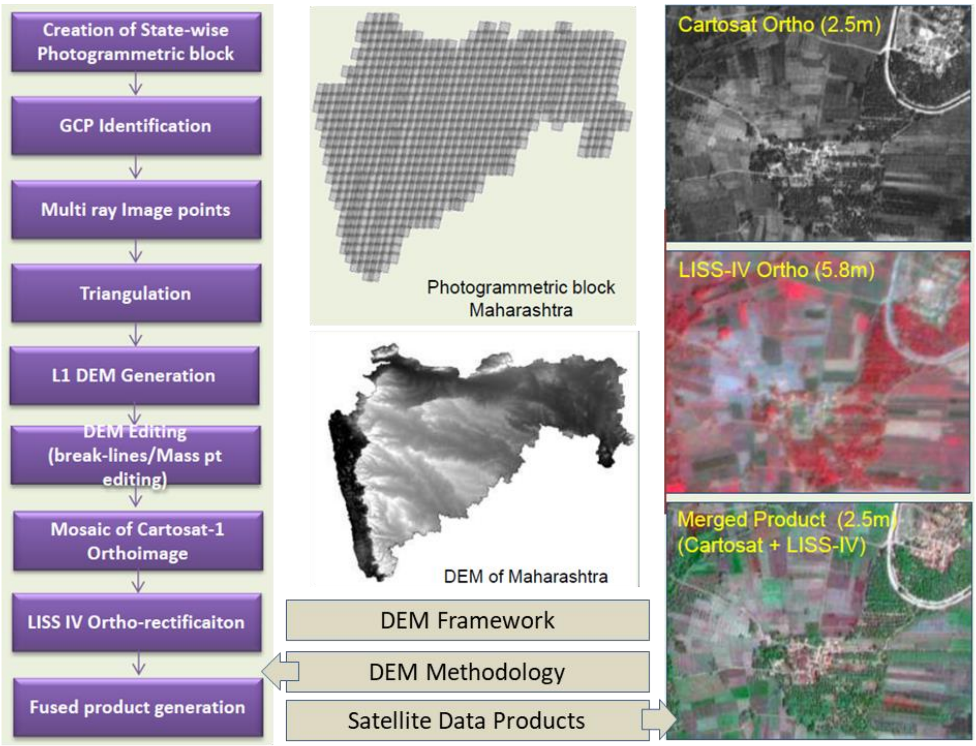
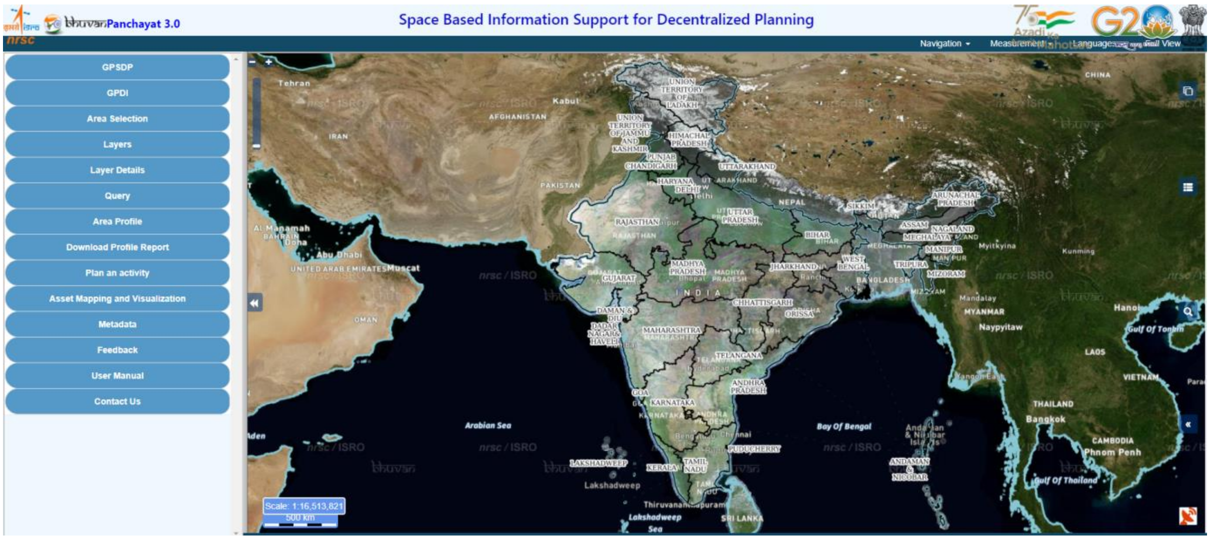


Fig. 10.16 Approach and products of three dimensionally corrected remote sensing data along with DEM of a large state

10.4.3 Web Portal

Following preparation of database, an open-source Web GIS portal Bhuvan Panchayat was designed and implemented so as to achieve best possible dissemination of geospatial data is available to Panchayat institutions. Augmenting this smartphone application was developed to support reporting of asset inventory from each village location as near real time process.

Development of Bhuvan Panchayat portal consisted of building database of satellite images, digital elevation model products, vector layers of road, infrastructure and administrative boundaries up to panchayat level. Portal (Fig. 10.17) also included a village level planner tool for suggesting newer interventions (Gram Panchayat Spatial Development Planner module) for Panchayat level planning of assets. This portal has been upgraded in to newer version along with newer database preparation programme aimed at revising the land use/land cover database as SIS DP 2.0.



10.5 Current Applications in Rural Development and their role in Governance

10.5.1 Integrated Watershed Management

Watershed Management is an integrated approach for conserving soil and water so that ecosystem amelioration is achieved in rural landscape, through a participatory approach. Application of geospatial technology has been strongly associated with this paradigm since its inception for planning and success in monitoring the progress through high resolution remote sensing-based methods as in Sujala project, preceded by SIS-DP and IMDS efforts. Buoyed with this information as well as due to countrywide need for monitoring 8200 projects spread across India, Department of Land Resources, Ministry of Rural Development, Government of India requested National Remote Sensing Centre to monitor impact of the watershed management interventions. Earlier the initiative was known as Integrated Watershed Management Programme (IWMP), while it is been reframed as Watershed Development Component of Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) which addresses core soil and water conservation domain. Pradhan Mantri Krishi Sinchayee Yojana – Watershed Development Component (WDC-PMKSY, now versioning as 2.0 from earlier 1.0) aims to enhance the judicious use of natural resources, particularly based on soil and water conservation measures. NRSC designed and developed the required technological interventions for monitoring of IWMP watersheds through the Bhuvan IWMP web interface called Srishti, across the country (Fig. 10.18). Srishti hosts range of IWMP related GIS database categories in addition to the annual high-resolution images of 2.5 m color pixels. Functionaries at state level (called SLNA, State Level Nodal Agencies) and below (called WCDC/PIA, Watershed cell cum Data Centre or Project Implementing Agency) can upload various types of information on watershed projects and related biophysical aspects, for a wider access, display and updation across chain of organization. Portal is augmented by a smart phone application named Drishti. Drishti available as download from Bhuvan website uses global positioning system signals of smart phone and tags the photograph captured. Ancillary information on each element monitored can be updated using a standard format

This is a first-time effort in using Geo-ICT Technology, across the country to realize transparency in project handling at this magnitude in terms of ability to detect and report activity implementation using high resolution color satellite image for entire project period, operational level use of geospatial technology enabling holistic management of natural resources for rural development.

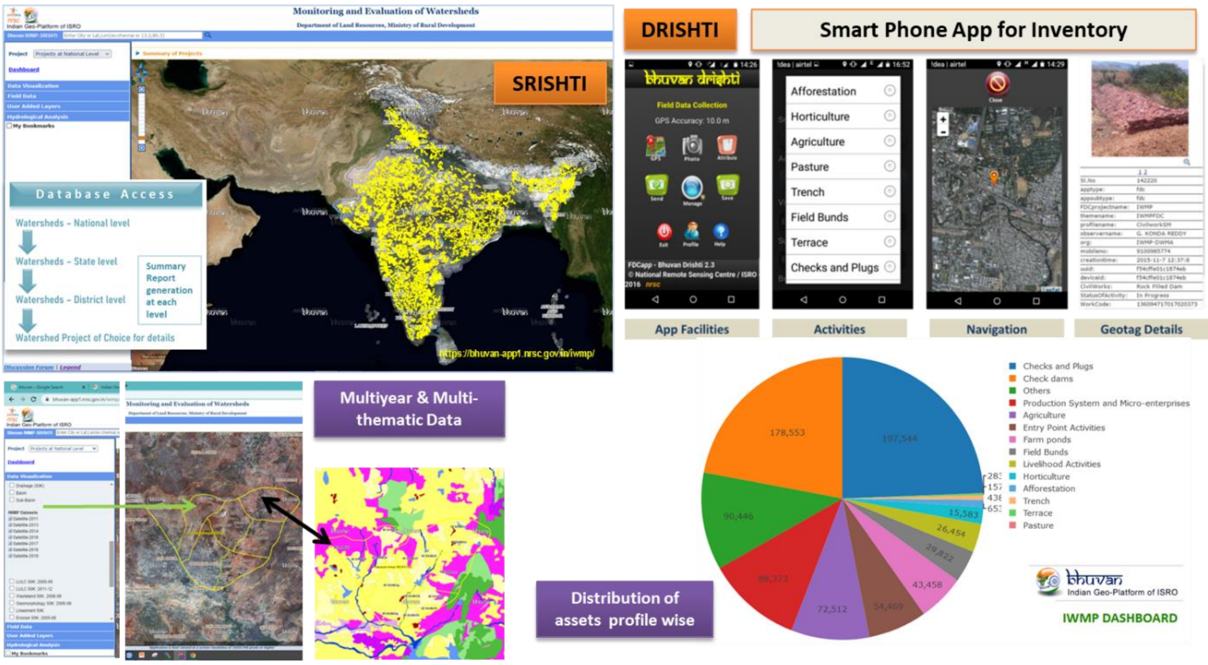


Fig. 10.18 Srishti and Drishti as Web portal and App for supporting monitoring of watershed projects under WDC PMKSY 1.0 products. Project uses multiyear remote sensing data and multi-thematic data, whereas distribution of assets created is displayed in dashboard

WDC PMKSY creates wide network of farm ponds, check dams and other water and soil conservation measures apart from supporting many other natural resource management actions as well as rural livelihoods. A geospatial data-oriented Web GIS solution on Bhuvan (Srishti) along with smart phone-based application (Drishti) have been developed and implemented on Bhuvan. The project aims at Monitoring and impact evaluation of Watersheds sanctioned under IWMP using multi temporal high resolution satellite data (Fig. 10.19) coupled with geotags as proof for interventions, taken by stake holder state departments. Indian Remote Sensing images in tandem with smart phone-based inventory followed by GIS service on ISRO's web GIS portal (NRSC,2017), Bhuvan, will serve as supporting evidence for developmental activities done on the ground. This project was taken up by NRSC at the request of DoLR, MRD, GOI wherein the monitoring was taken up in 8200 projects across India. For monitoring, 32000 satellite scenes have been procured envisioning collectively, operating their budgets, exercising their skills and leveraging their initiatives (Resourcesat L4, CARTO 1 & 2 series). Total geotags collected by the state watershed departments is 16.50 lakhs.

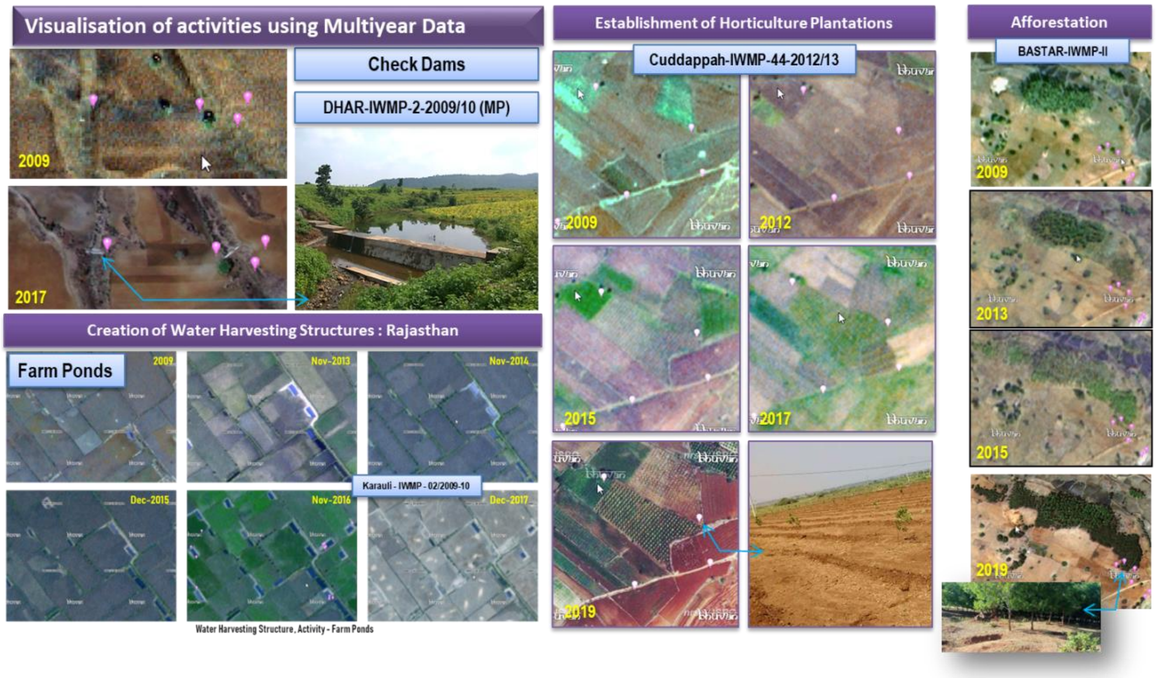


Fig. 10.19 Impacts of Watershed interventions demonstrated through IRS H res pan sharpened natural color composite images in different projects across nation. Plantation establishment is clearly seen. Sequence of farmponds in lower left side illustrates the persistence of ponds over time.

a) Digital Elevation Model from Cartosat & Watershed Delineation

Precision orthorectified imagery determines the quality of monitoring of rural development interventions in current context, since decision making level has mandated furnishing of satellite image verified asset creation on the ground. Towards this, satellite images need to geometrically correspond to each other, which is made possible by orthorectified image sequence. Core technology for this photogrammetry-based creation of digital elevation models from high resolution stereo image pairs, in turn helping to build a three dimensionally corrected satellite images. Creation of such digital images serves another critical purpose of defining the terrain in precise manner which guides the delineation and characterisation of hydrological units at various level/organisation. Digital models of elevation can help to delineate the units from micro watershed up to basins.

Cartosat 1 sensor provides stereo pairs at 2.5 m spatial resolution which are subjected to orthorectification to develop a elevation model. The Cartosat-1 has a pair of Panchromatic cameras having an along track stereoscopic capability using its near-nadir viewing and forward viewing telescopes to acquire stereo image data with a base-to-height ratio of about 0.63. The spatial resolution is 2.5m in the horizontal plane. Each camera has a pixel array of size 12000 giving a swath of about 27 km. The methodology of CartoDEM preparation comprises (Fig. 10. 11) of stereo-strip triangulation of 500km strip stereo pairs using high precise ground control points, interactive cloud masking, automatic dense conjugate pair generation using matching approach. Seamless homogeneous DEM is produced by steps such as i) TIN modeling of irregular DEM, ii) interpolation for regular DEM generation and iii) automatic strip to strip mosaicing. These automatically generated DEM tiles are evaluated for quality and tile editing to remove anomalies (Fig. 10.20). The Fig. 10.20 shows the function flow of CartoDEM generation for a segment of 500km. The primary output unit is a tile of 7.5’ X 7.5’ extents with DEM spacing of 1/3 arc-sec, and co-registered ortho-image of resolution 1/12 arc-sec.

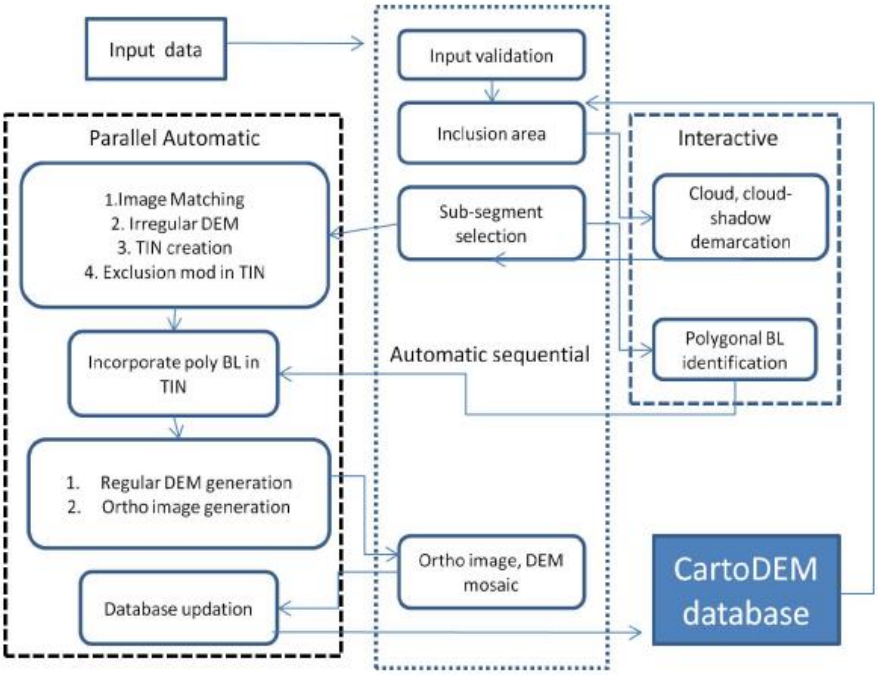


Fig. 1 0.20 Approach for Creation of Cartosat based DEM Database

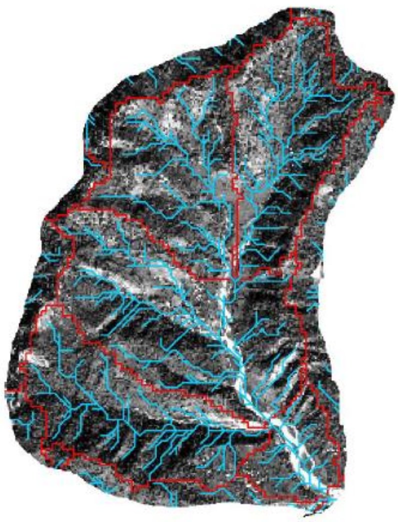


Fig. 10.21 Delineation of Water divide (red lines) as hydrological boundary units following creation of drainage network (blue lines). Subunits of the main micro watershed unit are evidently seen

However, data sets are available at 1 and 3 arc-sec. i.e., 30m and 90m spacing at equator which are generated by sub sampling the original 1/3 arc-sec data. The CartoDEM is a surface model of elevation and covers land surfaces of India. It is comprised of tiles that contain at least 0.01% of Indian landmass are included. As per the design of CartoDEM, the DEM accuracy is 8m at LE90 and 15m at CE90 for ortho data.

Standard COTS based tools enable automatic delineation of watershed boundaries and drainage patterns based on algorithms that follow the virtual flow of water from highest to lowest point in any given geographic extent. Essentially tool calculates flow direction for each pixel of the DEM considering a convolution of 3X3 pixels and weighs them from 1 to 128 as indicating the direction for a given tile. Drainage lines and their orders can be delineated subsequent to it for entire tile selected (Fig. 10.21). Upon these inputs, pour points have to be suggested to algorithm to suggest point of confluence for the catchment. Based on the point of convergence of entire flow above the pour point watershed boundary is identified. Vectors generated have pixelation effect which needs to be splined for a visually appealing and naturally corresponding boundary at feasible detail. Detail of the drainage extracted and watershed delineated is illustrated for a Cartosat DEM, showing ridge line in red tone, which may need to be harmonized before adapting to management unit required at policy compliant aggregation.

10.5.2 NABARD Sponsored Watershed development

National Bank for Agriculture & Rural Development (NABARD) has been providing the financial support for development activities in selected watersheds. Geo spatial technology was used to monitor these watersheds. Phase-I of the project completed where in monitoring of 108 watersheds spread over in four states viz. Telangana, Rajasthan, Madhya Pradesh and Gujarat have been completed. In Phase-II Monitoring of additional 500 watershed development projects were carried by using Remote Sensing and GIS tools. Resourcesat-2 and Cartosat1 satellite data was used for monitoring the watershed related activities. As per the advice of NRSC, NABARD has established a Remote sensing cell, which is a distinguished example of institutionalisation of geospatial application with a user organisation. NABARD is going to monitor watersheds hereafter through their cell with regular handholding and oversight of NRSC.

10.5.3 GIS Implementation of MGNREGA: GeoMGNREGA

Ministry of Rural Development (MoRD) is the nodal Ministry for the development and welfare activities in the rural areas of the country. MoRD envisages sustainable and inclusive growth of rural India through a multi-pronged strategy for eradication of poverty by increasing livelihood opportunities, providing social safety net and developing infrastructure for growth. Department of Rural Development (DoRD) felt the need to make use of space-based inputs and geospatial technology in MGNREGA, by geotagging the assets created and monitoring the scheme. MGNREGA is World’s largest rural employment programmes aiming to address critical Sustainable Development Goals (SDGs). Towards this BHUVAN platform-based interface has been implemented to enable monitoring (Pujar et.al., 2019b) of rural employment generation activities called Bhuvan GeoMGNREGA. Interface designed and developed at NRSC, presents specific use of global positioning system through smart phone applications, in combination with remote sensing and web GIS tools, for facilitating recording, reporting, and monitoring of MGNREGA. The time line of events demonstrated the distinct milestones related to rollout (Nov, 2016), reaching of 1 crore asset mark (Apr, 2017), completing 2.93 Crore target (Mid 2019), initiation of before-during-after geotagging for Bhuvan based fund allocation (Dec, 2019) and release of Yuktdhara (Aug, 2021) (Fig. 10.22). As on date total completed asset geotags tally stands at 5.29 Crore (Phase I geotags 3,75,09,638, Phase II: Stage 3 (After): 1,54,80,561) pointing towards the centrality of MGNREGA operation through Geospatial application.

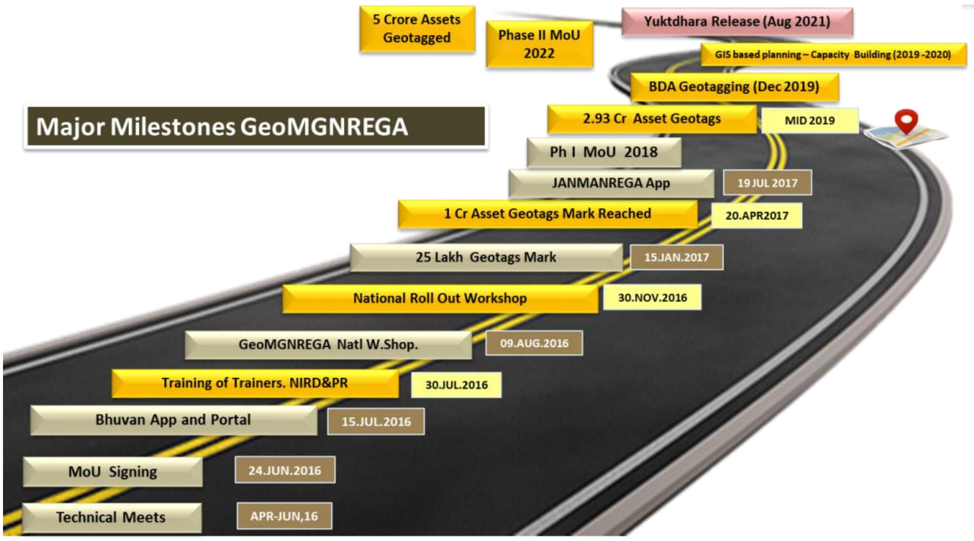


Fig. 10. 22. Timeline of GeoMGNREGA Project implementation with multi-institutional cooperation

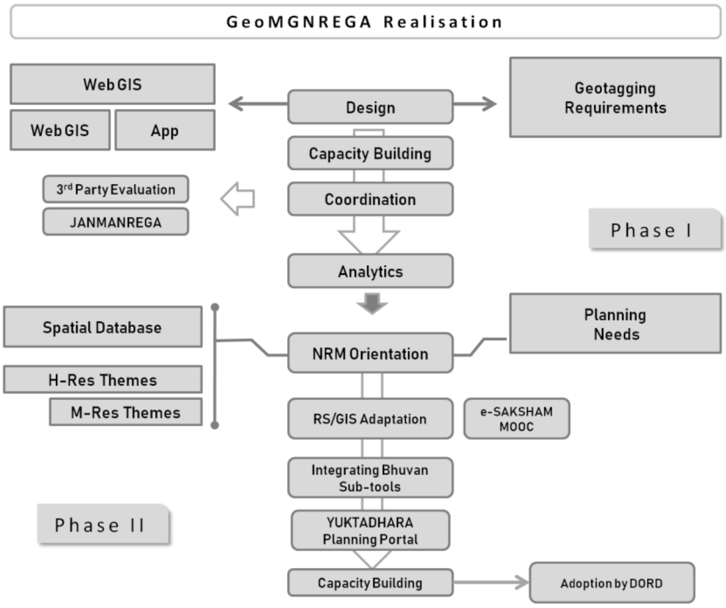


Fig. 10.23 Realising the GeoMGNREGA using open-source Web GIS / Smart app and phases of implementation

GeoMGNREGA has now reached a substantive stage of acceptance and incorporation in to operational approach for MGNREGA, since its inception in 2016. As a GIS based implementation, for the world's most prolific rural safety net initiative, the process strengthens measures to safeguard livelihoods of lowest strata of village societies. It has delivered a multistakeholder information system at expected level. Use of smart phone application and web GIS rendition in tandem (Fig. 10.23), has built a formidable database of no precedence, in terms of pan-Indian coverage as well as scope to improve the entire chain of activities in to transparent and fully accountable paradigm (Pujar et.al., 2019). Various analytic products have been rendered on the portal using open-source spatial analysis approach on a gridded base of 5km corresponding to ECV representation in NICES portal of NRSC. This gridded analytics (Fig. 10.24) presents temporal patterns of asset creation as well.

a) Planning of MGNREGA Activities

NRSC has taken up analytics of the geotags inventoried involving both open source as well as commercially available algorithms (Pujar et.al, 2022). This is followed by realization of a planning portal, Yuktdhara, (Fig. 10.24 Left) that addresses the need for multi-theme-based suitability decisions now and hereafter for all MGNREGA activities. The capacity building for this development as well as principles of GIS in planning new activities has been accomplished so that stakeholders realize the significance of GIS and role of bhuvan based tool for scientifically allocating the works. GeoMGNREGA is put to operational use by Ministry across all states and it continues to support the rural employment generation work implementation. Yuktdhara, the planning portal of GeoMGNREGA has been inaugurated by Hon'ble Ministers for Rural Development and Space along with State Ministers of Rural Development on Aug 23, 2021.

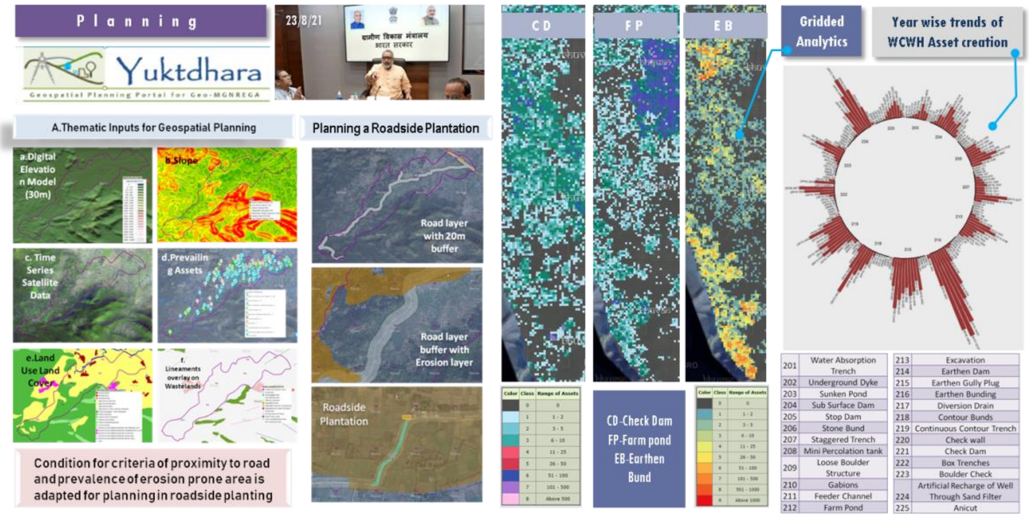


Fig. 10.24 Planning and Analytics under GeoMGNREGA addresses multithematic aspects of planning as well as tracing the spatial and temporal patterns in geotagging approach. Right half of the illustration shows spatial gridded pattern on asset distribution with a circular temporal plot of asset creation trend. Also seen is the inauguration event of Yuktdhara by Minister for Rural Development

NRSC has realized the planning portal Yuktadhara, for supporting the planning activity under GeoMGNREGA using NRM principles. Portal integrates major pan Indian thematic layers available under NRSC with due visualization tools as well as GIS overlay open-source algorithms for facilitating planning new activities. Yuktdhara provides "Probable Locations' for possible interventions to be taken up as part of planning using principles of GIS overlay in the online tool. Portal has built in scope for linking with NREGASoft so that planning is coupled with financial aspect for an activity planner. Two other major additional components, apart from the overall scope of MoU viz., Third Party Evaluation solution and JANMANREGA App were provided to MoRD. In Third Party Evaluation module, NRSC has furnished end-to-end solution including sample outlay framework, realization of smart phone application, Web GIS service, field demonstration and concomitant revision of app as well as final capacity building for stakeholders. In JANMANREGA app, total geospatial customization from Bhuvan services for the app interface, initial ideation and support for realising the process, including field testing and feedback-based revisions.

10.5.4 Agriculture infrastructure: RKVY and PDMC

Rashtriya Krishi Vikas Yojana (RKVY), launched in 2007, was an effort by Department of Agriculture Cooperation & Farmers Welfare (DAC&FW), Govt. of India, to enhance public investment in agriculture and allied sectors. The scheme was introduced to ensure that states will draw up more inclusive and integrated, comprehensive agriculture development plans based on agro-climatic conditions, availability of technology and natural resources. The objective was to ensure the increase in agricultural productivity and overall growth in the agriculture sector by promoting the adoption of modern agricultural technologies, improving agriculture infrastructure, and providing farmers with solutions related to sustainable farming practices. Also, the goal was to reduce the yield gaps in important crops and to include the local needs while bringing quantifiable changes in various agricultural components in a holistic manner.

Use of Space technology is emphasized in all fields of governance. NRSC-ISRO has major strengths in applying Geospatial, ICT and IOT technologies for diverse governance areas. They were entailed in this innovative endeavour to bring better transparency, scalability and innovative catalouging and management of RKVY assets. A smartphone App was developed for Geo-tagging and reporting of assets to Bhuvan interface along with a dashboard. This unique technological innovation has enabled online visualization of assets and contributed significantly for making progress monitoring more straightforward at both state and central levels. Geotagging initiative is taken up using an android based app to precisely locate RKVY assets through the Bhuvan Geoportal, which provides the facility to visualize assets spread in the context of high-resolution image backdrop with GIS analytical capabilities. Till date 6,15,464 assets have been geotagged in the project by the field functionaries, of which Agricultural Mechanisation, Micro-irrigation and horticulture dominated the overall scenario with 38, 18 and 17 per cent of total assets respectively. Towards this project, capacity building has been conducted for West Bengal state and hand holding is maintained.

Per Drop More Crop (PDMC) scheme was launched in 2006 by Department of Agriculture Cooperation & Farmers Welfare (DAC&FW), Govt. of India. The objective was to enhance water use efficiency in the agriculture sector by promoting appropriate technological interventions like drip & sprinkler irrigation technologies and encourage the farmers to use water saving and conservation technologies. It has resulted in achieving convergence of investments in irrigation at the field level, expand cultivable area under assured irrigation, and improve on-farm water use efficiency to reduce wastage of water, enhance the adoption of precision-irrigation and other water saving technologies. The scheme is an integral part of water conservation and sustainable agricultural practices, particularly in water-scarce regions. The approach is to adopt precision-irrigation and minimize wastage while maximizing agricultural output.

NRSC was involved in the development of an Android App to precisely locate, analyse and generate reports of the uploaded PDMC assets and visualisation through Bhuvan Geoportal.

The Fig. 10.20 presents a glimpse of the activity carried out, Geotag information and other details under RKVY and PDMC projects. Geotagging initiative is taken up using an android app to precisely locate PDMC assets through Bhuvan Geoportal (Fig. 10.25). During Nov 2020- Oct 2021 13140 assets have been geotagged in the project by the field functionaries. Till date 3,06,900 assets have been geotagged in mirco-irrigation and other categories, of which Maharashtra, Telangana and Andhra Pradesh dominate the distribution with 52, 16 and 11 percent of assets.

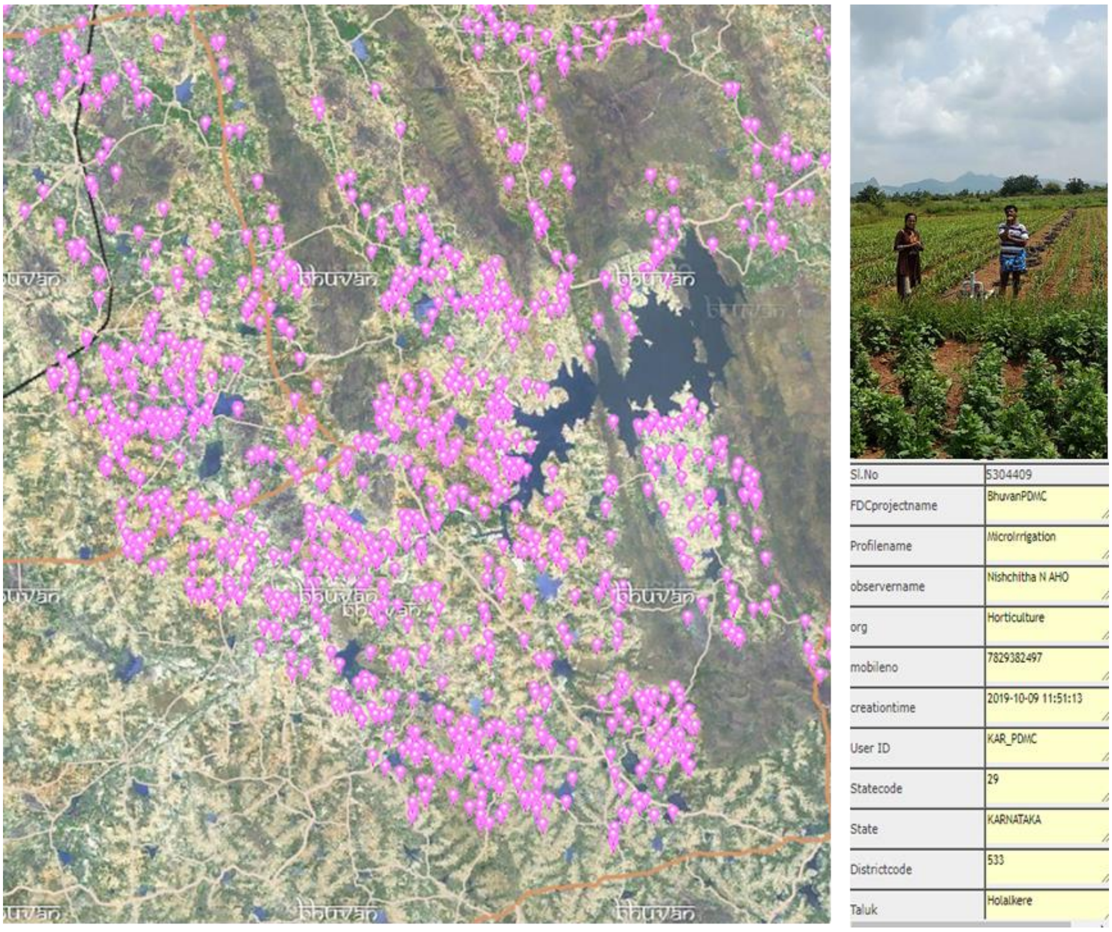


Fig. 10.25 Per Drop More Crop Geotags for Madadkere, Chitradurga, KRN reveal intense pattern of implementation. Sample Geotag detailing the asset implemented is illustrated

10.5.5 Rural Connectivity Monitoring (PMGSY)

Rural road connectivity is a vital component of rural development since it promotes access to economic and social services to rural areas, thereby increased marketing of rural products (e.g., agricultural produce, cottage industry etc.), communication, access to health and education services as well as employment, which in turn expands rural growth opportunities. This will result in better income opportunity and will help in poverty alleviation. Further, accessibility is related to the quality of road network and transportation system between different villages in the rural areas. Presently about 65 % of the freight and 85 % of passenger traffic is through rural road network in India. With majority of the Indian population living in rural areas, rural roads demand attention, not just to achieve intended targets of new road construction but also towards a more sustained connectivity of these roads.

Pradhan Mantri Gram Sadak Yojana (PMGSY) under the Ministry of Rural Development was conceptualized and launched on 25th December, 2000 as a centrally sponsored scheme, with the broad objective of sustainable poverty reduction in rural areas. The main objective of PMGSY is to provide basic access by way of single all-weather road to all eligible unconnected habitations in the Core Network. The programme intended to connect all 'eligible' unconnected habitations that have:

- A population of 500 people and above in plain areas

- A population of 250 people and above in special category states, Schedule V Tribal Areas, Desert areas and in selected Tribal and Backward Districts (as identified by the Ministry of Home Affairs)

Under PMGSY, approx. 6,26,034 km of length has been constructed till 31st March 2020. It is a challenge to manage such a gigantic activity using traditional methods, which is not only tedious and time-consuming but also difficult to ensure timely retrieval of the desired information. To overcome these difficulties, the use of Geo Informatics is taken up to help in effective planning, decision making and monitoring of PMGSY roads.

The Tripartite Agreement on Use of Geo Informatics in Rural Road Projects under Pradhan Mantri Gram Sadak Yojana (PMGSY) was made and executed at New Delhi on 7th March, 2017 between National Rural Infrastructure Development Agency (NRIDA), National Remote Sensing Centre (NRSC) and Center for Geo-Informatics Application in Rural Development (CGARD). Under this project National Remote Sensing Centre (NRSC) and National Institute of Rural Development & Panchayat Raj (NIRD&PR) has jointly taken up to produce geospatial datasets for the country. This project is to extract and identify roads connectivity status in terms of length based on inputs provided by NRIDA. The Online Management Monitoring and Accounting System (OMMAS) is software designed by the Center for Development of Advanced Computing, Pune, under the scheme of Pradhan Mantri Gram Sadak Yojana as an online web-based system for centralized database of rural roads that enabled data of NRIDA. Efforts comprised of generating a spatial database on road connectivity with respect to habitations connected under completed roads. Hence, it was essential to generate a rural road map based on satellite imagery for the roads sanctioned from the year 2000-01 onwards for further investigation and analysis. NRSC (ISRO) carried out generation of rural road geospatial database by extracting road features from high resolution satellite imagery for 14 states out of 29 states using interactive heads-up display method. Efforts addressed generation and harmonisation of rural road geospatial database (14 states) and development of PMGSY dashboard on Bhuvan web portal for 29 states (Fig. 10.26). Road, habitation and long span bridge database have been prepared for states Maharashtra, Manipur, Meghalaya, Bihar and Chhattisgarh States.

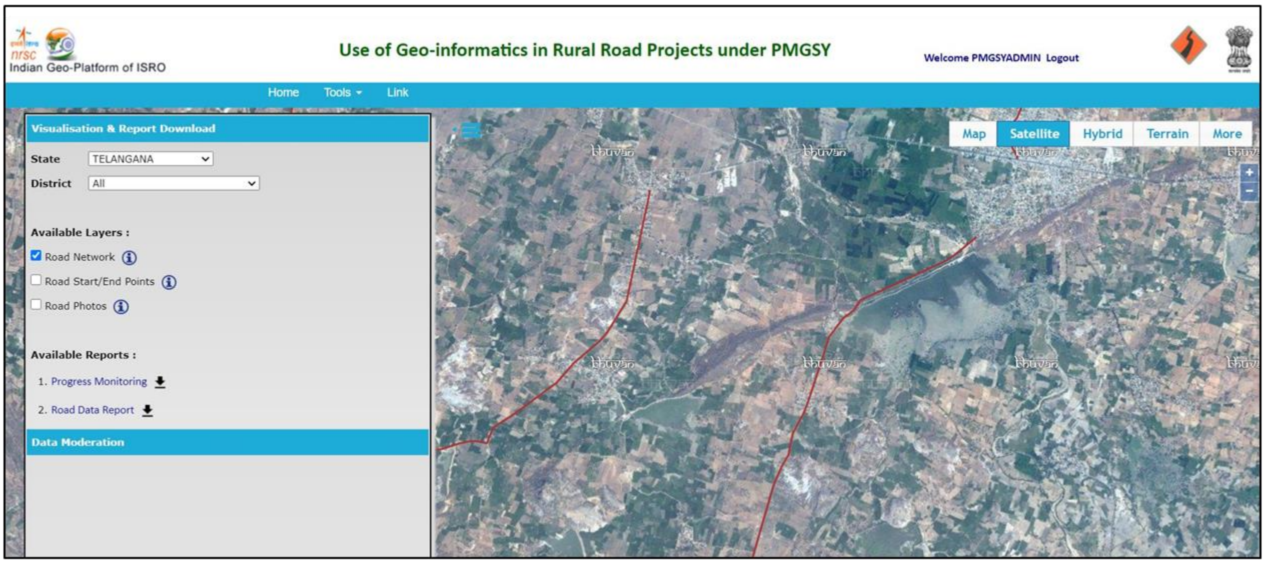


Fig. 10.26 Visualization module on Bhuvan portal

10.5.6 Monitoring of VSS forest areas under World Bank support

Assessment of forest cover improvement in Village Forests across VSS (Vana Samrakshana Samithi, Forest Conservation Committees) funded by a World Bank initiative was taken up at the request of Andhra Pradesh Forest Department. Greening activities were carried in 1998-99 period and its impact was seen after 5-year period. Out of 20 sites analysed using medium resolution LISS III multispectral data pairs, six sites clearly showed substantial resurgence of the vegetation followed by five showing no change in vegetation status. In fact, six sites even witnessed removal of vegetation over the study period due to various reasons that may or may not be linked to the intervention process taken up. Geospatial analysis showed as illustrated a clear establishment of teak crop (as evident from ground truth) from erstwhile low stock situation in 1998 due to the protection offered by villagers due the project. Establishment of eucalyptus plantation was also witnessed coupled with recovery of dense forest adjacent to coppiced teak sector (Fig. 10. 27). Coppicing is phenomenon of recovery of tree crop from felled stem stumps, which is a vegetative regrowth prevalent in many dry area species. Distribution of villages with respect to reversion to dense forest and plantations shows a range of 2- 35 and 10-75 ha respectively (Fig. 10.27). Application of this nature reveals the strength of empowering villages in greening efforts, which in principle are capable of forest restoration, supported by spatial information as a tool for policy devolution.

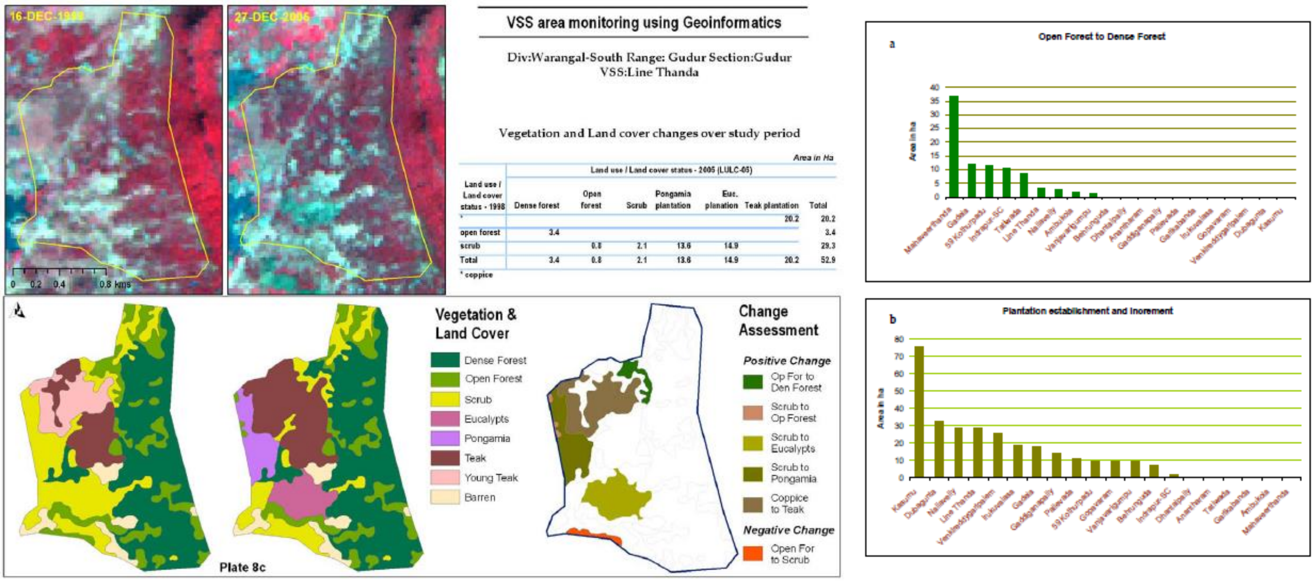


Fig. 10.27 Monitoring of VSS using Geoinformatics showing land cover changes (left) and trends of land cover change in villages (right) in Andhra Pradesh Forest edge areas

10.6 Geospatial technology framework and implications for policy support

10.6.1 Experiences with current geospatial tools & solutions

a) Overwhelming Stakeholder response and accomplishing transparency and accountability

Application of Geo-ICT tools for governing rural development programmes such as WDC-PMKSY and Geo-MGNREGA witnessed unprecedented response from functionaries especially at implementation level. Instances of applying techniques of recording field photos with geotags, as a fool proof step of reporting works transparently and quickly furnished the context, clarity, precision with respect to works that were executed. Functionaries adopted the process with commitment and soon realised the ease of inventory towards building a centralised repository of information. Cases of applying geotagging in preventing malpractices such as ghost capacity building sessions were noteworthy, as a desirable spinoff of positioning technology, for instance. Detailed grid of information provided by high resolution images coupled with less than meter accuracy of geolocation of entities on field, demonstrated flexibility of communicating the work completion with high confidence. Web GIS played major role in increasing the access of information to all stakeholders at any point of time. Setting of monitoring mechanism of MGNREGA asset creation using three stages reporting, though appeared simple, leads to new level of transparency in good governance. Strength of Bhuvan system supporting financially linked operations of rural development works strengthened decision making at Central level so that assets were created in accountable manner. Apart from this, most notable point of utilisation of spatial data for planning and budgeting was illustrated in the early application of thematic information for identifying exhaustive set of interventions using Bhuvan data. Efforts using spatial data revealed to the planning team the potential to create meaningful works, based on data on small canals under AIBP, in Mathura district, to create employment opportunities, which they though hitherto were totally exhausted by already constructed conventional assets.

b) Learnings in applying android tools for inventory & continuity of customisation

Open-source technology combining Android with open GIS development accomplished information technology solutions over a very large clientele. However open-source technologies have limitations in terms of handling certain intrinsic computational management aspects. For instance, lack of memory handling for which a commercial suite may offer time saving customisation, which is often not the case in open-source modules. High degree design appeal and strong user orientation to make commercial suites better than a competitor may not occur in several open-source solution that may lead to reduced ease of operation for a neophyte.

Innovative approaches gradually evolved by several state level functionaries to apply GeoICT tools, revealed requirements of revising the customisation techniques at time. Specialised ticketing system or social media groups were laid out to seek and understand the feedback on each of the tool implemented. Requirements such as, secured photographic captures with no tampering of location content, providing image map service to geotag spread visualisation, incorporating navigation tools for guiding the inventory personnel in remote settings were customised further after basic framework of smart phone application was delivered. A key functionality of moderating the collected asset geotags required iterative development since user needs of ensuring the quality of data collected kept evolving. However, dilution of quality of geotags is another aspect not related to development aspect, since it is influenced by the casualness of personnel who do not filter the undesirable content either because of ignorance or lack of time.

c) Felt needs of incorporating planning and monitoring mechanisms

Response of Ministry towards establishment of Geospatial information systems evolved in to a clear need of spatial information in to planning new interventions for natural resource management such as soil and water conservation, plantation efforts and maintenance of prevalent assets. Towards this NRSC enhanced the support to include tools to integrate variety of thematic information for planning and monitoring at implementation level of functionaries. Efforts of establishing such portal modules required compilation of latest spatial datasets including high resolution digital elevation models. However, constraints of policy related interpretations as well as delays related to permission of database interoperations have impacted the full realisation of use of such modules.

d) User requirement for collaboration with other national and international institutions

Conviction and confidence suffused in to community of MGNREGA functionaries due to use of nationally homogenous spatial content, has provided opportunity for Central decision making to attempt networking international agencies (IIED) connected to rural employment in India, so that synergy of technological accomplishments is harnessed. Several institutions supported by voluntary spirit (FES) and international relations are in the process of integrating with Bhuvan GeoMGNREGA for adding value to planning, analytics, grassroot level service, modelling climate change impacts through hydrological principles etc. Such instances offer scope to incorporate best practice guidelines in to ongoing national efforts, so that they complement each other in terms of approaches, techniques and outreach experience.

e) Delayed realisation of technology potential and resource constraints

However, at times lack of corresponding responses to the technological increments between implementing and user agencies can corrode the accomplishments made in terms of fool proof functioning or comprehensive support to all level of functionaries. Absence of desirable alacrity, in executing simple yet critical linkages between database units operating in respective agencies or institutions also can hamper the complete realisation of information system to the logical end. Lack of understanding on the part of decision makers about the criticality of the step or impending legacy constraints in arriving at facilitation would delay the technological maturity. Uncertainties of open-source technological ambience, at times complicated by control by cyber security policies without proper caveats for sharing harmless content as well as cautious approach of developers due to lack of complete knowhow of the open-source modules, can also derail the implementation of well-meaning programmes, in turn sapping the confidence of users and facilitators alike.

10.6.2 Need for continuous capacity building and incorporating feedback

Technology spread can be accomplished only when pedagogically perfect capacity building programme is taken up, since participants may differ in terms of experience and qualifications in projects of interdisciplinary nature such as watershed development. Nuances of use of tools and principles needed for smooth operational execution are to be conveyed to practitioners with clarity. Such an effort requires good quality follow up and handholding since minor gaps in understanding should not deter trained personnel from applying techniques to practice of tools for governance. Occurrence of errors committed during operational phase, due to lack of understanding of technology, can multiply in to large volume of corrections that would be time consuming, even if small fraction of stakeholders commits mistakes in reporting.

Various phases in technology evolution are key aspects of working with frontier geospatial technology. Incremental developments in commercial or open-source technology modules get added over to prevalent tools, in relatively quicker succession, of late. It happens due to convergence of various technologies in to spatial information systems enabled by high degree of interoperability. Communicating such value additions to tools of governance requires follow up capacity building sessions. Without such efforts teams may often fail to keep pace with essence of developing applications which may occur either due to broken skill path or transfer of personnel across and within line departments. Though online capacity building programmes or workshops have added opportunity to conduct flexible training sessions, it is desirable to have in person training sessions whenever, a magnitude of revision added to tools/techniques exceeds major fraction. Especially the sessions incorporating core technical personnel either from allied departments or suppliers of equipment need to be conducted in person keeping view of the need to experiential learning.

Keeping in view of the sheer size of personnel needed to be trained for paradigm such as Geo-MGNREGA or similar programmes, it is preferable to prioritise the target geographic settings requiring early intervention of technology driven approaches, due to higher degree of backwardness, compared to relatively develop rural sectors in the region. Often the frontier technology experts are in minimum strength at the early phase of technology practice and so it is required to prioritize the selection of target geographies.

10.6.3 Challenges in Technology Application and sensitisation of Decision makers

Rapid growth of geospatial technology, replete with innovations in terms of sensors, platforms, analysis techniques, three-dimensional data, and web-based technologies and cloud storage presents a clear challenge in applying the state of art technologies for rural development endeavours. Interplay of these elements and uncertainties associated with building a functioning system out of them comes with a challenge. Ability of Indian Space Ecosystem in attempting such integration through its experience elsewhere, such as realising satellite operations in space, qualifies as desirable strength in establishing upcoming geospatial information systems.

Different facets of same technology deployed differently by various interest groups, across various state institutions involved in rural development, may often require a national level harmonisation and standardisation. Such harmonisation can lead to a comparative understanding for tuning future strategy with regard to an informed decision making. Successful application of innovative tools in management of resources using Earth observation, across different states emerge as good solutions, driven by need for locally robust governance solutions, coupled with interests of academia and business. Experience of Earth observation framework of India matured well over last five decades, aptly led by ISRO's facilitation often, can be harnessed in accomplishment of adapting such local or regional solutions for national level optimisation. Networks of geospatial knowledge between Central and State space application institutions built based on principles of mutuality, sharing and handholding can establish good verification of the solutions built, towards achieving robust approaches over large spatial and temporal domain.

Varied approaches of adapting technology across states by functionaries, especially while adhering to precision of content generation during field inventory, especially with respect to quality and relevance of information may bring in undesirable elements in database. Shortcomings in terms of completeness of information can bring down usability of content for analysis and future planning.

Applying state of the art fourth information revolution (4^{th} IR) technologies can have great bearing on establishing a deep content for rural development. Platform furnished by Geographic Information served through Web GIS can enable online serious games (Beri, et.al., 2022) so that planning can be done with enough alternatives explored with implications clarified before deciding on the interventions. Uncertainty of climate change induced vulnerabilities requires such multiple path approaches. Virtual reality transgressing in to extended reality (XR) has complete potential to merge in Meta as the new ambience of digital platform. Immersion that can be made possible using VR/AR tools can leverage information with high grain detail especially related to natural resource management. Such development would make it possible for any stakeholder to appreciate the dynamics, impact and scenarios of grassroot level development with flexible options to decide upon.

10.7 Conclusion

Rural development in the current sense of implementation using social, economic and technological interventions attempting to impact rural poverty and resource degradation can be substantially supported by remote sensing and GIS technology. Legacy geospatial database efforts have given critical headway in furthering the cause. Post 2014, unprecedented emphasis on applying space technologies by PMO opened vista of web enabled geographic information systems coupled with smart phone application tools so that high resolution precision rectified pixels have been coupled with near real time field inventory. Devolution of these technological approaches have added hitherto unimagined value to governance of rural development initiatives in domain of rural employment, soil and water conservation, agriculture infrastructure monitoring as well as climate change vulnerabilities. ISRO would take further initiative in applying newer technologies as value addition to geospatial framework through data collected from sensors on board platforms at various near Earth and polar orbits from Indian and international sensors. It is imminent hereafter that decision makers would incorporate such approaches for better management of human and natural resources in rural context and achieve integration of various development domains for sake of Indian villages.

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