Overview of Remote Sensing & GIS Applications

Indian Institute of Remote Sensing
Indian Space Research Organisation (ISRO)
Department of Space, Govt. of India, Dehradun

OVERVIEW OF REMOTE SENSING & GIS APPLICATIONS

E-BOOK

Abstract

The lecture notes on overview of Remote Sensing consists of fourteen chapters covering technology and thematic applications of Remote Sensing. The first three chapters are on Basic principles of Remote Sensing, GIS technology and Global Satellite Navigation System (GNSS). The remaining eleven chapters are on different applications of Remote Sensing and GIS with special emphasis on governance applications. The chapters also supported with relevant references and study materials.

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About ISRO

Indian Space Research Organisation (ISRO) is the space agency of India. The organisation is involved in science, engineering and technology to harvest the benefits of outer space for India and the mankind. ISRO is a major constituent of the Department of Space (DOS), Government of India. The department executes the Indian Space Programme primarily through various Centres or units within ISRO.

ISRO was previously the Indian National Committee for Space Research (INCOSPAR), set up by the Government of India in 1962, as envisioned by Dr. VikramA Sarabhai. ISRO was formed on August 15, 1969 and superseded INCOSPAR with an expanded role to harness space technology. DOS was set up and ISRO was brought under DOS in 1972.

The prime objective of ISRO/DOS is the development and application of space technology for various national needs. To fulfil this objective, ISRO has established major space systemsfor communication, television broadcasting and meteorological services; resources monitoring and management; space-based navigation services. ISRO has developed satellite launch vehicles, PSLV and GSLV, to place the satellites in the required orbits.

Alongside its technological advancement, ISRO contributes to science and science education in the country. Various dedicated research centres and autonomous institutions for remote sensing, astronomy and astrophysics, atmospheric sciences and space sciences in general function under the aegis of Department of Space. ISRO's own Lunar and interplanetary missions along with other scientific projects encourage and promote science education, apart from providing valuable data to the scientific community which in turn enriches science.

ISRO has its headquarters in Bengaluru. Its activities are spread across various centres and units. Launch Vehicles are built at Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram; Satellites are designed and developed at U R Rao Satellite Centre (URSC), Bengalure; Integration and launching of satellites and launch vehicles are carried out from Satish Dhawan Space Centre (SDSC), Sriharikota; Development of liquid stages including cryogenic stage is carried out at Liquid Propulsion Systems Centre (LPSC), Valiamala & Bengaluru; Sensors for Communication and Remote Sensing satellites and application aspects of the space technology are taken up at Space Applications Centre (SAC), Ahmedabad and Remote Sensing satellite data reception processing and dissemination is entrusted to National Remote Sensing Centre (NRSC), Hyderabad. The Indian Institute of Remote Sensing (IIRS) - is a constituent unit of Indian Space Research Organisation (ISRO), Department of Space, Govt. of India focused training and capacity building in the area of Remote Sensing and Geospatial technologies. For more details, the readers are advise to visit official website- www.isro.gov.in

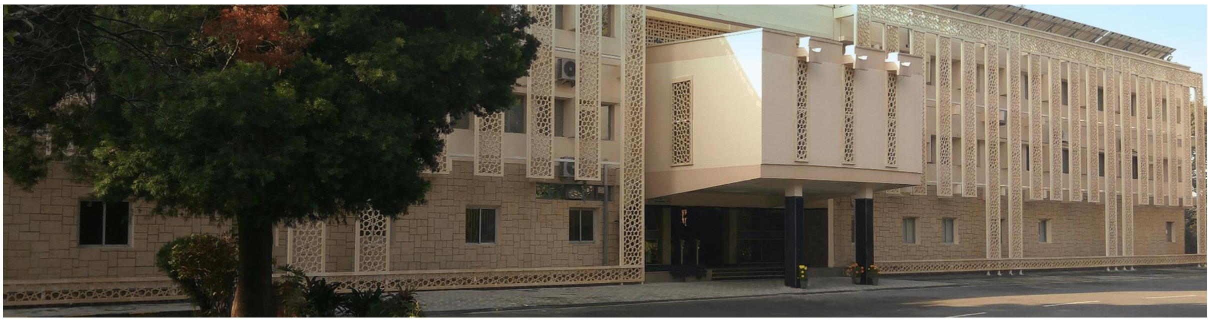
About IIRS

The Indian Institute of Remote Sensing (IIRS) - is a constituent unit of Indian Space Research Organisation (ISRO), Department of Space, Govt. of India. Since its establishment in 1966, IIRS is a key player for training and capacity building in geospatial technology and its applications through training, education and research in Southeast Asia. The training, education and capacity building programmes of the Institute are designed to meet the requirements of Professionals at working levels, fresh graduates, researchers, academia, and decision makers. IIRS is also one of the most sought after Institute for conducting specially designed courses for the officers from Central and State Government Ministries and stakeholder departments for the effective utilization of Earth Observation (EO) data. IIRS is also empaneled under Indian Technical and Economic Cooperation (ITEC) programme of Ministry of External Affairs, Government of India providing short term regular and special courses to international participants from ITEC member countries since 2001. The M.Tech. course in 'Remote Sensing & GIS', being offered by the institute in collaboration with the Andhra University, Visakhapatnam, is approved by the All India Council for Technical Education (AICTE).

To widen its outreach, IIRS has started live and interactive Distance Learning Programme (DLP) since 2007. IIRS has also launched e-learning course on Remote Sensing and Geo-Information Science since August, 2014.

The Institute has a strong, multi-disciplinary and solution-oriented research agenda that focuses on developing improved methods/ techniques for processing, visualization and dissemination of EO data & Geo-information for various societal applications and better understanding of Earth's system processes. Currently, Microwave, hyperspectral and high-resolution EO data processing and their applications are some of the prime research areas. State-of-the-art laboratory and field-based instrumentation and observatories network help meeting the research goals and objectives.

IIRS hosts headquarters of Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP), affiliated to the United Nations and provides support in conducting the Remote Sensing and GIS training and education programmes. IIRS also plays a key role in the activities of Indian Society of Remote Sensing (ISRS), which is one of the largest non-governmental Scientific Societies in the country. For more details, the readers are advise to visit official website- www.iirs.gov.in



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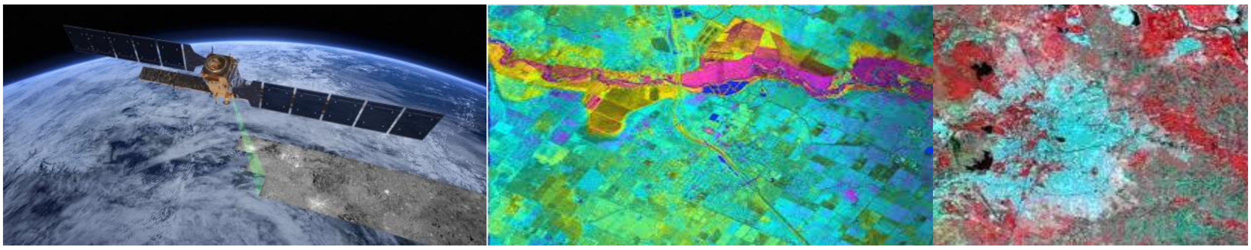
Chapter 1

Fundamentals of Remote Sensing



1. Introduction

Rapid development and changing life style has made significant impact on environment and are altering the earth surface processes and creating ecological challenges. The impact of development on the environment is significant as the rapidly growing population, urbanization and other development efforts have exerted tremendous pressure on natural resources and have caused their depletion and degradation. Biodiversity is declining at an unprecedented rate - as much as a thousand times what it would be without the impact of human activity. Half of the tropical rainforests have already been lost. Land degradation affects as much as two thirds of the world's agricultural land. As a result, agricultural productivity is declining sharply. The conservation measures are far from satisfactory and as development processes and interventions still continue, natural resources will be subjected to greater damage in the future. Hence there is an urgent need to look for alternative strategies and approaches for better and more efficient management of natural resources in order to ensure their sustainable use. This is further compounded by the ever-increasing occurrences of natural hazards. Therefore, there is a greater demand for most authentic timely information on a suit of geophysical parameters and environmental indicators. Towards this earth observation from space provides a vantage point where a large number of sensors have been deployed onboard satellites providing geospatial information needed to understand the earth system as a whole. Remote sensing plays a key role in providing geo information required for monitoring the Earth surface, ocean and the atmosphere at several spatio-temporal scales and have become crucial for protecting the global environment and achieving sustainable development, Space based observations specifically, during natural and human-induced hazards are critical for reducing disaster losses.

2. Definition of Remote Sensing

"Remote sensing is the science of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information"

Remote sensing, also called earth observation, refers to obtaining information about objects or areas at the earth's surface by using electromagnetic radiation (light) without coming in physical contact with the object or area. The basic process involved in remote sensing is the interaction of the electromagnetic radiation with the earth's surface and detection at some altitude above the ground.

Remote sensing systems have four basic components to measure and record data about an area from a distance (Fig. 1). These components include:

- Emission of electromagnetic radiation (EMR)
- Transmission of energy from the source to the surface of the earth, as well as absorption and scattering
- Interaction of EMR with the earth's surface: reflection and emission
- Transmission of energy from the surface to the remote sensor
- Sensor data acquisition

- Data transmission, processing and analysis

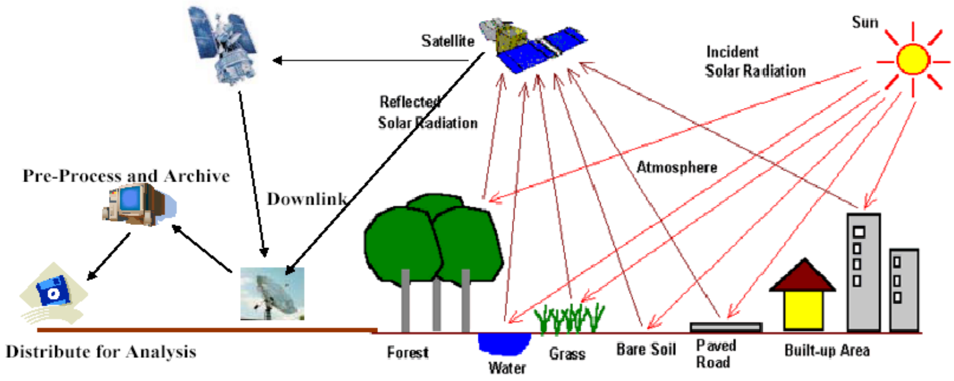


Figure 1. Remote sensing process.

With respect to the type of energy resources, the RS technology is defined as passive or active (Fig. 2):

- Passive Remote Sensing makes use of sensors that detect the reflected or emitted electro-magnetic radiation from natural sources.
- Active remote Sensing makes use of sensors that detect reflected responses from objects that are irradiated by artificially generated energy sources, such as radar.

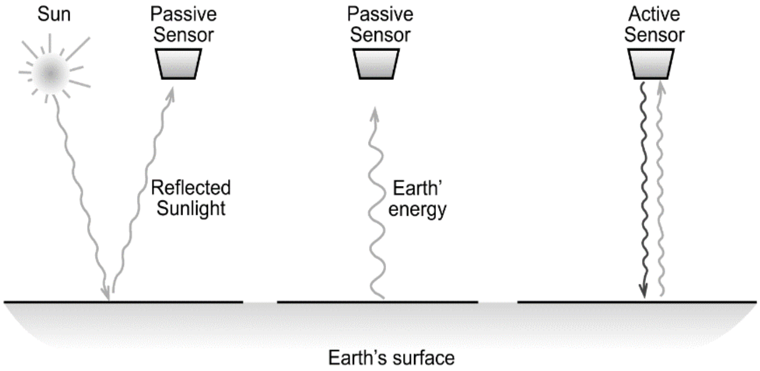


Figure 2. Passive and active remote sensing.

With respect to Wavelength Regions, the RS technology is classified as:

- Visible and Reflective Infrared Remote Sensing operating at a range of 0.4μm – 2.5μm
- Thermal Infrared Remote Sensing operating at a range of 3μm - 14μm
- Microwave Remote Sensing operating at a range of 1mm- 1m

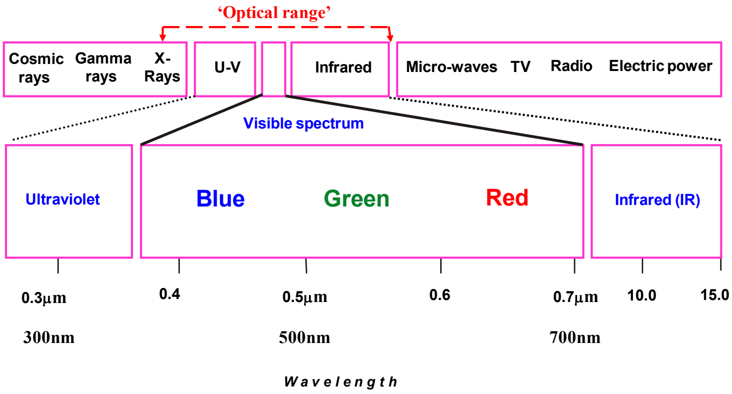


Figure 3. Electromagnetic spectrum.

3. Interaction of EMR with the Earth's Surface

Radiation from the sun, when incident upon the earth's surface, is either reflected by the surface, transmitted into the surface or absorbed and emitted by the surface. The EMR, on interaction, experiences a number of changes in magnitude, direction, wavelength, polarization and phase. These changes are detected by the remote sensor and enable the interpreter to obtain useful information about the object of interest. The remotely sensed data contain both spatial information (size, shape and orientation) and spectral information (tone, color and spectral signature).

In the visible and reflective Infrared remote sensing region, the radiation sensed by the sensor is that due to the sun, reflected by the earth's surface. A graph of the spectral reflectance of an object as a function of wavelength is called a spectral reflectance curve. Figure shows the typical spectral reflectance curves for three basic types of earth feature vegetation, soil, and water in the visible and reflective Infrared region Fig. 4.

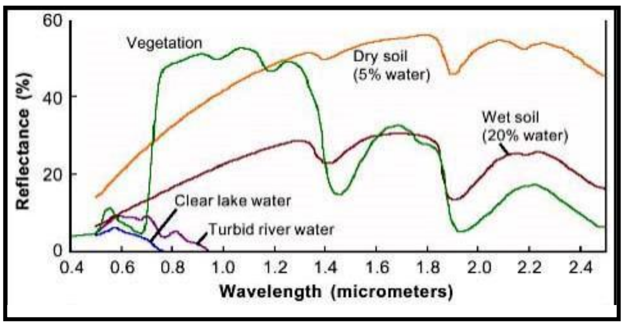


Figure 4. Typical spectral reflectance curves for vegetation, soil and water

The band corresponding to the atmospheric window between 8 μm and 14 μm is known as the thermal infrared band. The energy available in this band for remote sensing is due to thermal emission from the earth's surface. Both reflection and self-emission are important in the intermediate band from 3 μm to 5.5 μm.

In the microwave region of the spectrum, the sensor is radar, which is an active sensor, as it provides its own source of EMR. The EMR produced by the radar is transmitted to the earth's surface and is reflected (back scattered) from the surface to be recorded by the radar system again. The microwave region can also be monitored with passive sensors, called microwave radiometers, which record the radiation emitted by the terrain in the microwave region.

4. Platforms and Sensors

In order to enable sensors to collect and record energy reflected or emitted from a target or surface, they must reside on a stable platform away from the target or surface being observed. As space provides one of the most vantage points for earth observation, two prominent orbits are considered for Earth observation: the geo-stationary orbit and the polar orbit. The geo-stationary orbit is such a position that it keeps pace with the rotation of the Earth. These platforms are covering the same place and give continuous near hemispheric coverage over the same area day and night. These are mainly used for communication and meteorological applications. This geo-stationary orbit is located at an altitude of 36,000 km above the equator Fig. 5.

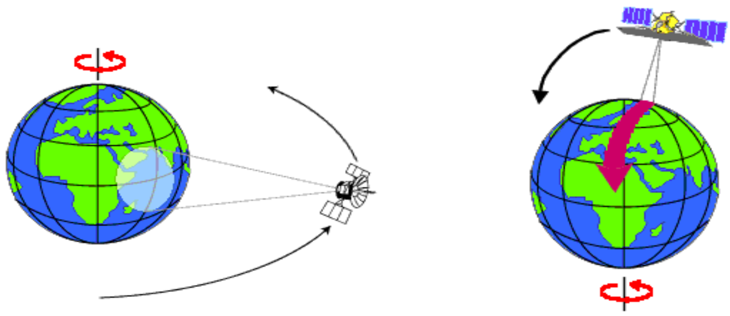


Figure 5. Geostationary and near polar orbits.

The second important remote sensing orbit is the polar orbit. Satellites in a polar orbit cycle the earth from North Pole to South Pole. The polar orbits have an inclination of approximately 99 degrees with the equator to maintain a sun synchronous overpass i.e. the satellite passes over all places on earth having the same latitude at the same local time**.** This ensures similar illumination conditions when acquiring images over a particular area over a series of days. The altitude of the polar orbits varies from 600 to 900 km, approximately.

5. Resolution

Resolution is defined as the ability of an entire remote-sensing system, including lens antennae, display, exposure, processing, and other factors, to render a sharply defined image. It depends on large number of factors that can be grouped under:

(i) ***Spectral Resolution***: The spectral band in which the data is collected.

(ii) ***Radiometric Resolution***: It is the capability of the sensor to differentiate two objects based on the reflectance / emittance differences.

(iii) ***Spatial Resolution***: It is the capability of the sensor to discriminate the smallest object on the ground. Higher the spatial resolution smaller the object that can be identified. Spatial resolutions vary from few Kms to half a meter.

(iv) ***Temporal Resolution***: It is the capability to view the same target, under similar conditions at regular intervals.

6. Land Observation Satellites

Today a large number of earth observation satellites provide imagery that can be used in various applications.

6.1 Indian Remote Sensing Satellites

India is one of the major providers of the earth observation data in the world in a variety of spatial, spectral and temporal resolutions. India has launched several satellites including earlier generation IRS 1A, IRS 1B, IRS 1C, IRS 1D, IRS P2, IRS P3, IRS P4, IRS P6 and Cartosat series and latest Resourcesat 2 for different applications, the details of these are listed in Table 1 A &B

Table 1A: Indian earth observation satellites

Satellite Name	Launch	Sensors	No. of Bands /spectral region	Resolution (meters)	Swath Width (km)	Revisit Time
Cartosat-3	2019	MSS PAN	4-VIS/NIR 1	1.12 0.28	17	Agile

Satellite Name	Launch	Sensors	No. of Bands /spectral region	Resolution (meters)	Swath Width (km)	Revisit Time
Cartosat 2E	2017	MSS PAN	4- VIS/NIR 1	1.8 0.6	16	Agile
Resourcesat 2A	2016	LISS-4	3- VIS/NIR	5.8		5 days
		LISS-3	4 - VIS/NIR/SWIR	23.5		
		AWiFS	3- VIS/NIR/SWIR	56		
Resourcesat-2	April 20, 2011	LISS-4	3- VIS/NIR	5.8	70 141 740	24 days
		LISS-3	4 - VIS/NIR/SWIR	23.5		
		AWiFS	3- VIS/NIR/SWIR	56		
CARTOSAT-2, 2A, 2B	2007-2010	Panchromatic	1	80 cm	10 Km	Agile
CARTOSAT-1	March 2005	Panchromatic	1	2.5 m	25 Km	
IRS-P6	17th October 2003	LISS III	4- VIS/NIR/SWIR	23	140 km	24 days
		AWIFS	4- VIS/NIR/SWIR	56	740 Km	
		LISS IV	3- VIS/NIR	5.8	23.9 km	5 days
		LISS IV	1	5.8	70 km	5 days

Satellite Name	Launch	Sensors	No. of Bands /spectral region	Resolution (meters)	Swath Width (km)	Revisit Time
IRS-1D	September - 1997	WiFS	2- R/NIR	189	774	5 day
		LISS-III	3- G/R/NIR	23	142	24-25 days
			1-SWIR	70	148	
		PAN	1	6	70	
IRS-1C	1995	WiFS	2- R/NIR	189	810	5 day
		LISS-III	3- G/R/NIR	23.6	142	24-25 days
			1-SWIR	70.8	148	
		PAN	1	5.8	70	
IRS-1B	1991	LISS-I	4- VIS/NIR	72.5	148	22 days
		LISS-II	4 (same as LISS I)	36.25	74	
IRS-1A	1988	LISS-I	4 -Same as above	72.5	148	
		LISS-II	4- Same as above	36.25	74	

Table 1B. Indian SAR Missions

Satellite Name	Launch	Sensors	Spectral region	Status
NISAR	2023	SAR	L and S band	To be launched
EOS-4	2021	SAR	C-Band	Operational
NOVASAR-S	2018	SAR	S-band	Operational
EOS-1 (RISAT2BR2)	2020	SAR	X-band	Strategic
RISAT 2B/2BR1	2019	SAR	X- band	Strategic
SARAL	February 25, 2013	AltiKa, DORIS, LRA, Argos-3	2 bands : Ka-Band /K-Band	Not Operational
RISAT-1	April 26, 2012	SAR	C-Band	Not operational
RISAT 2	April 20, 2009	SAR	X-Band	Not operational

6.2 Global Satellites

Other remote sensing satellites include LANDSAT series, SPOT, ASTER, MODIS, IKONOS, QUICK BIRD, and Sentinel series etc. details of these are listed in Table 2.

Table 2: Earth observation satellites from other countries.

Satellite	Spatial resolution	Channels	Swath at nadir (km)	Revisit days at nadir
NOAA -AVHRR/3	1.09 km	6	2900	1
Landsat 7 ETM+ (multispectral) Landsat 7 ETM+ (thermal)	30 m 60 m 15 m	6 1 1	185	16

Satellite	Spatial resolution	Channels	Swath at nadir (km)	Revisit days at nadir
Landsat 7 ETM+ (panchromatic)				
Landsat 8 OLI (multispectral) Landsat 8 OLI (panchromatic)	30 m 15 m	8 1	185	16
Landsat 8 TIRS (thermal)	100 m	2	185	16
Landsat 9 (Multispectral) Landsat 9 (Panchromatic)	30m 15m	8 `	185	16
SPOT 5 (multispectral) SPOT 5 (panchromatic)	10 -20 m 2.5 m	4 1	60 60	26 (2-3 off-nadir)
SPOT 6 (multispectral) SPOT 6 (panchromatic)	8 m 1.5 m	4 1	60	26 (1-3 off-nadir)
SPOT 7 (multispectral) SPOT 7 (panchromatic)	6m 1.5	4 1	60	26
IKONOS (multispectral) IKONOS (panchromatic)	3.2 m 0.82 m	4 1	11.3	≃141
QuickBird (multispectral) QuickBird (panchromatic)	2.44 m 61 cm	4 1	16.8	≃2.4 (40°N Lat)
WorldView-1 (panchromatic)	50 cm	1	17.7	≃1.7 (40°N Lat)
WorldView-2 (multispectral)	1.85 m	8	16.4	≃1.1

Satellite	Spatial resolution	Channels	Swath at nadir (km)	Revisit days at nadir
WorldView-2 (panchromatic)	46 cm	1		(40°N Lat
MODIS	250 m (bands 1-2) 500 m (bands 3-7) 1 km (bands 8-36)	36	2330	1
Proba-V	100 m	4	2250	1-2
WorldView-3 (multispectral) WorldView-3 (panchromatic) WorldView-3 (SWIR) WorldView-3 (CAVIS)	1.24 m 31 cm 3.70 m 30 m	8 1 8 12	13.1	<1 (40°N Lat)
Sentinel -1 (IW) Sentinel -1 (WV) Sentinel -1 (SM) Sentinel -1 (EW)	5x20 m 5x5m 5x5 m 20x40 m	1 mode 1 mode 1 mode 1 mode	250 20 80 400	12 (with 1 satellite) 6 (with 2 satellites)
Sentinel -2 [2014]	10 m 20 m 60 m	4 6 3	290	<5 at equator
Sentinel -3 (SLSTR) Sentinel -3 (OLCI) Sentinel -3 (SRAL)	500 m - 1 km 300 m 300 m	9 + 2 for fire monitorin g 21 2 modes	1420 1270 >2	<1 at equator <2 at equator 27

Satellite	Spatial resolution	Channels	Swath at nadir (km)	Revisit days at nadir
Rapid eye (5 satellites constellations)	MSS-5m	5 bands	177 km	Daily (off-nadir) / 5.5 days (at nadir)
Dove Satellites (Planetscope)- constellation of 180 satellites	3-5 m	3/4/8 bands	24x16km (variable)	Daily
VENμS -VM1	5.3 m	12	27.5	2
Skysat (21 satellites)	[SkySat-1, SkySat-2] -A/B PAN: 0.86 m MSS: 1.0 m [SkySat-3 - SkySat-15] -C PAN: 0.65m MSS: 0.81m [SkySat-16 - SkySat-21] –C PAN: 0.57m MSS: 0.75m	MSS- 4 PAN- 1	8 km at nadir (SkySat-1 to -2) 5.9 km at nadir (SkySat-3 to -15) 5.5 km at nadir (SkySat-16 to -21)	Constellation: sub-daily, 6-7 times at worldwide average, 12 times max. Satellite: 4 - 5 days
Pleiades Neo (4 satellites)	MSS-1.2m PAN – 0.30 m	6 1	14km	0.5 days
HyspIRI (VSWIR) HyspIRI (TIR)	60 m 60 m	220 8	145 600	19 5

6.3 Meteorogical Satellites

United States of America launched the first meteorological satellite TIROS-1 in April 1960. For 6 years after that, 10 satellites of the TIROS series were launched and used for conducting various observations and experiments. The TIROS series were low elevation orbit satellites. In 1966, the first geostationary meteorological satellite ATS-1 was launched by the United States and highlighted that satellite observation was effective for meteorological monitoring. The success of meteorological satellite observation intensified the trend toward using this new technology to develop meteorology and improve weather forecasting.

Table 3. History of Meteorological satellites

Year	Satellite	Country
1960	First meteorological satellite	USA
1966	First geostationary meteorological satellite	USA
1970	NOAA series of satellite	USA
1975	GOES	USA
1977	GMS and METEOSAT	JAPAN, Europe
1982	INSAT	India
1994	GOMS	Russia
1997	FY-II	China

Meteorological satellites fall into two general classes in terms of their orbital characteristics.

- **POES or Polar Orbiting Environmental Satellite**
- **GOES or Geostationary Operational Environmental Satellite**

6.4 INSAT Program

The Indian National Satellite (INSAT) system is one of the largest series of multipurpose Geo-stationary satellites launched by ISRO build to satisfy the telecommunications, broadcasting, meteorology, and search and rescue needs of India. The program was established with the commissioning of INSAT-1B in 1983. INSAT space segment consists of 24 satellites out of which 11 are in service (INSAT-3A, INSAT-4B, INSAT-3C, INSAT-3E, KALPANA-1, INSAT-4A, 4B, INSAT-4CR). The

Indian geostationary satellites with payloads for meteorological applications are given in table 4 below:

Table 4. Indian Meteorological Satellites

Satellite	Launch Date	Sensors	Applications
INSAT- 1A	Apr 1982	VHRR(Very High Resolution Radiometer) Visible bands: 0.55-0.75mm (Res- 2.75 Km) IR : 10.5-12.5 mm (Res- 11 Km)	• Outgoing Long wave radiation (OLR) • Rainfall estimations • Snow detection • Cloud Top Temperature • Monitoring cyclones and monsoon • Weather Forecast • Climate change studies
INSAT- 1B	Aug 1983		
INSAT- 1C	July 1998		
INSAT- 1D	June 1990		
INSAT- 2A	July 1992	Visible bands: 0.55-0.75mm (Res- 2 Km) IR : 10.5-12.5 mm (Res- 8 Km)	
INSAT- 2B	July 1993		
INSAT- 2E	Apr 1999	VHRR bands similar o INSAT 2B + Water Vapour band (5.7-7.1 mm) CCD: (a) Visible band at 0.62–0.68 μ m, (b) Near IR band at 0.77–0.86 μ m and (c) Short wave IR band at 1.55–1.69 μ m.	
Kalpana-1	Sept 2002	Very High Resolution Radiometer (VHRR) and Data Relay Transponder (DRT). 3 bands: visible, thermal infrared and water vapour infrared (similar to INSAT 2E)	

Satellite	Launch Date	Sensors	Applications
		Images captured every half an hour.	
INSAT-3A	Apr 2003	VHRR and CCD similar to INSAT-2E	
INSAT- 3D	July 2013	• 6 channel multi-spectral Imager • 19 channel Sounder	
INSAT 3DR	2016	• 6-channel imager and a 19-channel sounder	

6.5 Other ISRO Missions

ISRO has also launched the Oceansat-I in May, 1999 and Oceansat 2 in 2009. Oceansat 1 had an Ocean Colour Monitor (OCM), an optical sensor with 8 narrow spectral bands with high resolution and higher dynamic range and Multi frequency Microwave Scanning Radiometer (MSMR). Oceansat 2 along with OCM, it has a scatterometer and a Radio Occultation Sounder. Oceansat 3 was launched in November 2022 with 3 payloads OCM, SSTM-1 and SCAT-3. These sensors are most suited for dynamic events in coastal and mid ocean regions.

Table 5. Payload characteristic of OceanSAT Satellites

Satellite	Date	Payload/ Sensor	Spectral Resolution	Spatial Resolution	Applications
OceanSAT 3	26th November 2022	Ocean Colour Monitor (OCM)	13 bands VIS (0.40 µm - 0.75 µm) NIR (0.75 µm - 1.3 µm)		Ocean color/biology
		Scatterometer (SCAT-3)	Ku Band		Sea Surface winds

Satellite	Date	Payload/ Sensor	Spectral Resolution	Spatial Resolution	Applications
		Sea Surface Temperature Monitor (SSTM) -1	2 bands TIR (6.0 μm - 15.0 μm		Surface Temperature (Oceans)
OceanSAT 2	Sept 23, 2009	Ocean Colour Monitor (OCM)	8 bands	360m	• Monsoon and cyclone Forecast • Antarctica sea ice • Fisheries and primary productivity estimation • Detection and Monitoring phytoplankton • Sediment dynamics
		Ku-band Pencil Beam scatterometer (SCAT) Radio Occultation Sounder for Atmosphere (ROSA)- ITALY	Polarization HH and VV	26x46 Km inner beam 31x65 Km outer beam	

MeghaTropiques: Launched in October 2011 is an Indo-French collaborative satellite mission with an aim to study the water and energy cycle of the tropical region. Parameters like rainfall, water vapour, Total precipitable water, humidity profile, sea surface winds and radiation fluxes can be estimated. It has the following payloads

- **MADRAS:** Microwave Analysis and Detection of Rain and Atmospheric systems (19,23,37,89,157 Ghz) Conical Scan, Swath 1640 km
- **SAPHIR:** Scanner for Atmospheric Profiling of Humidity in the Inter-Tropics: 183 Ghz Across Track Scan, Swath 1200 km
- **ScaRaB:** Four-channel Scanner for Radiation Budget
- **GPS –** ROS GPS Radio-Occultation System

6.6 Indian Navigational Satellites

Indian Regional Navigation Satellite System (IRNSS) is an indigenous satellite based positioning system of India, established by ISRO. Its major objective is to provide reliable position, navigation and timing services. It consists of 7 seven satellites (3 in Geostationary and 4 in Geosynchronous orbit). Details of these are given in Table 6.

Table 6. List of IRNSS Satellites (Source: www.directory.eoportal.org)

IRNSS spacecraft	Longitude (E)	Inclination	RAAN	Launch Date
1A	55.0º	29º (±2)	135º	July 1, 2013
1B	55.0º	29º (±2)	310º	April 4, 2014
1C	83.0º		274º	October 15, 2014
1D	111.75º	29º (±2)	135º	March 27, 2015
1E	111.75º	29º (±2)	310º	January 20, 2016
1F	32.5º	± 5º	270º	March 10, 2016
1G	129.5º	± 5º	270º	April 28, 2016

6.7 Other Missions

The U.S. Air Force program in meteorology began with the launch of the first DMSP (Defense Meteorological Satellite Program) satellite on September 16, 1966. The principal instrument is the OLS (Operational Linescan System) which images in both the visible and thermal IR. Later DMSPs also carried onboard the Special Sensor Microwave Imager (SSM/I) which measures vertically and horizontally polarized radiation at 19.36, 22.23, and 85.5 GHz and horizontally at 37.0 GHz. The first satellite whose primary mission is to measure precipitation is TRMM (Tropical Rainfall Mapping Mission), a joint research project between the U.S. (NASA) and Japan (NASDA: National Space Development Agency). The basic objective of TRMM is to obtain estimates of the vertical profile of the latent heat (heat resulting from a change of state) released through condensation of water vapor in the atmosphere, especially in the Equatorial Inter tropical Convergence Zone (ITCZ). The TRMM Observatory has three primary instruments:

- **The Precipitation Radar** (PR) built in Japan, capable of making 3-D rainfall distribution measurements. The PR is electronically scanning radar that operates at 13.8 GHz using horizontal polarization. It has a horizontal resolution of 4.3 km at nadir and a scanning swath width of 220 km.
- **The Multi-Channel Microwave Radiometer** (TMI), which seeks information on the integrated column precipitation content, its areal distribution, and its intensity. The TMI operates at five frequencies, ranging from 10.65 GHz (45 km spatial resolution) to 85.5 GHz (5 km resolution); dual polarization at 4 of the frequencies provides 9 channels.
- **The Visible Infrared Scanner** (VIRS) to provide high-resolution (2.1 km at nadir) information on cloud cover, cloud type, and cloud top temperatures, being a radiometer operating at 0.63, 1.6, 3.75, 10.8, and 12.0 mm.

7. Comparison of Remote Sensing to Traditional Observations

RS data, with its ability for a synoptic view, repetitive coverage, observations at different resolutions, provides a better alternative for natural resources management, environmental monitoring and disaster management as compared to traditional methods. It provides images of target areas in a fast and cost-efficient manner. While air photos and fieldwork remain critical sources of information, the cost and time to carry out these methods often make them unviable and the human ability of observation is subjective and individual dependent, thereby making it even more unviable. Remote sensing instrumentation makes it possible to observe the environment with EM radiation outside the visible part of the EM spectrum; the invisible becomes visible. Remote sensing is flexible in that there is a variety of Remote sensing observation techniques and a diversity of digital image processing algorithms for extracting information about the earth's surface. The data can be easily integrated into a Geographical Information System thus making it even more effective in terms of solution offering.

8. 3-D Mapping from Space

Topographic variations are one of the most important attributes for detection and mapping of surface processes and features associated with it. Digital Elevation Models (DEMs) are used for visual and mathematical analysis of topography, landforms, as well as modeling of surface processes. It provides easy extraction of commonly used terrain parameters such as slope, aspect, curvature, and slope length. To derive this, the DEM must represent the terrain as accurately as possible and should cover larger spatial domain at a reasonable cost. In this regard satellite photogrammetry has been a major step forward as it is possible to map large areas with very few images obtained from orbiting satellite. Photogrammetry is the technique of acquiring measurements from images in stereoscopic mode. Satellite images have already proven their capabilities in the field of natural resource management and with the advent of high resolution satellite data ranging from 10 m for SPOT in 1986 to 5.8m for IRS 1C/1D in 1995/1997 and with stereo capabilities have resulted in higher mapping accuracies and automated generation of a DEM with sub-pixel accuracy. The recent launches of high resolution like CARTOSAT series; IKONOS, world view etc., have opened up new vistas for digital mapping at a large scale for cartographic applications

9. Drone (UAV) Remote Sensing

With the availability of multi-resolution and multi-frequency temporal image data from suite of operational as well as experimental Earth observation satellites, research as well as operational applications have gained momentum. However, there are challenges like availability of very high spatial resolution (<1m) and one does not get the data when needed. Satellite data are only available when a satellite is passing over a specific location, which varies once in a week to once in 15 days or more (temporal repitivity). Though there are space borne satellites and constellation of satellites that provide data at very high spatial resolution (<1 m) but due to cost, limits their usage. In addition, optical remote sensing (RS) satellites data are constrained by cloud cover, view angle and acquisition time. Due to the development of robotics, computer vision and sensor miniaturization, remote sensing by drone/UAV has brought a paradigm in the field of RS by giving end-users the ability to control acquisition features. Ultra-high spatial resolution (cm to mm) and acquisition flexibility like fly everywhere, any time; high-spatial/temporal resolution data, flexibility to install any sensors are the strengths of drone RS. They are a low cost version of airborne data with high versatility and flexibility, as compared to airborne systems or satellites. The data acquired are unaffected by cloud cover as they can fly at low altitudes. UAV data complement ground observations and data collected from aircraft and satellite remote sensing platforms. For example, in many time-critical situations like disasters (earth quake, floods etc.) where timely acquisition of remote sensing data with high temporal resolution is critical for dynamical monitoring and analysis of disaster situation or applications like precision agriculture where it requires high temporal resolution along with high spatial resolution data to asses within-field variations of crop condition, so as to respond to fertilizer, pesticide, and water needs drones can bridge the gap and provide the vital data/information required.

In addition to this satellite and manned aircraft platforms operate on fixed orbits i.e. along the preset regular paths but in many applications, e.g., small town planning, very small islands mapping, archaeology, and infrastructure damage detection, there may be requirements to collect data in an irregular pattern, so as to map the fine details. The lack of flexibility of satellite data acquisition makes utilization of traditional platforms in these scenarios challenging. Drones due their flexibility, maneuvering, economy, data acquisition on demand have been recognized as a complementary/supplementary technology to traditional platforms.

Both platforms have their advantages and shortcomings, when macro view of the terrain is required then one use satellite data and when micro view of the terrain is needed one can opt for drone technology. Table 7 highlights the pros and cons of each platform.

Table 7. Pros and Cons of data acquisition by Satellite and UAV based platform

	UAV	**Satellite**
Flexibility	High	Low
Cloud dependence	No	Yes
Meteorological constraint	Wind and precipitation	No
Processing	High	Analysis ready data
Operator required	Yes	No
Cost	Low	High

Payload	Interchangeable	Permanent
Legislation	Restrictive	None

10. Conclusion

In future launch of satellite constellations will improve the spatial/temporal resolution, data acquisition cost of satellite remote sensing, and the synergy between UAV and satellite data (UAV/Satellite synergy) would be essential for understanding the dynamics of the Earth's surfaces. The use of geosynchronous orbit for providing high spatial resolution data will be a major break-through to receive bio-geophysical parameters in real time basis. Remote sensing coupled with geographical information systems where the data can be integrated with other information, will provide geo-spatial information that is critical for decision making related to natural resource utilization, environmental monitoring and disaster management.

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Web Links

(i) http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter1/chapter1_2.

(ii) www.planetary.brown.edu/arc/sensor.html

(iii) http://www.ersc.edu/resources/EOSC.html

(iv) www.isro.org

(v) www.spaceimage.com

(vi) www.eospso.gfc.nasa.gov

(vii) www.landsat.org

(viii) www.spotimage.fr/home

(ix) www.space.gc.ca

(x) www.esa.int/export/esasa/ESADTOMBAMC_earth_O.html

(xi) https://earth.esa.int/eogateway/missions/pleiades-neo

Chapter 2

Geographic Information Systems (GIS)

1. Introduction

Geographic information System (GIS) is an emerging technology, which integrates geographical or locational data and information with Information and communication technologies for understanding and solving geographical problems. GIS provides integrated software tools that captures, stores, analyzes, manages, and presents data related to location(s). When we study the concept and theory of geographical data and information then it is referred as Geographical Information Science and when we study it with respect to the societal context then it is referred as Geographical Information Studies. Sometimes it is also termed as Spatial Information Systems as it deals with location data for objects positioned in any space, not just geographical. The data related to geographical information about the earth and its feature is also known as “Spatial Data”. The spatial data uses different data models to represent geographical features in a computer system. Typically, spatial data are of two types according to the storing technique, namely, raster data and vector data. The non-spatial or attribute data models are used to store and manage the characteristics of geographical features in GIS. The discipline that deals with all aspects of spatial data handling is called Geoinformatics or Geomatics. It can be defined as a "*Science and technology which integrates GIS, information technology and mathematics to study the geography*”.

During the initial phases of development, GIS has been extensively used for data creation/conversion/digitization of paper maps, storing and generating printable maps. With the advent of time, the scenario has changed drastically wherein the spatial analysis became the core strength of GIS for scientific analysis and planning. GIS also facilitates modeling to arrive at local specific solutions by integrating the spatial and non-spatial data such as thematic layers and socio-economic data. The modern GIS is capable to handle large amount structured and unstructured data for informed planning and decision making. This has enabled the development of advanced spatial algorithms, spatial modeling techniques and better display and visualization systems.

GIS systems are used in many areas such as cartography, remote sensing, land surveying, public utility management, natural resource management, precision, agriculture, photogrammetry, geography, urban planning, emergency management, navigation, aerial video, and localized search engines and in many location-based services. The major applications of GIS includes

- Earth surface based scientific investigations;
- Resource management, reference, and projections of a geospatial landscape—both manmade and natural;
- Asset management and location planning;
- Archaeology; environmental impact study;
- Infrastructure assessment and development;
- Urban planning; cartography, for a thematic and/or time based purpose;
- Criminology;
- GIS data development geographic history;
- Marketing; logistics; population and demographic studies;
- Prospectively mapping;
- Location attributes applied statistical analysis;
- Defense and strategic applications; and more applications.

Some of the specific use cases of GIS are:

- GIS may allow emergency planners to easily calculate emergency response times and the movement of response resources in the case of a natural disasters;

- GIS might be used to find wetlands that need protection strategies regarding pollution; or GIS can be used by the industry for site suitability analysis to setup new business locations.

In this chapter, we will be discussing the basic concepts of GIS, data models, spatial relationships and analysis, spatial data quality and uncertainty issues in GIS.

2. Types of GIS: Evaluation of GIS

The advancements in geospatial technology is allied with high computing capabilities and advanced visualization systems using contemporary ICT solutions. GIS has quickly incorporated distributed systems and databases for interoperable solutions for effective decision making whereas microcomputer has allowed GIS to be applied to new fields and has improved GIS education and awareness. Due to advancements in ICT, the data creation and storage mechanism has drastically changed in recent past using online participatory approach known as crowdsourcing or collaborating mapping. Today, the current GIS technology enables the concept of "map anywhere and serve anywhere". With recent developments, there is a leap in the development of spatial analysis tools and logical processing methods in online GIS applications and platforms. This enabled the development of numerous spatial algorithms, spatial modeling techniques and better display and visualization of geospatial data for effective planning and decision-making.

2.1 Desktop or Single user GIS

The desktop GIS or single user GIS is an entry level, low cost solution that provides basic GIS data access, querying as well as map production and spatial analysis capability to its users. Desktop GIS applications provide excellent platform for geospatial data analysis to GIS professionals by providing the tools and technologies to analyze the patterns and problems for effective land management solutions. Technically, the desktop GIS is a collection of software and data products that runs on standard desktop computers. In a typical desktop GIS configuration, the digital geo-spatial data storage mechanisms vary from simple file system to database systems. Some of the popular desktop GIS softwares are listed in table 1.

Table 1- Popular desktop GIS software

Name of the software	Software type	Description
GRASS GIS	Free and Open source	Major tools available in the software includes geospatial data management and analysis, image processing, graphics and maps production, spatial modeling, and visualization (http://grass.osgeo.org)
QGIS	Free and Open source	QGIS is one of the most popular user friendly and open source GIS software which provides extensive tools for vector data handling. It can be easily integrated with GRASS and R (http://www.qgis.org/en/)
gvSIG	Free and Open source	Gvsig Desktop (gvSIG from this point forward) is a free GIS software and aims to represent, edit, analyse and manage information from the point of view of spatial relations (http://www.gvsig.com/en)
RGeostats	Free and Open source	RGeostats is the Geostatistical Package developed by the Geostatistical Team of the Geosciences Research Center of MINES ParisTech (http://rgeostats.free.fr/)
ILWIS	Free and Open source	ILWIS is popular GIS and image processing platform which provides various tools for raster and vector data analysis with special emphasis

Name of the software	Software type	Description
		on water resource applications (http://www.ilwis.org/)
ArcGIS	Commercial	ArcGIS is popular commercial desktop GIS software which provides vector and raster based GIS data creation, processing and analysis tools with various extensions especially in windows operating system platform. Vector data handling is major strength of ArcGIS (https://www.arcgis.com/)
ERDAS Imagine	Commercial	ERDAS is a popular commercial image processing software which provides various spatial data analysis tools for raster data formats **(**http://www.hexagongeospatial.com)
ENVI	Commercial	ENVI is popular image processing software which provides tools for LiDAR, SAR, multispectral or hyperspectral data sets (http://www.exelisvis.co.uk/).

2.2 Web-GIS and Geospatial Web

The recent advancements in Internet and related technologies have extended the use of geospatial data and information for variety of applications at different levels. The integration of GIS and Internet technology has emerged as one of the exciting technological advancement in geospatial domain known as Internet or Web based GIS. Some of the popular web based spatial data and information services are Google

Maps, Bhuvan geoportal, Bing Map, OpenStreetMap, etc. Today, Internet is emerging as a popular means of GIS data accessing, analyses and transmission and information services for various online applications.

The web based GIS applications are dynamic in nature, which is very important for its wider utilization e.g. if any client(s)/ user(s) or database administrator updates the data or information at server end, it will be available to all the users concurrently. It can also link real time data and information such as satellite images, weather information, traffic movements and accident information, etc. by integrating online sensors and observatories. A typical GIS application usually includes three essential elements: a) presentation also known as 'Graphical User Interface' (GUI), b) logic or processing, and c) data. The relationship between these three elements is that one element sends the request to other element and the other elements responses to the request through the same interface. This making and fulfilling of request is called client/ server-computing model. The element that makes request is called 'client' and the element that fulfills the request is called 'server'.

In geospatial domain, the web services are very important to achieve interoperability in data and information available with different data providers. Today, the geospatial services available in Internet through various geoportal s are increasing rapidly. There is a need of a methodology to locate desired services that provide access, data discovery and analysis capabilities for geospatial data. The interoperability of services across organizations and providers is important for seamless integration and sharing of spatial data from a variety of sources. Different organizations and commercial vendors develop their own data standards and storage structures for geospatial data. If GIS services are not interoperable, these data sets cannot interact or get overlaid to each other even though they are in the same organization or they belong to same commercial vendor. To solve the interoperability problems in GIS, the Open Geospatial Consortium (OGC) has introduced data and service standards by publishing specifications for the GIS services. OGC is a not-for-profit, international, voluntary, consensus standards organization founded in 1994. The major objectives of OGC are to lead in the development, promotion and harmonization of open geospatial standards. OGC have around 500+ members from industry, government, research and university across the world. The OGC GIS services can be grouped into six major categories as shown in table 2.

Table 2 - OGC Service specifications

S. No	Type	Use	Example
1	Catalogue Services	Allows users and applications to classify, register, describe, search, maintain, and access information about Web Services	CS Core,CS-W ebRIM, CS-W 19115/19119 CS-W ebRIM for EO, etc.
2	Processing Services	Provide operations for processing or transforming the data as per user defined parameters	Sensor Planning Service (SPS), Web Processing Service (WPS), Coordinate Transformation Service (CTS and Web Coverage Processing Service (WCPS), etc.
3	Encoding	Defines symbology encoding, an XML language for styling information that can be applied to digital feature (vector) and coverage data (raster)	Geography Markup Language (GML), CityGML Styled Layer Descriptor (SLD), SWE Common, etc.
4	Data Services	Tightly coupled with specific data sets and offer access to full or a portion of geospatial data. Original data access without physical download	Sensor Observation Service (SOS), Web Feature Service (WFS), etc.
5	Portrayal Service	Used for simple data visualization like map rendering	Web Map Service (WMS) and Web Map Tiling Service

S. No	Type	Use	Example
		and cartographic representation of the maps	
6	Others Services	Project/operation specific and other Web 3.0 services	GeoXACML, GeoRSS, Geospatial Objects, OWS Common, etc.

2.3 Mobile and Participatory GIS

The mobile GIS is a new technological advancement in geospatial domain and it has the strength not only to deliver the geospatial data to the mobile users everywhere and anytime, but also it can be used as an effective mode of geographic data creation and collection using participatory approach. Mobile GIS is an extension of Internet or web based GIS which provides GIS functionalities in portable devices such as mobile, PDA, tablet etc. Mobile GIS is an integration of various technologies viz. Mobile technology, GIS, GNSS, wireless communications, etc. Mobile GIS is a cost effective solution for data collection and creation directly from fields. Some of the exciting applications of mobile GIS include Location Based Services (LBS), crowdsourcing/ voluntary geographic information (VGI) and participatory GIS. Today, the mobile devices are embedded with GNSS which adds a location tag with the information transmitted by the device. The communication channels [like General Packet Radio Service (GPRS), Code division multiple access (CDMA), Worldwide Interoperability for Microwave Access (WiMAX), etc.] are required to transmit the information from mobile device to the receiver. The Second-and-half generation and above (2.5G, 3G and 4G etc.) networks provide the possibilities of a mobile Internet with high speed data transfer at a rate up to 256 kbps or better. Two of the leading network protocols used in high speed mobile application are GPRS and CDMA20001x.

The mobile GIS architecture is a combination of client at mobile and host at server level. The data and information is published at server end for mobile user similar to web based GIS application. The only major configuration required at server end is to tune the data size for low storage and limited computation devices like mobile and

PDA. The mobile GIS applications are best suited for smartphone devices where the multimedia components with GPS facility are available for the users. GIS operations in smart mobile phones are through the ICT evolution which has many exciting new applications of GIS. The mobile users are moving in a geographic space and they know their positions and they have access to the widely available geographic data and information from variety of servers. The mobility is "key" for mobile GIS applications. The theme specific GIS applications like mobile GIS for mapping, field data collection, spatial analysis and Location Based Services (LBS) etc. have become very popular among user communities.

The mobile GIS requires GIS applications and software to be installed on the smart mobile devices where the communication part can be online or offline depending upon requirements and availability. The GPS is one of important component of Mobile GIS where the location of the geography feature will be presented using coordinates recorded using GPS. The accuracy of the location varies from kilometer to a meter level.

2.4 Cloud Computing GIS

Cloud computing is one of most recent advancement in technology which has directly influenced the involvement of IT and related technologies in various business sectors. Cloud computing platform offers various services in virtual environment such as Software as Service (SaS), Infrastructure as Service (IaS) and Platform as Services (PaS). Here, Infrastructure refers to IT infrastructure and Platform refers to computer platform which are required to run any software application (s). The cloud computing technology has revolutionized the functioning and operations of IT services in Internet platform. Typically, the cloud computing is an integration of hardware, software, peoples (users), data and applications. GIS has adopted the cloud computing technology to enhance its uses and outreach by shifting various geospatial tools and functionalities to the cloud. Cloud-based tools are accessed for web-based GIS as geo-web services.

The cloud GIS can be considered as next generation GIS which offer 'GIS on Demand' based on user(s') or organization(s') requirements. The GIS software, data (spatial and non-spatial), computation infrastructure and platforms requirements are available for hire with a full scalability options. Various public and private clouds are getting popular such as ArcGIS Online, Cloud GIS (www.giscloud.com), Amazon web service, ThunderMaps, etc. In India, two major initiatives from Government namely, MEGHDOOT from Center for Development of Advanced Computing (CDAC) and National Informatics Centre (NIC) Cloud (http://cen.gisserver.nic.in) are getting popular among the users.

3. Geographical Data Representation

The data is a row of facts and figures on a subject or theme with respect to qualitative or quantitative variables. The power of GIS is its 'data', which allows various analytical capabilities to present the information in meaningful ways. Without data, GIS will become a simple drawing tool, which will be same as Computer Aided Design (CAD). GIS data represents geographical objects such as land use, land cover, elevation, trees, river, roads and other infrastructures in a digital form. In general, the geography is represented as either a Field or an Object. A field is a phenomenon that has a value everywhere in the geographic space. It can be discrete or continuous. An object is usually well distinguishable, discrete bounded entities. The space between them is potentially empty. The real objects can be divided into two major categories:

3.1 Discrete Data

Discrete data, which is also known as thematic, categorical, or discontinuous data in GIS often represents objects in both the feature (vector) and raster data storage systems (please refer following section for raster and vector data models). A discrete object(s) will have known and definable boundaries in the geography. In discrete object it is easy to define precisely where the object begins and where it ends. Typically a house is a discrete object within the surrounding landscape. Its boundaries and corners can be easily marked. Other examples of discrete objects could be lake, roads, and ward boundaries in the city.

3.2 Continuous Data

A continuous surface represents a geographic phenomenon in which each location on the earth surface is have a value or its relationship from a fixed point in space or from an emitting source. Continuous data is also referred to as field, non-discrete, or surface data. One type of continuous surface is derived from those characteristics that define a surface, in which each location is measured from a fixed registration point. These include elevation (the fixed point being sea level) and aspect (the fixed point being direction: north, east, south, and west). Another type of continuous surface includes phenomena that progressively vary as they move across a surface. The most suitable examples of progressively varying continuous data are temperature, fluid and air movement. These surfaces are characterized by the type or manner in which the phenomenon moves. The continuous and categorical data in a map representation are shown in Figure 1.

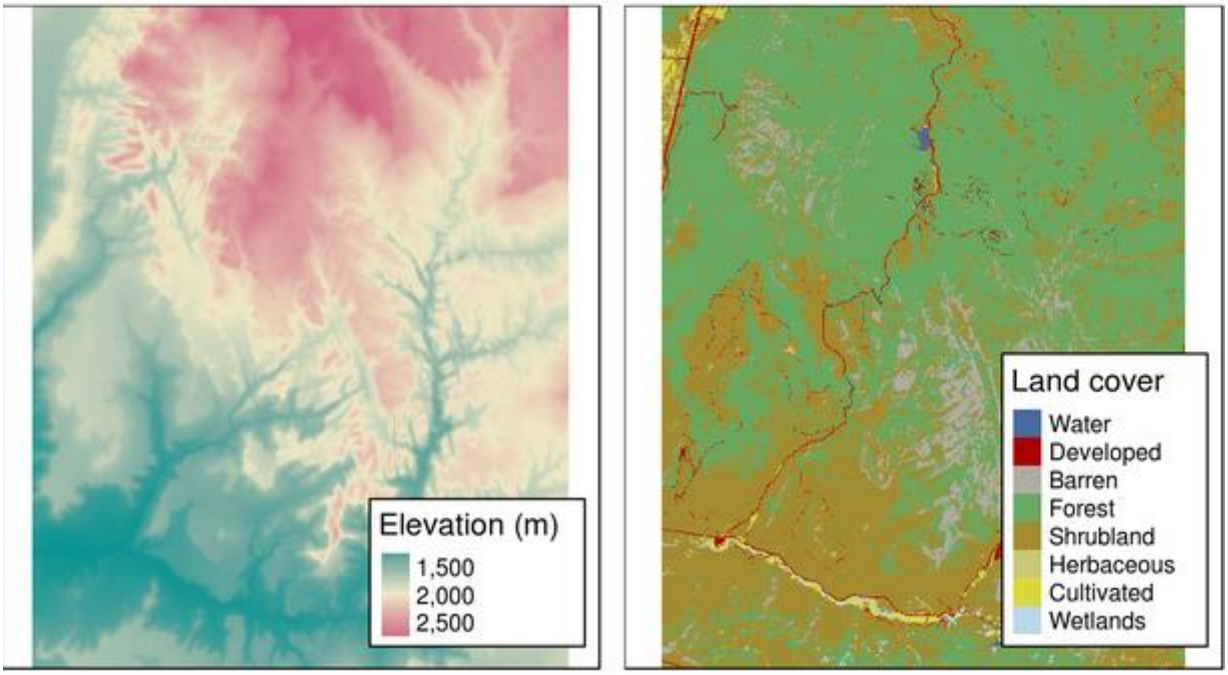


Figure 1- Continuous and Categorical Data

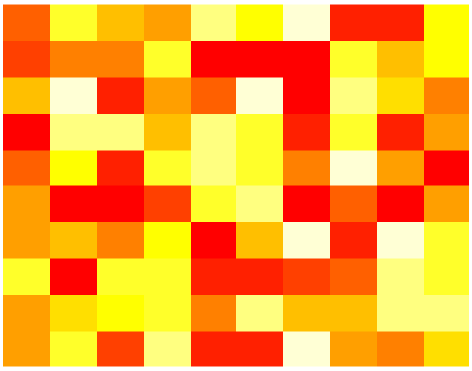
4. GIS Data Models

The real world observations (objects or events that can be recorded in 2D or 3D space) need to store in the computer system for effective understanding and analysis. Conversion of real world geographical variation into discrete objects or continuous field is done through data models. Typically, a Model is an abstract representation of the reality. It represents the linkage between the real world domain of geographic data and computer representation of these features. Data models discussed here are for representing the spatial information. Primarily in GIS, data models are of two types: (a) raster and (b) vector.

4.1 Raster Data Model

The raster data model consists of uniform series of square pixel and is referred to as a grid-based system. Typically, a single data value will be assigned to each grid location. Each cell in a raster carries a single value, which represents the characteristic of the spatial phenomenon at a location denoted by its row and column and is known as digital number or pixel value. The raster data model averages all values within a given pixel to produce a single value for the region. Therefore, the more area covered per pixel, the less accurate the associated data values. The area covered by each pixel determines the spatial resolution of the raster model from which it is derived. Specifically, resolution is determined by measuring one side of the square pixel. A raster model with pixels representing 10 m x 10 m (or 100 square meters) in the real world would be said to have a spatial resolution of 10 m; a raster model with pixels measuring 1 km x 1 km (1 square kilometer) in the real world would be said to have a spatial resolution of 1 km; and so forth.

Aerial photos and satellite imageries are commonly used form of raster data model, with one primary purpose in mind: to display a detailed image on a map area, or for the purposes of rendering its identifiable objects by digitization. Additional raster data sets used by a GIS contains information regarding elevation, a digital elevation model, or reflectance of a particular wavelength of light. Raster models are simple with which spatial analysis is easier and faster. Raster data is stored in various formats; from a standard file-based structure of TIF/TIFF, JPEG, IMG, GRID etc. Sample raster representation is shown in Figure 2.



A simple raster image of 10 x10 array of cells or pixels

Sample satellite image (Cartosat-2) – Raster representation

Figure 2- Sample Raster representation in Image

4.2 Vector Data Model

In vector data model the geographical features are stored in three basic geometries i.e. point, line and polygon. Vector data models use points and their associated X, Y coordinate pairs to represent the vertices of geographical feature (s). The characteristics of a geographic phenomenon are stored in a separate attribute table as a file or as a table in a database management system. The spatial information and the attribute information are linked via a simple identification key attribute or field that is given to each feature in a map. The vector model is extremely useful for describing discrete features, but less useful for describing continuously varying features such as temperature, soil type, elevation etc. Three basic geometries of vector data model are discussed here:

Points: Points are zero-dimensional objects that contain only a single coordinate pair i.e. (x, y). Zero-dimensional points are used for geographical features that can best be expressed by a single point reference i.e. by simple location. Examples include street light, wells location, building location or location of any point of interest. Points can also be used to represent areas when displayed at a small scale. For example, cities on a map of the world might be represented by points rather than polygons. No measurements are possible with point features. The representation in X, Y coordinates are shown in Figure 3.

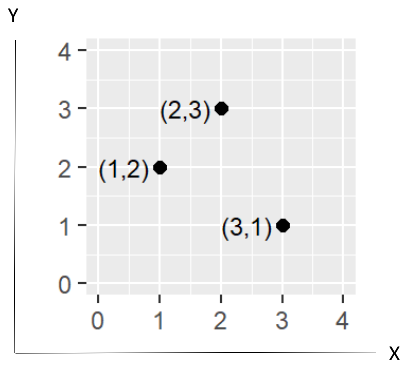


Figure 3- Vector points defined by X and Y coordinate values

Lines or Polylines: One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines. Typically, lines are composed of multiple, explicitly connected points and have the property of length but not area. A polyline is created with a sequence of two or more coordinate pairs called vertices. A vertex is defined by coordinate pairs just like a point, but what differentiates a vertex from a point is its explicitly defined relationship with neighboring vertices. A sample coordinate representation of line feature is shown in Figure 4.

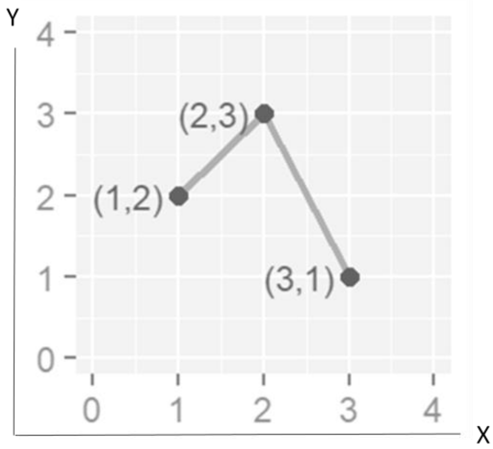


Figure 4- A simple polyline object defined by three connected vertices

Polygons: Polygons are two-dimensional geometry used for geographical features that cover a particular area of the earth's surface. Such *features may include lakes, park boundaries, buildings, city boundaries, or land uses. A polygon is composed of one or more lines whose starting and ending coordinate pairs are the same*. Polygons have the topological relations such as inside, within, and outside; in fact, the area that a polygon encloses is explicitly defined and calculated in GIS. Polygon features can measure perimeter and area but not length. A sample polygon representation in X, Y coordinates is shown in Figure 5.

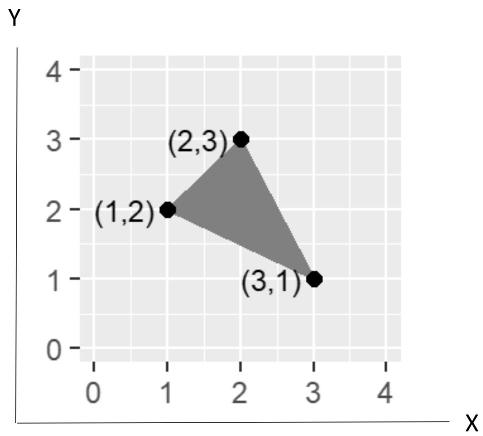


Figure 5- A simple polygon object defined by an area enclosed by connected vertices

Vector features can be made to respect spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines and triangulated irregular networks (TIN) are used to represent elevation or other continuously changing values. TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles.

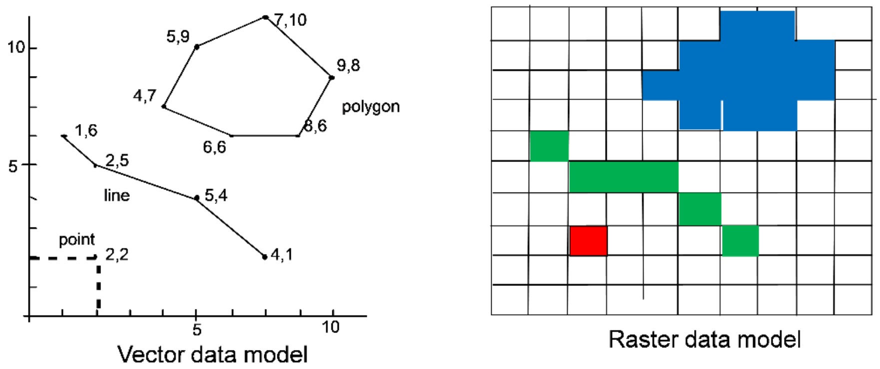


Figure 6- Vector and Raster representation of geographic feature

4.3 Object Orientation Data Models

The object oriented data models allow to store and manage geospatial data inside Relational Database Management System (RDBMS). The data types are defined as an object to store vector and raster data inside RDBMS. In an Object oriented data models, we not only define data structure in database management system but also define the operations that can be performed on it. Some of the popular examples of object oriented data model in GIS are ESRI Geodatabase, POSTGIS, Oracle spatial etc. These data models provide power of RDBMS for geospatial data for effective management of the data especially in multi user environment and are also known as Spatial Database Management System (SDBMS). In addition to typical SQL queries such as SELECT, CREATE statements, spatial databases can perform a wide variety of spatial operations like:

- *Spatial Measurements*: Finds the distance between points, polygon area, etc.
- *Spatial Functions*: Modify existing features to create new ones, for example by providing a buffer around them, intersecting features, etc.
- *Spatial Predicates*: Allows true/false queries such as 'is there a residence located within a mile of the area we are planning to build the landfill? '
- *Constructor Functions*: Creates new features with an SQL query specifying the vertices (points of nodes) which can make up lines. If the first and last vertices of a line are identical the feature can also be of the type polygon (a closed line).
- *Observer Functions*: Queries which return specific information about a feature such as the location of the center of a circle

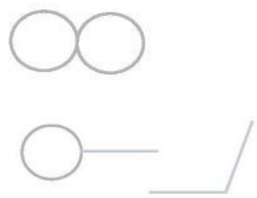
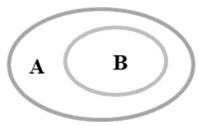
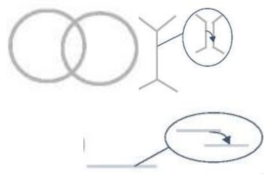
5. Spatial Relationship

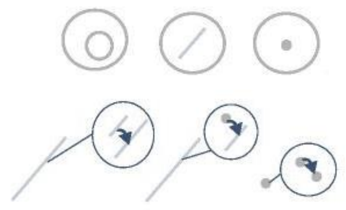
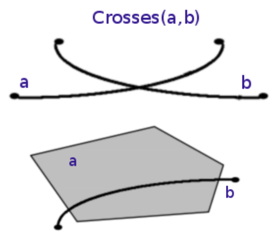
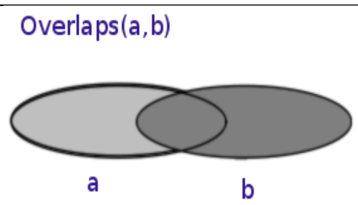
Spatial relationships are relation between objects in space in relation to some reference object when geometric properties are considered. Three types of spatial relationships are considered in geographic domain i.e. topological, metric and directional. The topological relationships are those that do not change under topological transformations and are defined as mathematical relationship between earth objects. The metric relationships are defined by measures of a metric space, and distances and angles are of those relations. The directional relationships are represented by relative orders between objects with respect to their directions.

5.1 Topological Relationship

The topology in GIS is generally defined as the spatial relationships between adjacent or neighboring features in geographic plane. Mathematically, the topology assumes that geographic features occur on a two-dimensional plane. Through planar enforcement, spatial features can be represented through nodes (0-dimensional cells); edges, sometimes called line (one-dimensional cells); or polygons/area (two-dimensional cells). Because features can exist only on a plane, lines that cross are broken into separate lines that terminate at nodes representing intersections rather than simple vertices. Some of examples of topological relationship are continuity, connectivity, contiguity, and adjacency in geographical domain.
The geographic objects are represented in three geometries i.e. point, line and polygons. The spatial relationships use the terms interior, boundary, and exterior with respect to these geometries. For example, a point is a 0-dimensional geometry that has an interior and an exterior, but no boundary. A line is a 1-dimensional geometry that has an exterior, an interior, and a boundary. As the boundary is at the end points of a line, if the line is a closed ring, there is no boundary. The polygon is a 2-dimensional geometry that has an exterior, an interior, and a boundary.

Table 3. Description of the spatial relationships

Spatial Relationship	Description	Example
Touches	A part of the geographical object from map layer 1 comes into contact with the boundary of a geographical object from map layer 2. The interiors of the features do not intersect	
Contains	A geographical object from map layer 1 completely encloses a geographical object from map layer 2. contact with any part of a geographical object from map layer 2	
Intersects	Any part of a geographical object from map layer 1 comes into contact with any part of a geographical object from map layer 2.	

Spatial Relationship	Description	Example
Within	A geographical object from map layer 2 completely encloses a geographical object from map layer 1.	
Crosses	The interior of a geographical object from map layer 1 comes into contact with the interior or boundary (if a polygon) of a geographical object from map layer 2 at a point.	
Overlaps	The interior of a geographical object from map layer 1 partly covers a geographical object from map layer 2. Only geographical object of the same geometry can be compared.	

5.2 Metric Relationship

Metric or distance relationship specify how far is the geographical object away from the reference geographical object. The Metric relationships include distance, direction (angle), and area. For example, the terminology such as at, nearby, in the vicinity, & far away can be used to define the metric relationship. We can also understand it by saying that Dehradun city is at 300 kilometers from New Delhi.

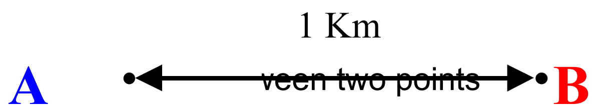


Figure 7- veen two points nting the distance

5.3 Directional Relationship

Directional relations are qualitative spatial relations that describe how a geographic object or a region is placed relative to other geographic objects or regions with respect their directions. The directional information is expressed as qualitative term using symbolic representation. For instance, north, south, east, west, southeast, southwest, northeast are directional relations. Such relations are used to describe and constrain the relative positions of a geographical objects or regions and can be used to pose queries such as “Find all objects/regions ‘a’, ‘b’, and ‘c’ such that ‘a’ is north of ‘b’ and ‘b’ is southeast of ‘c’.

6. Spatial Analysis – Analysis based on Geolocation of Entities

The core design of GIS itself is based on modelling of real-world phenomenon to assist in better decision making. Analysis of the data in GIS domain is carried out through two types of data models viz. raster model and vector model (Figure 1). The vector model is the discrete model of the real-world phenomena where the entities are represented using point, line and polygon features along with associated attributes whereas the raster data model represents the real-world entities as continuous grid i.e. pixel. Accordingly, the methods of spatial analysis vary for both the data models.

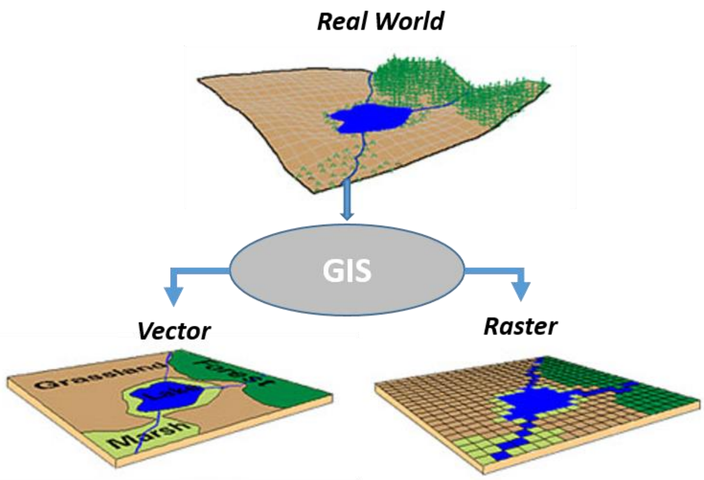


Figure 8- Basic concept of GIS design

The spatial analysis transforms the data captured by the GIS data capture system and maintained by data management system to useful information to be visualized by the Geo-visualization system. For example, a utility company providing power supply to households throughout a province may periodically need to analyze the total power consumption, the statistical distribution of peaks in consumption, the typical breakdown rate of power supplies during storms, the capacities of long-range connections, the overall flow capacity of a network, and others.

The ultimate goal of any information system is to transform raw data into useful information for better decision making. All types of analysis are performed as procedures of this system. The operation available in spatial analysis makes it the most sought for section of GIS. Day by day the requirement for spatial analysis is increasing. There is a demand for newer analysis operations to be performed by GIS. For example, finding the shortest route and tourist guide information system by means GIS is popular in web applications.

The main objective of this chapter is to make the reader understand the analysis of spatial data. By the end of this chapter, the reader should be able to understand the following points:

(i) The basic spatial analysis.
(ii) Type of spatial analysis i.e., vector and raster data analysis.
(iii) Method of vector and raster data analysis.
(iv) Difference between vector and raster data analysis

6.1 Vector Based Analysis

As mentioned above vector data model utilizes the geo-coordinates for spatial feature representation, this spatial representation includes one or multiple attributes as well. The attributes and geometry both contribute in the analysis process. Typical subtypes of vector GIS analysis functions include Geometrical Analysis, Topological Analysis, Interpolation and Approximation, Planning and Simulation

Geometrical Analysis is related to the proximity analysis (Buffering), overlays, distance measurement, pattern analysis and map manipulation (Figure 9).

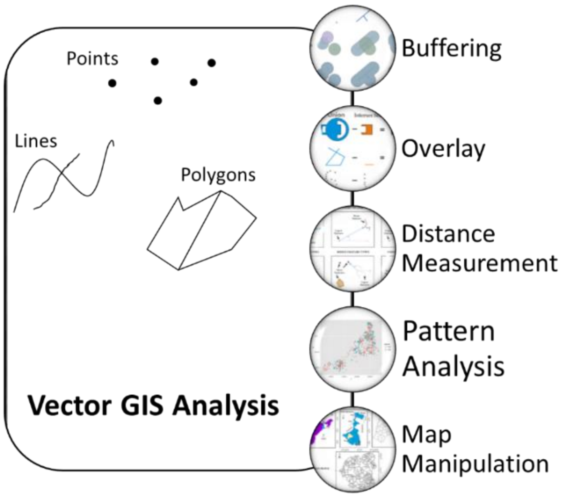


Figure 9- Basic methods of Vector GIS data analysis

Geometry of features stored in GIS is of great importance, the location of a feature, also compared with the location of other features, is a basic ingredient of geospatial information. Two or more sets of features may have to be overlaid and their geometries intersected to obtain ranges, neighborhoods, and buffers. Apart from these, the operations like topological analysis, network analysis adjacency and containment operations are also complemented by geometry of the features. These operation or functions are at the core of many spatial analysis processes, since geometry is a basic aspect of geospatial data. Polygon overlay, intersection, range queries, buffering, and nearest-neighbor search are examples of geometrical operations. Spatial filters in special arrangements help boost the performance of geometric operations.

Buffer analysis creates a boundary for the selected entity which can be any of the three features a point, line or polygon. The boundary defined can be used for the analysis with the boundary or outside the boundary. It should be clearly noted that the unit of buffer distance for the boundary is the unit of the layer. So, if you want to generate a 100m buffer around a road for restricting the construction of shops within this buffer, then you have to take care that the road layer is in planner projection system viz. UTM, LCC etc. The buffer analysis has the following primary variants:

- The buffer distance can be constant throughout the feature or it can depend a specific attribute value of the feature e.g., the buffer around the schools within a city can depend on the type of the school i.e., primary school with 100m buffer, secondary school with 50m buffer and higher secondary school with 25m buffer, these buffer distances need to be defined as a field in the attribute table of the school layer.
- The buffer can be on multiple zones e.g., buffer along river can be at 50m, 100m and 200m with different restriction within these buffer areas.
- The buffer can be towards specific side of the feature e.g., it can be towards either left or right side of a road depending upon the context of application

Applications of buffer analysis include government defining a distance of 200m from the river where no anthropogenic activities should be carried out. Nuclear power plant can also define a buffer distance around the nuclear reactor where any kind of movement is restricted.

Overlay analysis is another vector-based analysis which takes two or more vector layers as input to create a user defined output layer for example if we have a landuse map, population layer and a road layer then the local governing body can create a suitability map for setting up an industrial site which can benefit maximum population

(population layer) and is well connected from road (road layer) as well as do not disturb any existing landuse pattern (landuse layer).

The basic geometrical operations performed in vector overlay analysis are:

(i) Point-in-Polygon Overlay: This operation creates a point layer as output with all the point within the overlay extent and with all the attributes of point and the polygon.

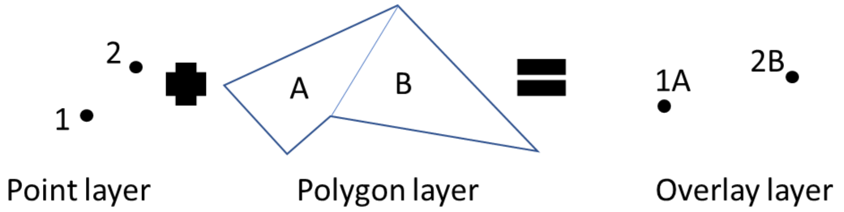


Figure 10- Point-in-Polygon overlay operation

(ii) Polygon-in-Point Overlay: This operation is similar to the point-in-polygon but the output is the polygon layer with all the attributes of polygon and point layer with the overlay extent (Figure 11).

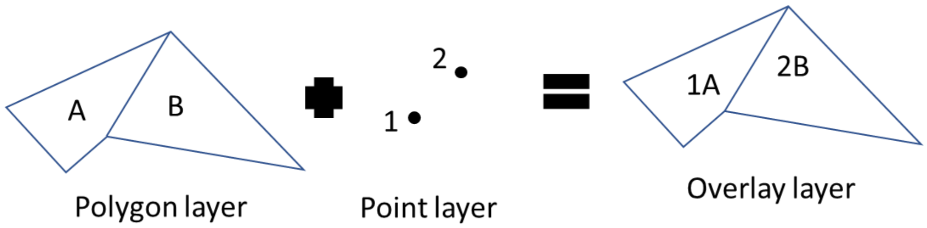


Figure 11- Polygon-in-Point overlay operation

(iii) Line-in-Line Overlay: This overlay operation requires two line layers and produces a point layer as output containing the points at the intersection of the two-line layers. The output point layer contains attributes from both the input layers (Figure 12).

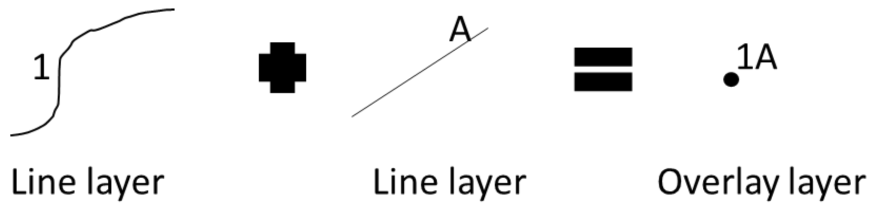


Figure 12. Line-in-Line overlay operation

(iv) Line-in-Polygon Overlay: The output of this operation is a line layer divided into different part as per the boundaries of the polygon layer and contains the attributes from both the layers (Figure 13).

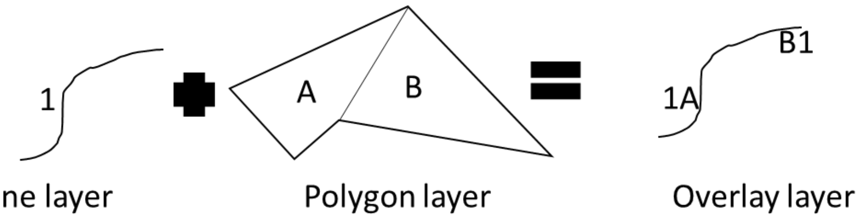
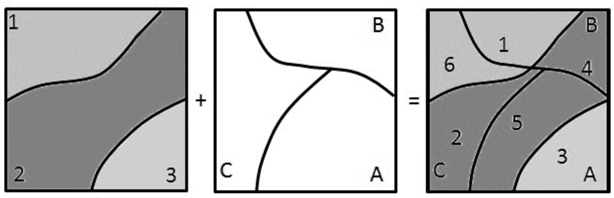


Figure 13. Line-in-Polygon overlay operation

(v) Polygon-in-Line Overlay: This operation generates the polygon output layer and the polygon falling within the line boundaries contains the attributes of line as well along with the attributes of the polygon.

(vi) Polygon-in-Polygon Overlay: The input layers for the operation are the two polygon layers and it produces a polygon layer as the output which contains a different set of polygons features which are created by the intersection of input polygon boundaries. The polygons in the output layer contain the attributes from all the intersection input polygons (Figure 14).



Polygon Topology

ID	Polygon (A)	Polygon (B)
1	1	B
2	2	C
3	3	A
4	2	B
5	2	A
6	1	C

Figure 14. Polygon-in-Polygon overlay operation

Based upon the above operations, many overlay functions and methods can be defined. Some of the most popular methods of vector overlay analysis are as follows:

(i) **Union Operation**: The union operation takes two polygon layers as input, creates an output layer with features, and attributes from both the layers. For example if we have landuse map polygon and the soil map polygon layer then the union operation will create an output layer with many polygons and each polygon having either landuse or soil or both the information. The union operation is similar to the polygon-in-polygon operation.

(ii) **Intersect Operation**: Intersect operation takes any feature (point or line or polygon) layers as one of the input and other the input layer as a polygon feature. The first layer is called the input layer and the other polygon layer is called the intersect layer. This operation preserves the features common to both the input layers; the output features have attributes from both the input layers. For example, the intersection of landuse layer and soil layer will create an output layer in which the features will have information from both the layers.

(iii) **Symmetric Difference**: Symmetric difference is the opposite of the intersect operation where the output layer consists of features which are not common to the input layers. This operation takes both the input layer as polygon layer and contains the features (polygon) and attributes from either one of the input layers. It does not contain the common features of the input layers.

(iv) **Identity**: Identity is similar to minus operation, it takes two feature layers (one of them is referred as input layer (point or line or polygon) and the other one is referred as identity layer (only polygon), this operation produce the output layer with geometry or spatial extent from the input layer but attributes from both the layers.

Distance measurement is one of another analysis in vector GIS wherein distance between geo-coordinates is measured in accordance with ground measurement i.e., the distance measured in layer is same as measured in ground. The measurements are like distance of a point from another point or line or a polygon, it can be between two lines or even between two polygons.

Pattern Analysis is very useful for determining and analyzing the distribution of spatial features. It provides the quantitative analysis of the distribution in terms of clustering, dispersion and randomness. The popular methods of pattern analysis are nearest neighbor analysis, spatial autocorrelation and clustering.

Map manipulation refers to the different kind of operation for making the layer specific to context and more readable. Some of the function involved in map manipulation are clip (extracting the features within a given boundary), dissolve (aggregating the feature based on attributes), append (combing the feature from different layer to create new layer), eliminate (removing the feature not meeting a specific condition, used for maintaining minimum mapping unit), update (edit the features), erase (remove the feature), split (dividing the feature into two or more feature) and many more.

Topological Analysis refers to network analysis as in routing and guidance. Topology is the branch of mathematics which deals with the spatial properties and relationship among features. These relationships among features are independent of any continuous deformation e.g., stretching etc. Topological operations presuppose a topologically correct data structure that is not inherent but has to be set up. They most often comprise also metrical aspects such as distances. Routing, traveling salesman problems, accessibility, and fleet management are prominent examples of topological operations.

Interpolation and Approximation is also an essential segment of GIS analysis. It is constituted by the statistical functions, for example, ranking, regression, trend surfaces, prediction, and filtering. Interpolations and approximations are used for lines and surfaces. Digital Terrain Models (DTM) is at the core of many other GIS analysis functions. They give reasonable estimates for heights based on interpolation and approximation assumptions. DTM can be used to generate contour lines, slope, and aspect models, viewshed models, and others.

Simulation and planning are introducing a wide arena of models and analysis requirements ranging from urban planning and its effects on flood disaster management to agriculture and geotargeting simulation models. GIS lends itself perfectly to simulation and planning. The what-if kind of scenario can be addressed by simulation operations and further planning can be done on that basis for future. These operations provide efficient means to model different variants of a planned project. Visualizing them brings more groups closer to the decision-making process. By also analyzing secondary effects, we become aware of future impacts of today's activities.

6.2 Raster Based Analysis

As discussed above the raster-based GIS analysis takes the input data in the form of regular grid represent the space with an attribute value in each grid cell. The cell or the grid value is used for the geospatial analysis. Broadly, the raster-based analysis is centered around the local, zonal, neighborhood and physical distance-based operations (Figure 15).

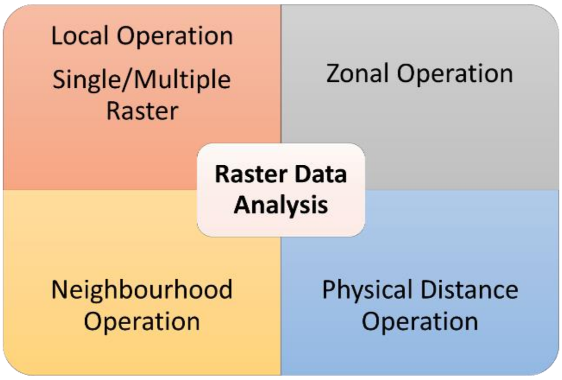


Figure 15- Basic Raster Data Analysis in GIS

Local Operations refers to the cell-by-cell operation in a geospatial raster data grid. The operation can be carried out on a single raster or on a set of different raster data sets. The operation can be any function based on the cell value(s) of the raster dataset(s). For example, a simple operation can be multiplying the entire raster data by a constant value, all the cell values are multiplied by the given constant value one-by-one. Similarly, the different raster data sets can be added or subtracted cell by cell e.g., calculating the Normalized Difference Vegetation Index (NDVI) is one such operation where multiple raster datasets are used.

For a single raster data operation, a number of functions are available like arithmetic, logarithmic, trigonometric and exponential operations. One of the popular applications of local operation is conversion of the slope layer from a radian to degree or vice versa, it involves trigonometric calculation on each cell value of the slope raster grid (Figure 16).

$$57.296 \times \arctan\left(\begin{array}{|c|c|c|} \hline 10.6 & 3.1 & 15.1 \\ \hline 18.5 & 12.5 & 19.4 \\ \hline 14.1 & 20.2 & 17.8 \\ \hline \end{array} \div 100 \right) = \begin{array}{|c|c|c|} \hline 6.05 & 1.77 & 8.58 \\ \hline 10.48 & 7.12 & 10.97 \\ \hline 8.02 & 11.41 & 10.09 \\ \hline \end{array}$$

Figure 16- Single raster layer local operation

Multiple raster operation involves the cell-by-cell calculations between two or more raster data sets. For example, calculation of the NDVI involves two raster data sets in which addition, subtraction and division operations are performed on cell-by-cell basis i.e.(addition of cell values/subtraction of cell values) as illustrated in Figure 17

$$\left(\begin{bmatrix} 12 & 31 & 21 \\ 15 & 40 & 32 \\ 14 & 29 & 19 \end{bmatrix} - \begin{bmatrix} 4 & 12 & 9 \\ 7 & 3 & 11 \\ 3 & 10 & 7 \end{bmatrix}\right) \div \left(\begin{bmatrix} 12 & 31 & 21 \\ 15 & 40 & 32 \\ 14 & 29 & 19 \end{bmatrix} + \begin{bmatrix} 4 & 12 & 9 \\ 7 & 3 & 11 \\ 3 & 10 & 7 \end{bmatrix}\right) = \begin{bmatrix} 0.5 & 0.44 & 0.4 \\ 0.36 & 0.86 & 0.48 \\ 0.64 & 0.48 & 0.461 \end{bmatrix}$$

Figure 17- Multi raster layer local operation

Similarly, a larger number of other measures can be applied on multiple rasters, measures like summary statistics (maximum, minimum, sum, mean, median etc.) are focused on numerical data values whereas the measures like majority, minority, uniqueness etc. are suitable for raster data with categorical values. Some of the application of local operations include change detection, site suitability analysis, satellite data classification for information extraction etc.

Neighborhood Operations refers to the operations where the value of a central cell is recalculated based on its neighboring cell values (Figure 18). There are many mechanisms to choose the neighbor of a cell viz. rectangle (a 3X3 area centered at the focal cell), circle (the cells located at the distance of selected radius), annuluses (a doughnut shaped neighbor), and wedges (Cone shape neighbor) etc. The selection of these neighbors is application dependent. The most popular application is the image filtering wherein a neighborhood window is selected and is moved across the image from one focal cell to another while calculating the new values for the focal cell based on the neighbors, the output produced by such operation enhances certain features in the image viz. edges or homogenous patches.

37	13	23	39
23	**32**	25	35
12	42	29	17
16	44	41	49
37	41	30	10
32	46	31	16
43	27	14	10
14	32	16	47
43	23	38	37

Figure 18- A rectangular neighborhood operation

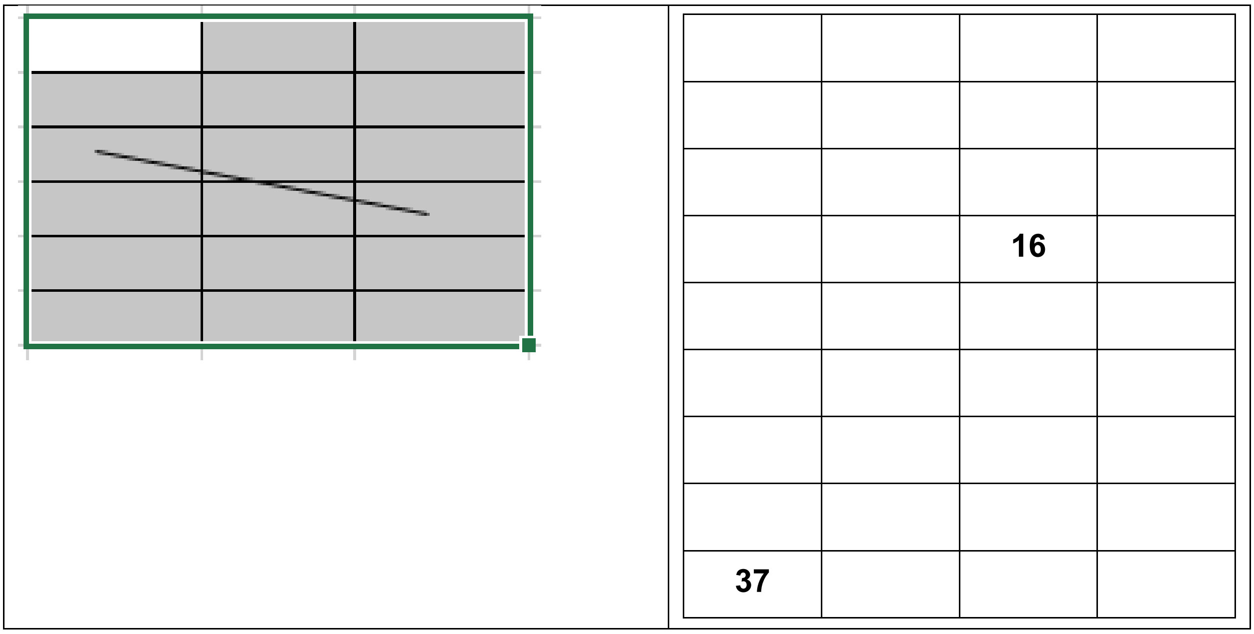
Zonal Operations select a specific zone consisting of a group of cells and generates statistics for the zone. It can be applied on a single raster (Figure 19) or more than two raster data. For the single raster, the zonal operation summarizes the cell values zone wise, whereas in case of two raster, it considers one of the rasters as zonal raster and summarizes the cell values of the other input raster for each zone in the zonal raster.

44	49	10	28
17	**23**	43	16
35	40	35	16
43	21	21	13
12	11	30	37
25	29	17	38
12	17	23	36
19	27	16	25
47	16	38	22

Figure 19- Single layer zonal operation (three zones)

Physical Distance Operations

Physical distance and cost distance are the two important distances, which are used in a number of spatial operations. The physical distance (Figure 20**)** is measured using Euclidean distance formula $(cell\ size \times \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2})$ whereas the cost distance refers to the cost of traversing the physical distance. One very popular application where distances are taken into consideration for spatial analysis is the travelling salesman problem.



(a) (b)

Figure 20- (a) Coordinates of the center of the cell are taken for distance calculation

(b) Physical distance operation empty cell gets the value in terms of distance from the nearest source cell i.e., either 37 or 16.

7. Spatial Data Quality and Uncertainty

A wealth of information is derived from spatial data through numerous techniques but not all data is ready to use and for information extraction, even a small error in the data can negatively impact the decision making process leading to heavy losses in terms of revenue, opportunities and other resources. The discrepancies in the spatial data quality (SDQ) occur mainly due to (1) data capture flaws (2) data transfer (3) cartographic effects (4) metadata (5) data source (6) data format (figure 21).

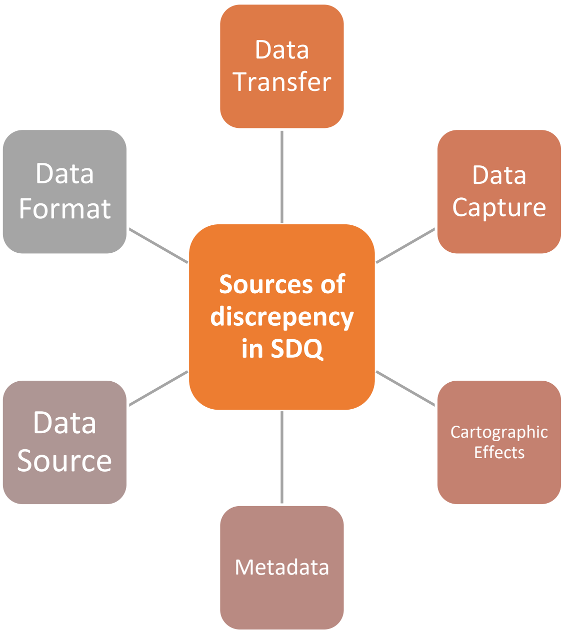


Figure 21- Sources of Data Discrepancies in SDQ

The source used for data collection many have inherent flaw, which propagates to the data also. The source can be a machine, old records or even the clients providing data to organisation.

Today there are numerous data format for spatial data storage and transfer and each format have their own merits and demerits. These formats are optimised for specific requirements e.g. one of the most common vector data format in GIS is shape file, which is simple and easily portable, but it does not contain topology, similarly example exists with raster data format also.

How the spatial data has been captured can also add discrepancy in the data i.e. a building or a well can be captured as a point or as a polygon, similarly two close by building can be misinterpreted as a single building. Scale of data capture plays important role to maintain desired quality of the data.

The cartographic effects refer to representation of the feature using various symbols, colors, size, texture, orientation etc. Although certain features are represented using a standard symbology but some representations are specific to application domain and intermixing of domain specific features representation degrades the data quality.

Data transfer strategy also induces discrepancy in the quality of the data. Often it is observed that in order to transfer the data suitable for desktop-based application to web based application, the user tries to optimise the data for making it web suitable. In such cases, the data quality is compromised in order to suit a particular platform or application.

Metadata is the data about the data; it conveys important ancillary information about the data. Quality of data is ensured if the metadata is regularly updated with the latest information, if there is any change in the original data and it is not updated in the metadata it leads to gaps in the information and propagates further as well in subsequent steps.

Researchers and Decision Makers across the globe have highlighted the concern on the impact of poor quality in research out comes and decision making activities. International geospatial organisation like International Society of Photogrammetry and Remote Sensing (ISPRS), Association of Geographic Information Laboratories in Europe (AGILE) have also emphasised on data quality standards. Several seminars and workshop are conducted annually by these organisations on spatial data quality standards. All these efforts are directed towards providing quality data for spatial decision-making.

The quality of the spatial data plays an important role in any geospatial workflow implementation; it is often considered as one of the critical pillar of geospatial technology and is defined as “fitness for use”. A geospatial workflow encompasses spatial temporal and thematic dimension of an application and according the quality of the data in these dimensions should be taken into consideration. The five important component of spatial data quality are (1) precision (2) accuracy (3) consistency (4) completeness and (5) lineage

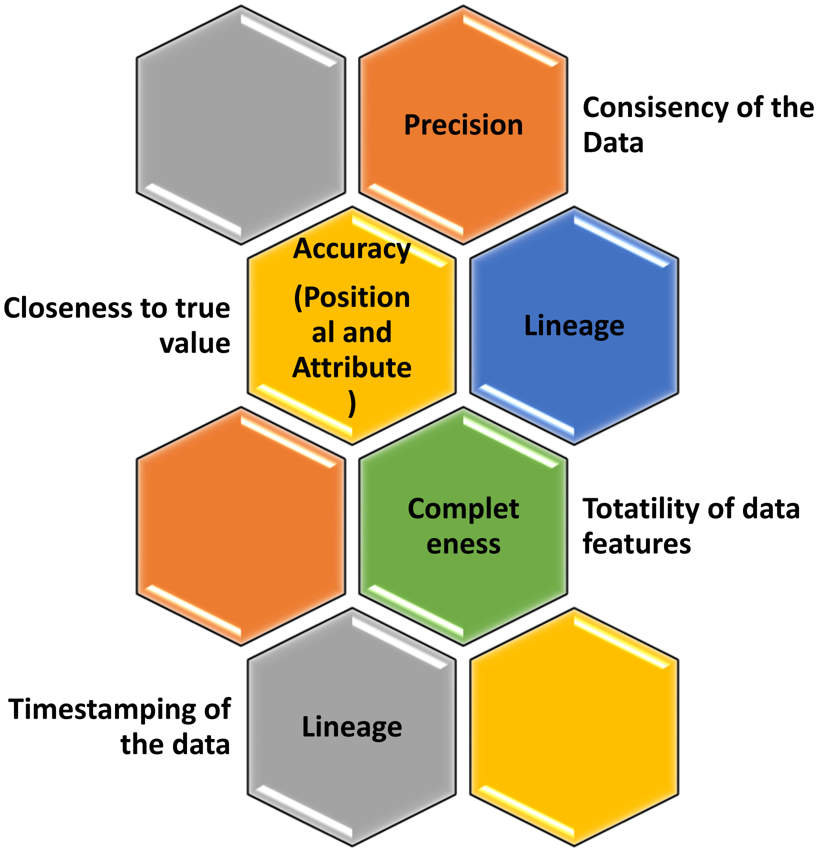


Figure 22- Components of Spatial Data Quality

The five important pillars of spatial data quality (figure 22) ensure reliability in the spatial data for obtaining meaningful results. The first and foremost component is the completeness of the data, which measures the degree of totality of features in the dataset. Accuracy is the measure of closeness to the true value i.e. and it is quantified by the difference between the observed value and the true value or the accepted values. Accuracy is further quantified via two components i.e. positional and attribute where positional accuracy is the measured by shift in geometric location from the actual ground location. The lineage component related to the true time stamping of the spatial data i.e. correct data creation/update date ensures that the decisions made from the data with correct timestamping. Data precision refer to the measure of data consistency; a consistent data ensures faithfulness of the data. Precision is often linked with the granularity or the resolution of spatial datasets.

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Chapter 3

Introduction to GNSS & IRNSS

1. Introduction

Traditional methods of surveying and navigation resort to tedious field and astronomical observation for deriving positional and directional information. Diverse field conditions, seasonal variation and many unavoidable circumstances always bias the traditional field approach. However, due to rapid advancement in electronic systems, every aspect of human life is affected to a great deal. Field of surveying and navigation has tremendously benefited through electronic devices. Many of the critical situations in surveying/navigation are now easily and precisely solved by GNSS based services in short time. Astronomical observation of celestial bodies was one of the standard methods of obtaining coordinates of a position. This method is prone to visibility and weather condition and demands expertise handling. Attempts have been made by USA and Russia since early half of 19th century to use space based artificial satellites. System TRANSIT was widely used for establishing network of control points over large regions. Establishment of modern geocentric datum and its relation to local datum(s) was successfully achieved through TRANSIT. Rapid improvements in higher frequency transmissions and precise clock signals along with advanced stable satellite technology have been instrumental for the development of global positioning system.

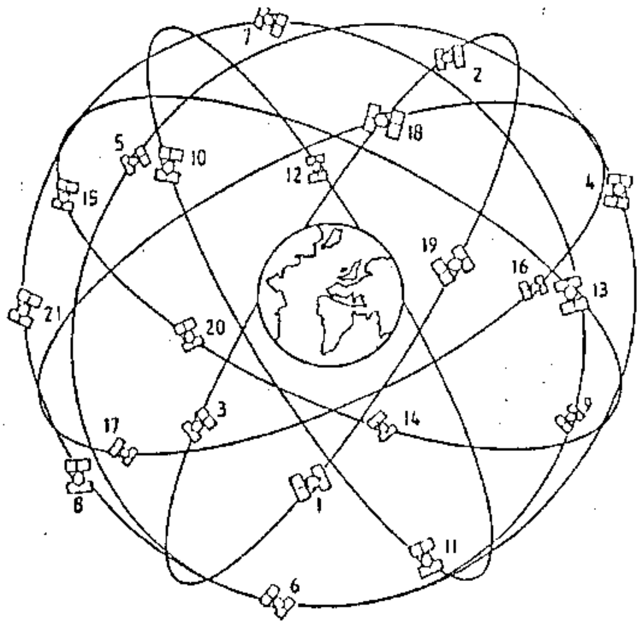


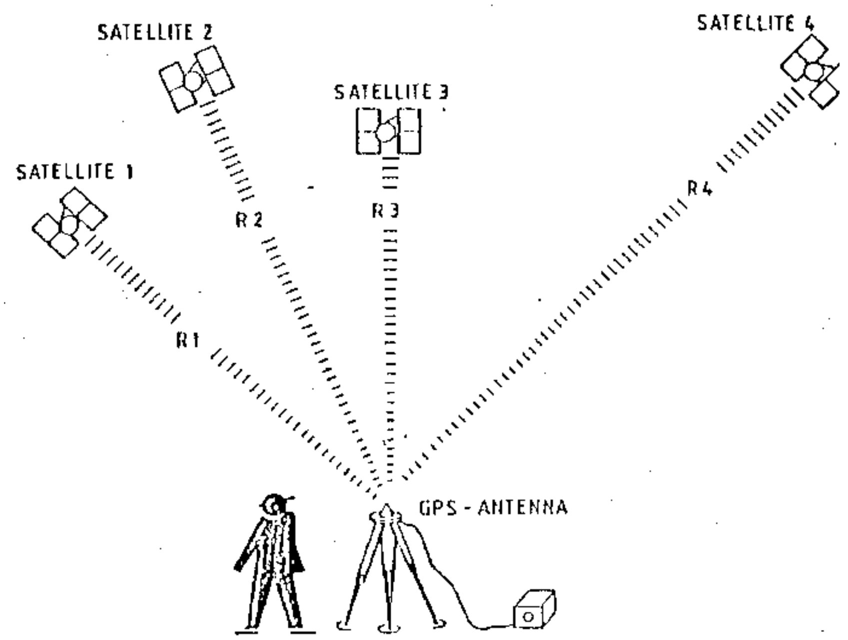
Figure 1. The Global Positioning System (GPS) constellation

The NAVSTAR GPS (Navigation System Time and Ranging Global Positioning System) is a satellite based radio navigation system. It is providing precise three-dimensional position, course and time information to a suitably equipped user. GPS has been under development in the USA since 1973 and achieved its final operational capability (FOC) in 1995. The US Department of Defense as a worldwide navigation and positioning resource for military as well as civilian use for 24 hours and all weather conditions primarily develops it. In its final configuration, NAVSTAR GPS consists of minimum 21 satellites (plus 3 active spares) at an altitude of 20200 km above the earth's surface (Fig.1). Russian GLONASS has been aimed at similar capabilities and achieved its final operational capability (FOC) in 1995. Global Navigation Satellite System (GNSS) is a worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation. Nowadays, about 30 or more satellites are maintained in NAVSTAR GPS and 24 or more satellites are maintained in GLONASS. Beidou constellation by China also got completed in early 2020 and is capable of providing PNT services globally. Galileo the fourth upcoming GNSS constellation has 24 operational satellites as of 21, March 2023 and need few more satellite launches for the completion of the Galileo constellation.

2. Basic principle of positioning with GPS

The GPS satellites act as reference points from which receivers on the ground resects, their position. The fundamental navigation principle is based on the measurement of pseudoranges between the user and four satellites (Fig.2). Ground stations precisely monitor the orbit of every satellite and by measuring the travel time of the signals transmitted from the satellite four distances between receiver and satellites will yield accurate position, direction and speed. Though three-range measurements are sufficient but fourth observation is essential for solving clock synchronization error between receiver and satellite. Thus, the term "pseudoranges" is derived. The secret of GPS measurement is due to the ability of measuring carrier phases to about 1/100 of a cycle equaling to 2 to 3 mm in linear distance. Moreover the high frequencies L1 and L2 carrier signal can easily penetrate the ionosphere to reduce its effect. Dual frequency observations are important for large station separation and for eliminating most of the error parameters. There has been significant progress in the design and miniaturization of stable clock. GPS satellite orbits are stable because of the high altitudes and no atmosphere drag. However, the impact of the sun and moon on GPS orbit though significant can be computed completely and effect of solar radiation pressure on the orbit and tropospheric delay of the signal have been now modeled to a great extent from past experience to obtain precise information for various applications.

Figure 2. Basic principle of positioning with GPS



Comparisons of main characteristics of TRANSIT AND GPS reveal technological advancement in the field of space based positioning system (Table 1)

Table 1: **Details of TRANSIT AND GPS**

Details	TRANSIT	GPS
Orbit Altitude	1000 Km	20,200 Km
Orbital Period	105 Min	12 Hours
Frequencies	150 MHz 400 MHz	1575 MHz 1228 MHz
Navigation data	2D :	4D : X,Y,Z, t velocity
Availability	15-20 minute per pass	Continuously

Accuracy	30-40 meters (Depending on velocity error)	15m (P code/No. SA 0.1 Knots)
Repeatability	-------	1.3 meters relative
Satellite Constellation	4-6	21-24
Geometry	Variable	Repeating
Satellite Clock	Quartz	Rubidium, Cesium

GPS has been designed to provide standalone navigational accuracy of ±10m to ±15 m. However, sub meter as well as centimeter level accuracies, in the relative or the differential mode has been achieved and it has been proved that broad varieties of problems in geodesy or geodynamics can be tackled through GPS. Commonly, when more than one GPS constellation is used for an application, it is termed as GNSS solution. Versatile use of GNSS for a civilian need in following fields have been successfully practiced viz. navigation on land, sea, air, space, high precision kinematics survey on the ground, cadastral surveying, geodetic control network densification, high precision aircraft positioning, photogrammetry without ground control, monitoring deformations, hydrographic surveys, active control survey and many other similar jobs related to navigation and positioning.

3. Various Segments of GPS

For better understanding of GPS, we normally consider three major segments namely, space segment, Control segment and User segment. Space segment deals with GPS satellites systems, Control segment describes ground based time and orbit control prediction, whereas User segment includes various types of existing GPS receivers and its application (Table 2).

Table 2: **Brief account of functions and various segments along with I/O information.**

Segment	Input	Function	Output
Space	Navigation message	Generate and Transmit code and carrier phases and navigation message	P-Code C/A Code

			L1, L2, L5 carrier Navigation message
Control	P-Code Observations, Time	Produce GPS time predict ephemeris manage space vehicles	Navigation message
User	Code observation, Carrier phase observation, Navigation Message	Navigation solution Surveying solution	Position velocity time

The official U.S. Government information about the Global Positioning System (GPS) and related topics are given on http://gps.gov/ . GLONASS (Global Navigation & Surveying System) a similar system to NAVSTAR GPS is developed by Russia and is now a valuable complementary system to GPS and a part of GNSS.

4. Basic Components of GPS receiver and its components.

The main components of a GPS receivers are: antenna with pre-amplifier, RF section with signal identification and signal processing, Micro-processor for receiver control, data sampling and data processing, precision oscillator, power supply, user interface, command and display panel, memory, data storage. Some of the antennas are: mono pole or dipole, Quadrifilar helix, Spiral helix, Microstrip, Choke ring.

5. Classification of GPS receivers

GPS receivers can be divided into various groups according to different criteria. Most prominent classification of GPS receivers is based on acquisition of data types, for example: C/A code receiver; C/A Code + L1 Carrier phase; C/A Code + L1 Carrier phase + L2 Carrier phase; C/A code + p_code + L1, L2 Carrier phase; L1 Carrier phase; L1, L2 Carrier phase; L1, L2, L5 Carrier phase.

Some of the important features for selecting geodetic receivers are: tracking of all satellites, both frequencies, full wavelength on L2, low phase noise-low code noise, high sampling rate for L1, L2 and L5, high memory capacity, low power consumption, full operational capability under anti spoofing condition. Further, it is recommended to use dual or multi - frequency receiver to minimize influences due to ionosphere and take advantages in ambiguity solution.

RINEX Data format: Receiver Independent Exchange Format is globally accepted standard data interchange format for raw satellite navigation system data. This was first developed by the astronomical Institute of the University of Berne for easy exchange of GPS receiver data collected from different receivers manufactured by different firms. There is a need to have a common format to make use of data collected by various receivers as each vendor have their own proprietary format of storing the received GNSS data.

6. Types of GPS Positioning

Major types of possible positioning methods are: Single Point Positioning (Static mode or Kinematic mode), Relative Point Positioning (Static mode or Kinematic mode), Real-time data collection (point, line, and area), Post mission processing.

6.1 Sources of Errors

The main sources of errors are satellite clock errors, receiver clock errors, satellite orbit errors, atmospheric errors (Ionosphere and Troposphere), multipath error and human errors.

6.2 Geometric Dilution of Precision (GDOP)

A common question is that what is the relationship between the range error and the error in computed position. Or, in other words, how many meters of error are introduced in our computed position as a result of one meter of error in measuring distances to the satellites? The answer is that it depends on the number and the geometry of the satellites used. If four satellites are clustered near each other, then one meter of error in measuring distance may result in tens or hundreds of meters of error in position. But if many satellites are scattered around the sky, then the position error may be less than 1.5 meters for every meter of error in measuring distances. The effect of the geometry of the satellites on the position error is called Geometric Dilution of Precision (***GDOP***), which can roughly be interpreted as the ratio of the position error to the range error.

7. Other satellite positioning system

Earlier NAVSTAR GPS (popularly known as GPS) was the only global satellite positioning system, but now many nations or agencies are making an effort to have their own satellite positioning system providing position and other applications available at either regional or global scale. Hence, the satellite positioning system has given rise to new term called Global Navigation Satellite System (GNSS). Some of the satellite positioning systems are listed below in table 3.

Table 3: Satellite positioning system having global coverage (03.07.2018)

System	Country	Orbital height & period	Number of satellites	Frequency
GPS	United States	20,200 km, 12.0h	≥ 24 (at present 32)	1.57542 GHz (L1 signal) 1.2276 GHz (L2 signal)
GLONASS	Russia	19,100 km, 11.3h	26	Around 1.602 GHz (SP)* Around 1.246 GHz (SP)*
Galileo	European Union	23,222 km, 14.1h	24 (at present 22, initial operations started from 15 Dec. 2016)	1.164-1.215 GHz (E5a and E5b) 1.215-1.300 GHz (E6) 1.559-1.592 GHz (E2-L1-E11)
Beidou	China	21,150 km, 12.6h	28 launched (15 in operation)	B1: 1,561098 GHz B1-2: 1.589742 GHz B2: 1.207.14 GHz B3: 1.26852 GHz

***the frequency varies with each satellite.**

8. Regional Satellite Navigation Systems.

These systems have limited coverage over a specific area. Some of such systems are IRNSS or NAVIC, BEIDOU, and QZSS, DORIS established or under development by

India, China, Japan, and France respectively to have coverage over their respective nations and regions of interest.

8.1 Indian Regional Navigational Satellite System (IRNSS)

The Indian Regional Navigational Satellite System (IRNSS) is an autonomous regional satellite navigation system developed by the Indian Space Research Organization (ISRO), which is under total control of Indian government. It is also known as the Navigation Indian Constellation (NAVIC) providing the navigation services.The Indian satellites are placed at either geostationary or geosynchronous orbits (36,000 km), so as to have a larger signal footprint and lower number of satellites to map the region. This system provides two types of services, Standard Positioning Service (SPS) and Restricted Services (RS) for Special use, with seven satellites in constellations. The satellites are namely IRNSS-1A, IRNSS-1B, IRNSS-1C, IRNSS-1D, IRNSS-1E, IRNSS-1F, IRNSS-1G and IRNSS-1I. IRNSS-1H has failed during the launch. Three of the satellites in the constellation are placed in geostationary orbit. These GEOs are located at 34 East, 83 East and 132 East longitude positions. The GSOs are in orbits with a 24,000 km apogee and 250 km perigee inclined at about 29 degrees. Two of the GSOs cross the equator at 55 East and two at 111 East. Such an arrangement ensures that all seven satellites have continuous radio visibility with Indian control stations. The satellite payloads consists of atomic clocks and electronic equipment to generate the navigation signals. Figure 3 depicts the space segment of IRNSS.

Lift-off Mass	1425 kg
Physical	1.58 metre x 1.50 metre x 1.50 metre
Orbit	Geosynchronous, at 55 deg East longitude with 29 deg inclination
Power	Two solar panels generating 1660 W, one lithium-ion battery of 90
Propulsion	440 Newton Liquid Apogee Motor, twelve 22 Newton Thrusters
Control	Zero momentum system, orientation input from Sun & star Sensors
Mission Life	10 years
Launch date	Jul 01, 2013

Launch site	SDSC SHAR Centre, Sriharikota, India
Launch	PSLV - C22

Table 4: IRNSS-1A specifications

The IRNSS-1A, the first of the IRNSS satellites developed by India, constituting the Indian Regional Navigation Satellite System space segment, has a mission life of 10 years (Table 4) and was launched successfully at 23:41 hrs. on 1st July 2013. It has a lift-off mass of 1,425 kg, and the satellite was launched into a sub Geosynchronous Transfer Orbit with a 284 km perigee (nearest point to Earth) and 20,650 km apogee (farthest point from the Earth) with an inclination of 17.86 degree with respect to the equatorial plane. It is designed to provide accurate position information service to users in the country as well as the region extending up to 1,500 km from its boundary, which is its primary service area. The data from the satellite would help the country in a range of fields including disaster management, vehicle tracking, fleet management, precision farming, marine navigation, mapping, and geodetic data capture, precise timing, visual and voice navigation for drivers, integration with mobile phones and terrestrial, aerial and marine navigation, terrestrial navigation aid for hikers and travelers.

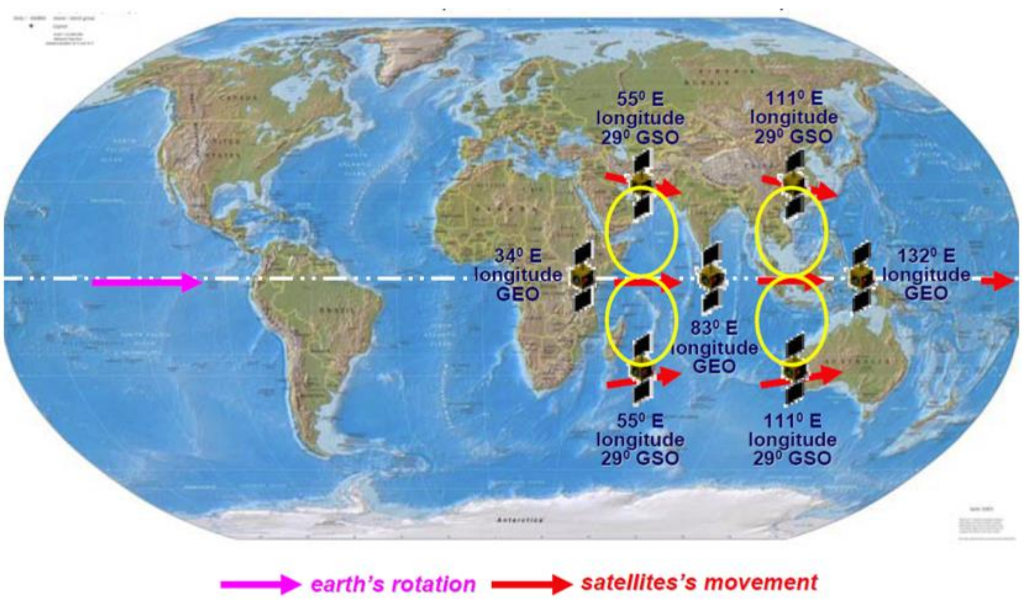


Figure 3. IRNSS Space Segment

IRNSS satellite carries navigation payload, which transmit navigation service signals to users, by operating in L5 (1176.45 MHz) and S band (2492.028 MHz) with a highly accurate Rubidium atomic clock and the ranging payload of a C-band transponder, which facilitates accurate determination of the range of the satellite. IRNSS is providing a position accuracy of better than 20 meters (upto 5m) in the primary service area. The navigational system provides two types of services -- Standard Positioning Service, which is provided to all the users and Restricted Service, which is an encrypted service provided only to the authorized users. An additional L1 band (Table 5) will now be available from IRNSS 1J onwards (https://www.isro.gov.in/update/25-jun-2021/navic-l1-adopts-indigenous-digital-codes-designed-isro-and-iisc).

Table 5: Specification of NavIC Signals (IRNSS 1J onwards with additional L1 band)

	Centre Frequency	**Bandwidth**	**SPS Modulation**
L-Band (L1)	1575.42 Mhz.	24 MHz.	S-BOC
L-Band (L5)	1176.45 Mhz.	24 MHz.	BPSK
S-Band	2492.028 Mhz.	16.5 MHz.	BPSK

8.2 GPS Aided GEO Augmented Navigation (GAGAN)

GAGAN is a Satellite Based Augmentation System (SBAS) implemented jointly with Airport Authority of India (AAI). The main objectives of GAGAN are to provide Satellite-based Navigation services with accuracy and integrity required for civil aviation applications and to provide better Air Traffic Management over Indian Airspace. The system is interoperable with other international SBAS systems and provide seamless navigation across regional boundaries. The first GAGAN navigation payload was flown on GSAT-8, which was launched on May 21, 2011, and the second on GSAT-10 launched on Sep 29, 2012. GSAT-15 has also been added in GAGAN. Figures 4 and 5, depicts the infrastructure and assistance mechanism of GAGAN respectively.

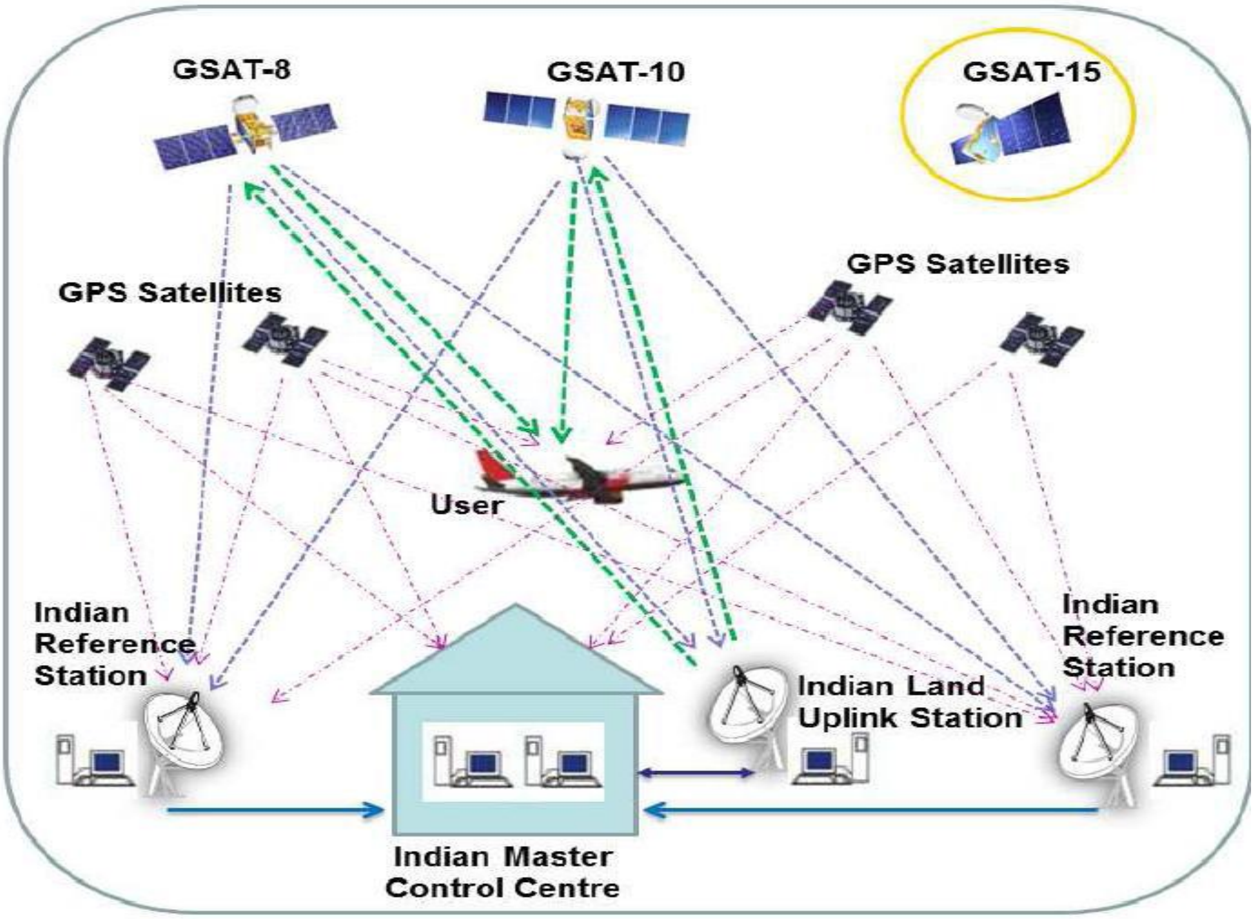


Figure 4. GAGAN SABS Infrastructure

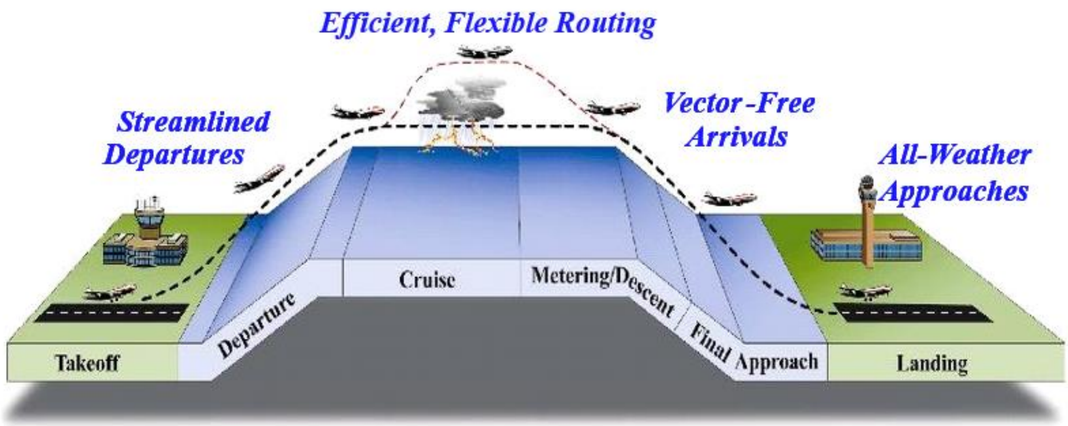


Figure 5. GAGAN assistance in various stages of flight

9. Mobile Mapping: Fundamentals and Applications

Mobile Mapping is the combination of geographic information system (GIS) software, global positioning systems (GPS), and mobile computing devices. Mobile Mapping fundamentally changes the way information is collected, used in the field, and shared with the rest of an organization. Mobile Mapping allows you to visualize information in a digital map, collect information where you observe it, and interact directly with the world around you, while improving productivity and data accuracy. Until recently, gathering and using information in the field was a paper-based process with multiple points of data entry without access to real-time information or the ability to accurately communicate field observations back to the office. The recent developments in mobile mapping technologies have benefited many field-based information gathering, user tasks by increasing the efficiency and accuracy with which field workers collect information. Mobile mapping greatly improves the field processes which include Asset inventory, Asset maintenance, Inspections and Incident reporting using Personal digital assistant (PDA). PDA is a handheld computer, also known as a palmtop computer. PDA has a touch screen for entering data, a memory card slot for data storage and at least one of the following for connectivity: IrDA (Infrared Data Association), Bluetooth and/or Wi-Fi.

9.1 Architecture of Mobile GIS

The architecture of mobile GIS is very similar to that of Internet-based GIS, using client-server architecture. It has three major components: the client, the server, and the network services. Client-server applications usually implement what is referred as Three Tiered Architecture. This architecture divides the application into a presentation tier, a business logic tier and a data management tier. Each tier can be replaced or updated without affecting the others. The presentation tier consists of client side components, which are used to send requests to the server and to view the results (maps and data). The business tier is the core of any solution and consists of the server side components including the Web server and application server. The data management tier is responsible for the management of both spatial and attributes data in the application. In some cases, one server is used for both the business and data management tier. In other cases each tier can be on a separate server.

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Chapter 4

Ground based Geospatial Tool for 3D Modeling and Applications

1. Introduction

3D modeling is the process of developing a mathematical coordinate-based representation of any surface of an object in three dimensions via specialized software by manipulating edges, vertices, and polygons in a simulated 3D space. The term "3D modeling" refers to the process of creating a three-dimensional representation of an object using specialized software. This representation, called a 3D model, can convey an object's size, shape and texture. One can create 3D models of existing items, as well as designs that have not yet been built in real life.

These replicas incorporate the points, lines and surfaces that make up the physical environment. They use coordinate data that identifies the location of horizontal and vertical points relative to a reference point. Due to these spatial relationships, you can view the representation from various angles. Various technologies came together to enable 3D modeling, including:

- CAD, which turns survey data into a 3D model.
- GPS, which allows engineers to pinpoint precise locations.
- Light Detection and Ranging (LiDAR), a remote sensing technology that uses a pulsed laser to measure variable distances.
- Aerial photogrammetry, which enables engineers to extract topographical data from aerial photographs taken by drones.
- Point-cloud modeling, which involves using laser scanning technology to create a set of three-dimensional data points used to create a model.

2. Potential Users

For more than a century, close-range photogrammetry was used as a reliable geometric measurement tool, for describing buildings and monuments from terrestrial photographs. The technique till recently required huge investments in terms of relatively large amounts of money and skilled staff. Recent development in the digital imaging technology and a general hype for 3D products have significantly changed the perspective in terms of its economic and scientific usage. The technique is no longer restricted to a few specifically trained technicians, but is on the contrary conquering new fields. Today, close-range photogrammetry (or 3D optical measurement techniques) has widespread applications much beyond architecture, archaeology and cultural heritage preservation. It is also increasingly being used in different engineering sectors. A few potential users of the technique are listed below:

- Administrators
- Decision Makers
- Engineers
- Researchers in Medical profession
- City Planners
- Natural Resource Scientists
- Entertainment Industry

Also, besides single images, image sequences and video streams are increasingly being processed using the same photogrammetric principles. In this way not only static scenes can be surveyed, but also dynamic processes are being captured, and photogrammetry can also be employed for tasks such as traffic monitoring and security surveillance.

These new developments have become possible due to significant progress in sensor technology, automation and, perhaps above all due to the fact that today virtually everybody can capture digital images using inexpensive cameras or mobile phones. They are proof of a very vital and fascinating discipline with lots of potential for future growth and applications.

Here we will be talking about few methods of 3D modelling.

3. Methods of 3D Modelling with Ground Instruments

3.1 Digital Photogrammetry

Digital photogrammetry is now increasingly recognized as being a powerful tool in inventory and monitoring activity particularly with reference to Natural Resource Management. However, the high material costs and skills required by digital photogrammetry may deter non-photogrammetrists from using this technique in their research and applications. In Aerial Photogrammetry the camera is mounted in an aircraft and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the aircraft flies along a flight path. These photos are processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view). These photos are also used in automated processing for Digital Elevation Model (DEM) creation. On the other hand, in Close-range Photogrammetry (CRP) the camera is close to the subject and is typically hand held or on a tripod.

More or less any camera is suitable for photogrammetric applications. Two basic camera types are employed in terrestrial photogrammetry. These are; metric cameras and non-metric cameras. A camera can be used as a metric one if the position of the projection center relatively to the image co-ordinate reference system is known and if the amount of lens distortion can be corrected. Metric cameras are designed and calibrated specifically for photogrammetric measurement. It has a known and stable interior orientation and is usually a fixed-focus camera. They also contain fiducial marks to recover the interior orientation. Nonmetric cameras are represented by a variety of fairly high quality hand-held cameras used by amateur and professional photographers to take good pictorial quality. The use of images obtained with digital non-metric cameras to metric surveying three-dimensional photogrammetric of objects, is being investigated by the specialists in the field. When employing non-metric digital cameras for photogrammetric works, the technical characteristics of specific and utmost interest are the metrics qualities of the system.

A variety of cameras and platforms may be used to obtain the photographic images to be used in CRP processing, including cameras housed in unoccupied airborne vehicles, suspended below helium-filled blimps, and mounted on tripods (Breithaupt et al. 2004). Through the use of these nontraditional methods, a resolution or ground sample distance of 0.25 mm and a spatial accuracy equivalent to 0.025 mm can be achieved. Theoretically, there is no limit to the resolution that can be achieved from CRP images (Matthews et al. 2006).

The revolution in digital technology has geared up production of mobile phones with built-in digital cameras. Such products give us the opportunity to take photographs of any object, at anytime instantaneously. This new facility in the mobile phone generation makes it convenient to use it in the digital terrestrial photogrammetric field. Mobile phone cameras which have 10 mega pixels have appeared in the market. As mobile phones are constantly carried, camera phones allow for capturing moments at any time. Cell phone manufacturers have recognized the need for optimization and are developing models with higher-resolution sensors and more powerful lens systems. In these circumstances, one has to analytically study whether mobile phone cameras are able of taking place of consumer grade digital cameras in close range photogrammetric applications. The full potential of the technique can be explored once its accuracy has been evaluated. In this situation, experts involved in photogrammetry are exploring the capabilities of these devices in terms of obtaining geometric data.

3.2 Close Range Photogrammetric Workflow

The methodology developed, is a general methodology applied to get the dense surface model out of 3D photographs. Fig. 1 demonstrates the general methodology used for the present study.

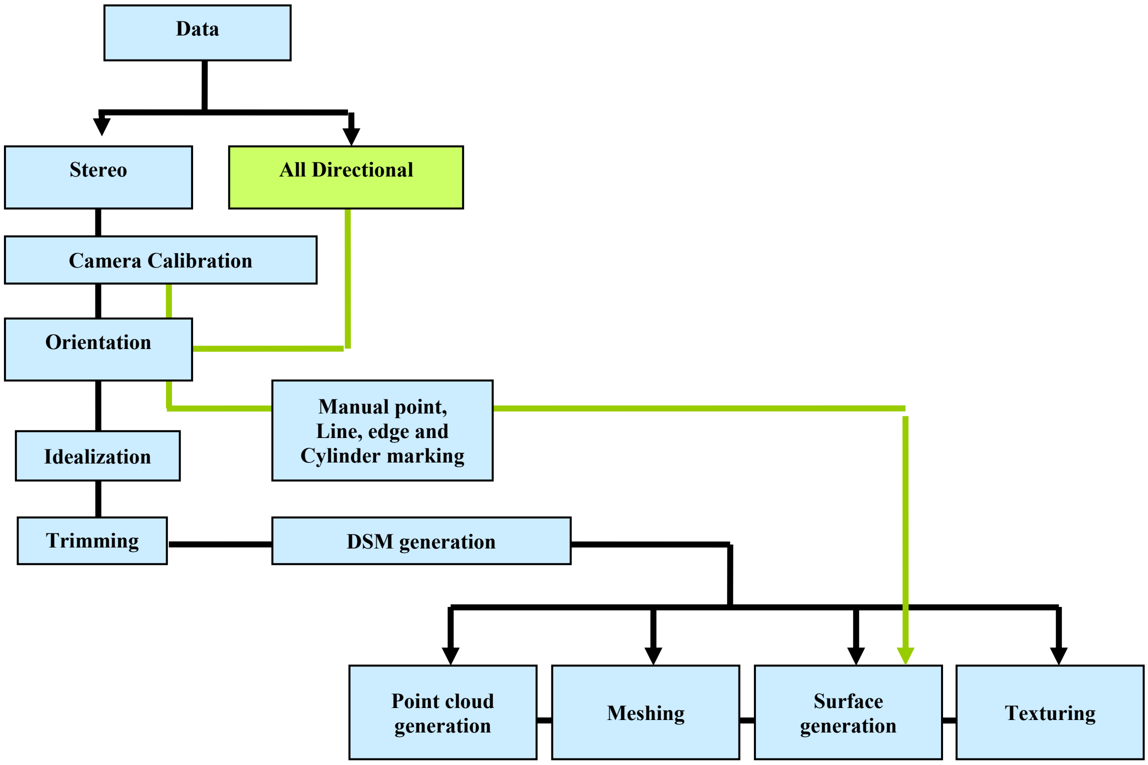
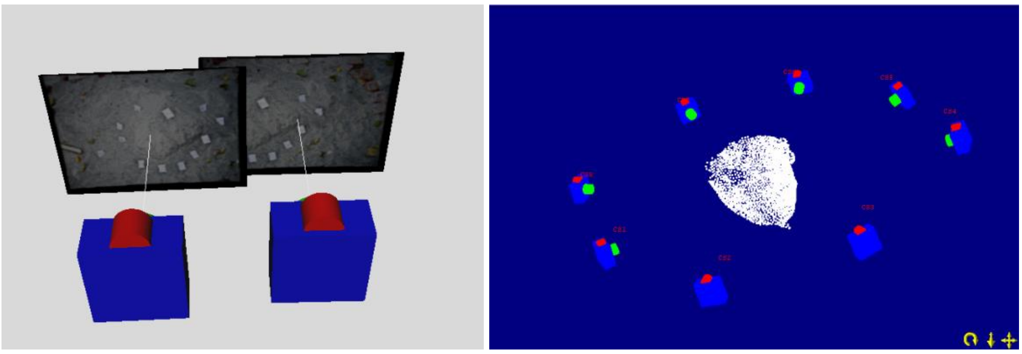


Figure 1. General mythology for Close Range Photogrammetric Measurements

3.2.1 Image Acquisition

The increased flexibility provided by CRP is most completely realized in the image acquisition. Because many of the rigors imposed by traditional photogrammetric processing are removed from CRP, almost any person who can take good quality photographs can take the photos necessary for 3D data processing. The images should be obtained using a convergent image pair configuration with an overlap of 90-95%. If multiple image pairs are combined to mosaics, an appropriate overlap between adjacent convergent pairs can be 5-10%. Image acquisition constraints such as maximum camera to object distance, object size, number and distribution of image points should be properly optimized as per project requirement. Figure 2 a and b describe two methods of image acquisition.



a **b**

Figure 2. a) Stereo image acquisition, b) All directional data acquisition

3.2.2 Camera Calibration

The work with non-metric cameras for photogrammetric purposes is accompanied by the following problems:

i. Defining the image co-ordinate system
ii. Defining the unknown elements of internal orientation
iii. Defining the distortion of lens

To derive accurate spatial data using consumer grade digital cameras, it is necessary to define several critical parameters which model distinct geometric characteristics of the imaging system.

The prime parameters normally recognized include:

i. camera focal length (f)
ii. principal point offset (x_P, y_P)
iii. radial lens distortion (K_1, K_2, K_3)
iv. tangential distortion (P1, P2)

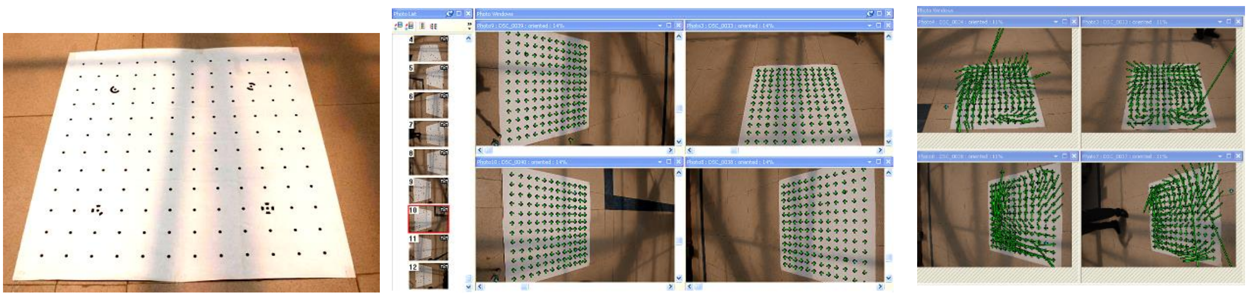
Since there are no universal standards for camera calibration, different software systems use slightly different combinations and many include additional parameters. An additional difficulty is that the accuracy and number of parameters required depends upon a variety of factors, most notably the final desired accuracy of the data to be acquired from the imagery, which is often unknown. There are also a variety of calibration software tools available, including: Matlab, PhotoModeler, iWitness, Camera Calibrator, LISA-FOTO which provide the required capability. The camera system should be re-calibrated at least every 12 months or before every project.

There are three basically different methods for camera calibration:

• **Calibration in advance:** Before surveying, in a laboratory (calibration centre) the unknown elements of internal orientation and distortion of lens shall be defined. The advantage of this method is that the calibration takes place at a laboratory and hence better accuracy at defining of unknown quantities is achieved. The problem with their fluctuation in time remains.

• **Calibration during the processing:** The unknown elements are defined by means of a special mathematical instrument. A larger number of control points is needed for their defining - at least 5 points, and it is recommendable 8-10 points per model, compared to 3 points per model when using metric camera.

• **Self-calibration:** It is based on the mathematical means of the geometry of overlapped areas for defining the unknown elements. The principles involved are similar to the ones, used for relative orientation of stereo-pair with analogue instrument. It is specific for this method that it does not require larger number of control points. Figure 3 describes the camera calibration process in detail.



a **b** **c**

Figure 3. a) Calibration sheet used for camera calibration b) Photograph auto-orientation during calibration process c) Residual error pattern

3.2.3 Orientation

Orientation refers to the position of angles of a camera station. The orientation of a Camera Station defines the position of and the pointing direction of the camera at the time of exposure of a photograph. The direction of view and rotation of each Camera

Station is defined by three Euler angles called omega, phi, and kappa. These angles define the rotation of the camera from a default position. These positions and angles are defined in terms of a right-handed coordinate system. Imagine the object you are measuring is sitting on the XY plane of a Cartesian coordinate system. To achieve desired accuracy in photogrammetric orientations and automatic target recognition a number of artificial targets were installed on each project area and some points were selected manually from the natural objects in the surroundings. Although the number of targets within a project has little impact on the precision of object triangulation, so long as there is a sufficient number in each image to support exterior orientation, which is typically by standard bundle adjustment in multiple camera networks. Practically total amount of 20-50 target points in the entire area are theoretically recommended, though each image should have at least 10 – 15 points (Fraser, 1984). Figure 4 shows textured model with sample target points.

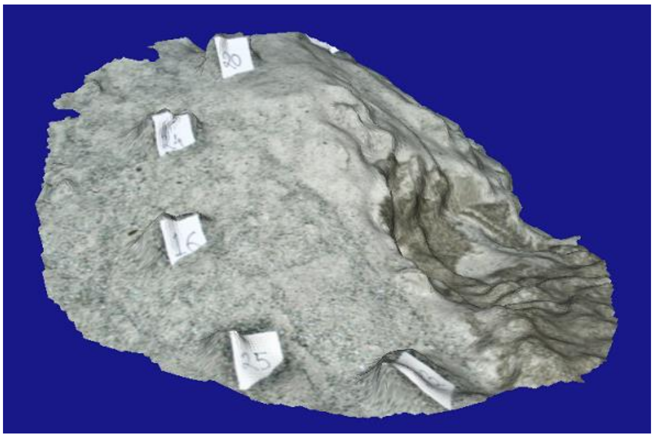


Figure 4. Textured model of a sand pile

Documenting and monitoring the natural and cultural resources would form the basis for future decision making. The availability of digital cameras and the increasing capabilities of computers and analytical software have dramatically expanded the variety of resource applications to which photogrammetry may be applied, while simultaneously decreasing the costs of acquisition, processing, and analysis. Close range photogrammetry provides a powerful tool for gathering full field 3D coordinate (non-contact) information about an object or test structure and also low cost compared to advanced real-time full field measurement systems.

3.3 Terrestrial Laser Scanning

Laser scanning is a prevalent technique used for the surveying of objects. It gives method of obtaining precise geometrical information in the form of three dimensional point clouds. These can be used to scan objects of varying scale from a few centrimetres to a few kilometres. Along with the shape of the objects the laser scanners also provides the surface properties like the reflected intensity of the laser and the colour information. These have found applications in different platforms like satellites, airplanes, drones, etc, but the most popular is the use as a terrestrial laser scanner which is a ground based device used to scan minute objects to large landscapes. Terrestrial Laser Scanning (TLS) is based on LiDAR (Light Detection and Ranging) technology and may also be called Terrestrial LiDAR or Tripod LiDAR (T-LiDAR). It is a ground-based remote sensing tool that is similar to Radar and Sonar, but uses visible to near infrared light emitted from a laser instrument that then records the reflected light waves from its targets. These recorded light waves can then be converted into points with X, Y, Z coordinates that can be georeferenced with a GPS unit to produce highly precise and accurate 3-dimentional images called point clouds, which can then be analyzed for scientific research. TLS is a tool that is quickly becoming very popular in the Earth sciences for topographic mapping, temporal and spatial geomorphic and tectonic change detection such as earthquakes, volcanoes, landslides, stream morphology studies, glacier mass balance and snow depth measurements. TLS is also used widely in biomass investigations in forestry, and for numerous engineering applications.

3.3.1 TLS Principles

The terrestrial laser scanners are based on one of three principles - Phase Shift, Time of Flight, and Triangulation-based systems. Each technology has varying acquisition distance, rate of acquisition and data accuracy/resolution based on which a technology is used according to the use. The Time of flight has the highest acquisition distance, thus is used in cases where large areas are to be surveyed. However these have low rate of acquisition and accuracy. Phase shift technology is the fastest of the three, but has a limited range of 80 to 120 metres. Triangulation scanners has the least acquisition distance of upto 5 metres as they are limited by the field of view of the laser and camera. Thus this is mainly used for scanning small objects of sizes from 1cm to upto a few metres.

a. **Time of flight:** In a time of flight system the distance of the object surface is calculated using the time taken by a laser pulse to travel from the instrument to the object surface and back to the instrument. As the laser pulse travels with the speed of light the distance travelled is calculated by multiplying the time of flight with the speed of light. The distance to the object will be the distance travelled by pulse divided by two.

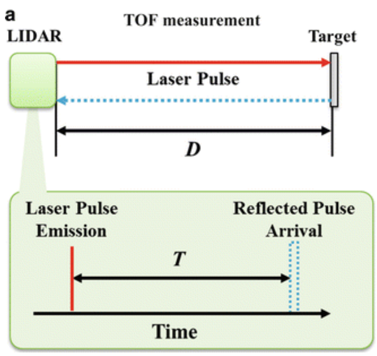


Figure 5. Concept of time of flight based laser scanning

b. **Phase shift**: There are two types of phase shift scanners one with alternating frequencies and other with alternating width. Both of them calculate the distance of the object's surface by measuring the difference between the phase of the emitted and reflected signals. Width modulation has the ability to distinguish between sharp discontinuities in shape the object whereas frequency modulation provides reliable measurements even when return energy is low. Phase shift systems have a maximum unambiguous range equal to a phase delay of one complete sine wave which limits the effective range of such systems.

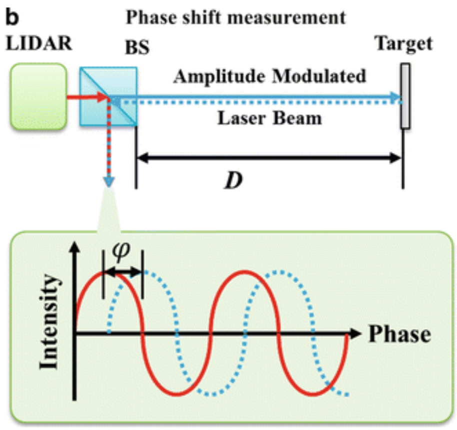


Figure 6. Concept of phase shift based laser scanning

3.3.2 Triangulation/Interferometry

This principle is used by most of the short-range scanners where a laser is emitted and returned ot a specific location on the CCD array of the onboard camera. These are generally equipped with a fringe projection system and a range of lenses. These help capture very fine detail scans of individual objects of size ranging upto a few metres. This require a professional lighting setup in order to capture accurate colour information.

3.3.3 Products

After a day in the field collecting TLS data, you will be able to produce highly accurate 3- dimensional, georeferenced point clouds of your field site and all specific targets involved that can be analyzed later in a lab. The digital photos that you took can also be merged with the point clouds to produce a 3-dimensional-photo-realistic point cloud. Below are some examples.

A B

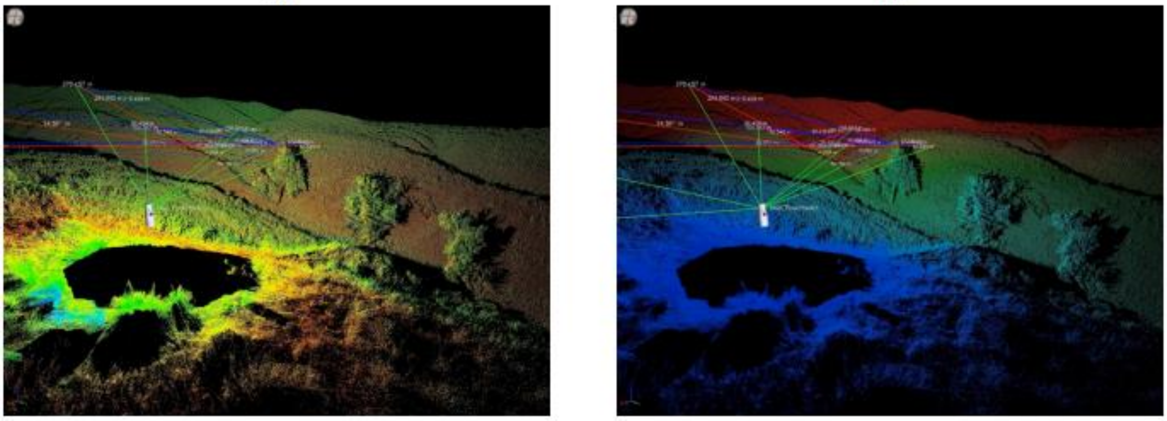


Figure 7. Product of Terrestrial laser scanning

3.3.4 Applications

In the past few years considerable attention has been received for the use of optical based range sensors for 3D documentation and modelling.(imaging & 2004, n.d). These instruments include laser scanners (phase-shift & triangulation) and strip projection based systems (Vosselmann & Maas, 2010)

Figure 8. Laser scanning using Interferrometry

Despite of the high costs and absence of fine textures, range sensors are gaining popularity in the heritage field as they directly provide range information in the scan results. During the surveying, the instrument should be able to see the object under different viewpoints; thus, it must be placed at various locations, or the object needs to be moved. To form a point cloud of the surveyed object, there is always a need to remove the errors like noise, holes before the registration of the data. The registration is generally performed using targets either manually or automatically. A finer alignment is done using iterative closest points or a least square method (Akca and Gruen, 2006).

Chapter 5

Geospatial Applications in Watershed Management for Rural Development Planning

Chapter 5- Geospatial application in Watershed Management for Rural Development Planning.

1. Introduction

Soil, water and vegetation are crucial natural resources for the existence of human being. There is tremendous pressure on the natural resources to meet the need of increasing population in the world. They are causing substantial problems to agricultures sustainability, livelihood opportunity and vulnerable communities. There is utmost need to conserve soil, water and vegetation. It was realized though watershed development programmes.

FAO has initiated watershed management projects since the late 1980s. learning the experience in implementing these projects, it advocated integrated and participatory mountains are very sensitive and maintain natural balance of its constituents are utmost important. watershed management programmes in the world. Understanding the special need and attention of watershed management programme aiming to concern fragile mountain ecosystem, FAO played a leading role in celebrating the observance of the International year of mountains (IYM) during 1998 to 2002. FAO implemented several project throughout the world on watershed management between 1990 to 2003. The broad objectives of the projects were to collect and disseminate the information generated by implementing watershed management projects and to support and guide in development of new generation projects by integrating hydrology and ecology, human ecology and environmental economic. Now the projects mainly focusing from a participatory to a collaborative approach as major shift.

2. Watershed Development in India

India initiated wasteland/degraded lands development programs in 1985. Govt. of India (GoI) identified development of land resources as major instrument for rural development and poverty alleviation. Therefore, three major projects as watershed programs were launched as (i) Integrated wasteland Development Program (ii) Drought Prone Areas Program and (iii) Desert Development Program. Later, these programs were brought under one umbrella and implemented as "Integrated Watershed Management Program (IWMP) from 2008. The aim of the IWMP was "to restore the ecological balances by harnessing, conserving and developing degraded natural resources such as soil, water and vegetation cover". It primarily envisaged reduction in soil run-off, rain-water harvesting, revival of natural vegetation and restoring of the ground water table. It helped in promoting multi-cropping, diverse agro-based activities that lead to sustainable livelihood to the people residing in the area of the watershed. In 2009, the IWMP project was converged with MGNREGS (Mahatma Gandhi National Rural Employment Guarantee Scheme) of Ministry of Rural Development of Govt. of India strengthen it further to support livelihood and employment of the rural people. Today, this IWMP program is being implemented as Prime Minister Krishi Sinchayee Yojna (Watershed Development Component) (WDC_PMKSY) since, 2014.

Watershed – a natural management unit: Watershed is most fundamental unit of soil and water conservation. Watershed is defined as a natural geo-hydrological unit, which collects water/runoff and drains to a common point or outlet. It is also being referred as catchment area or drainage basin. The ridges or hills, which act as a boundary between adjacent watersheds are the highest points within a watershed and are commonly referred as water divide lines/ridge lines. The common point or outlet to which the entire water drains may be a small stream, river, lake, dam, wetlands, estuary, sea or ocean. The watersheds could be as large as a major river basin (covering thousands of square kilometers) or as small as a farm micro watershed (covering few hectares), with the smaller watersheds always forming a part of the larger one.

Delineation of watershed is often done manually, which requires good capability of the staff and a lot time is spent to cover the large area. Now with the availability of high resolution of satellite data and GIS software it becomes quite easy and boundary are more reliable. It easy to interpret drainage lines of first and second order to delineate at larger scale. Watershed parameters such as relief ratio, stream length ratio, drainage density stream frequency etc. can be analysed using GIS. Watershed can be further sub-divided into sub-watershed and can be prioritized based on soil erosion severity. Watershed maps are also available on BHUVAN website for users.

3. Remote Sensing and GIS for thematic mapping

Remote Sensing (RS) data and Geographical Information System (GIS) play a rapidly increasing role in the field of watershed planning and management. One of the greatest advantages is its ability to generate thematic information and analyse these data in spatial and temporal domain. Watershed planning requires thematic information on soil, vegetation, land use / land cove, geology, geomorphology and terrain condition. Merged natural colour composites of Resourcesat-1 &2 in multispectral (5.8 m) and 1m in panchromatic mode with Cartosat-2 satellite data are available on BHUVAN website that can be used to prepare thematic information on that scale or smaller to the scale. Higher resolution satellite data provides more spatial variation. However, in selecting an appropriate resolution, the purpose for which the data is being generated must be considered.

Geospatial technology including the combined use of remote sensing (RS) data and Geographic Information System (GIS) platforms play a key role in hydrological modelling thus enabling us to study various stages and components of terrestrial water cycle in detail. Geospatial technology and its various components provide as well as helps in the generation of spatial information regarding terrain, geology, land use/land cover, soil, geomorphology, surface water bodies etc. GIS plays an important role in storage, manipulation as well as analysis of various spatial as well as non-spatial data thus enabling their integration into hydrological models and thus significantly enhancing their modelling capabilities.

3.1 Land use/ Land cover

In recent years, satellite remote sensing techniques have been developed, which have proved to be of immense value for preparing accurate land use / land cover maps and monitoring changes at regular intervals of time. A remote sensor records response which is based on many characteristics of the land surface, including natural and artificial cover. An interpreter uses the elements of tone, texture, pattern, shape, size, shadow, site and association to derive information about land use activities, which is also the basic information about land cover. Spatial distribution of land use/ land cover information and its changes is desirable for watershed development planning. One of the major advantages of remote sensing systems is their capability for repetitive coverage, which is necessary for change detection studies at various scales. Detection of changes in the land use/ land cover involves use of at least two period data sets. The changes in land use/ land cover due to natural and human activities can be observed using current and archived remotely sensed data. It is now possible to prepare up-to-date and accurate land use/ land cover map in less time, at lower cost and with better accuracy.

3.2 Soil Resources Inventory and Mapping

The information on soils with regard to their nature, physico-chemical characteristics and spatial distribution are of paramount importance in formulating any optimal land use plan. Indian Remote Sensing Satellite (IRS) data are being extensively used for soil resource-mapping purposes. The Standard False Color Composite (FCC), satellite imagery on 1:50,000 scale widely being used for soil resource inventory in semi-detail and reconnaissance survey. However, with the availability of high resolution PAN (5.8 m) and LISS III (23 m) data from IRS-1C/1D satellites and multispectral high resolution (LISS IV, 5.8 m) data from Resourcesat 1 &2 satellite, it is now possible to utilize these data for large-scale soil mapping, i.e. up to 1: 20,000 scale. Cartosat-1 and Cartosat-2 with spatial resolution of 2.5 m and 1m respectively are available today for mapping soils at large scale of 1:10,000 scale or larger suited for or micro level planning (village level. Standard soil surveys are normally carried out in different mapping levels e.g. Reconnaissance (1: 2, 50,000 scale); Semi-detailed (1: 50,000 scale) and Detailed (1: 20,000 or larger), depending on the requirement of the area.

Soil surveyor detects different soil formative environments through visual interpretation of geological maps, topographical maps and satellite images. The spatial extents of the soil formative environments are then used to delineate soil-landscape units known as physiographic units. Physiographic units / soil-landscape map units form the basis of soil mapping unit by establishing the relationships between these environmental conditions and the soil. Soil profiles were then studied in these physiographic units to characterize and classify the soils to prepare soil map.

3.3 Terrain analysis

Terrain attributes of watershed such as stream ordering, lengths, area, perimeter, slope and aspect etc. is required for planning. It is very difficult to compute all these parameters manually employing g traditional method. Use of DEM with GIS can not only make this task relatively easy but accurate as well. Digital Elevation Model (DEM) has become an inevitable component in most of the remote sensing applications viz. infrastructure development, watershed management and development, hydro-geomorphology, urban morphology, disaster management *etc*. DEM is defined as digital representation of the continuous variation of elevation over space. It is used to delineate watersheds, analyze channel networks, predict soil water content and predict erosion potential. Topographic attributes such as slope gradient, curvature, and upslope contributing area thematic maps are generated from DEM serves in the assessment of overland flow intensity and energy (Suresh Kumar *et. al*. 2008). Moreover, some combinations of these maps i.e. factors (hydrologic indices) can be used as indicators of drainage status, overland flow aggressiveness and erosion potential. Carto-DEM of the country is available to download from BHUVAN website.

3.4 Soil Erosion Risk Assessment

Assessing the soil erosion rate is essential for the development of adequate erosion prevention measures for sustainable management of land and water resources. The primary requirement of modelling is that the model input parameters be accurately quantified. Model input data can be obtained either directly from field measurements or derived from existing literature sources. Manual extraction of input parameters can be tedious and error-prone particularly with large watersheds and consequently, many researchers have sought means to automate the process. Most of these models need information related with soil type, land use, landform, climate and topography to estimate soil loss. Remote sensing data are used to generate model input parameters. Better description of these terrain parameters helps in predicting soil erosion with high accuracy. Revised Universal Soil Loss Equation (RUSLE) is most commonly used model to predict soil loss in various land use land cover types in the watershed. A case study has been disused to demonstrate preparation of thematic maps of the watershed and their integration to assess soil erosion risk area for conservation planning (Fig. 1) using remote sensing and GIS (Suresh Kumar *et. al.* 2006).

Soil erosion models can provide the exposure of various processes towards the climate change. For example, Gupta and Kumar (2017a) employed RUSLE model for identifying future climate change impact on soil erosion from a mid-Himalayan watershed. Also, using the CENTURY model, Gupta and Kumar (2017b) anticipated the influence of climate change on soil carbon sequestration in agro-ecosystems in the mid-Himalayan terrain. Similarly, Sooryamol et al. (2022) predict the future soil loss using SWAT model according to the projected rainfall amount in a lesser Himalayan watershed. Apart from this Singh et al. (2021) used WEPP model to model the surface runoff and sediment yield from a watershed of Himalayas. David Raj, et al. (2021) used the APEX model for predicting the land use-based surface runoff and sediment loss from the highly erosion vulnerable watershed of Shiwalik Himalaya and identified the scrubland as most vulnerable to erosion. Thus, the employment of empirical to process based model will provide more accurate assessment of the processes and functional relationships.

National Land Degradation (soil erosion) map was prepared by visual interpretation of satellite data considering terrain parameters (slope & aspect), land use land cover and by characterizing erosion features of past erosion (such as rills and gullies). It was taken up by the Department of Space along with partner institutions under National Natural Resources Census (NRC) at 1:50,000 scale by adopting uniform classification scheme.

4. Watershed Development Approach

It is an integrated and multi-disciplinary approach to suggest possible exploitation of resources within the limits of tolerance. Its prime objectives are to conservation of Soil and Water, improved ability of land to hold water, maintaining adequate vegetative cover for controlling soil erosion, rain water harvesting and ground water recharging. It provides benefits in promoting economic and social development of community, employment generation and other income generation and ecological balance. The watershed development plan can be grouped into largely two activities:

4.1 Land Resource Development Plan

Land resource development planning requires soil, land use / land cover, soil erosion risk and terrain information to assess land potential and to suggest suitable land use plan. In general, Land Capability Classification method is used to assess potential of the land. It is an interpretative grouping of soils based on inherent soil characteristics, external land features and environmental factors that limit the use of land. As per land capability classification, class 1 to class IV land is suited to agriculture. Classes V to

VII are not suitable for agriculture. These are used for pastures, forestry, wildlife and recreation purposes. Depending upon the degree of limitation and the kind of problems involved in management of soils, the land capability sub classes were also indicated to suggest suitable conservation measures.

4.2 Water Resource Development Plan

Water resource development plan includes in-situ water harvesting and check dams, significantly improve the water resource availability in the watershed. Check-dams are helpful in storing water for ground water recharge, which can be used for irrigation. Soil water conservation measures in agriculture land include (i). run off control structures: terraces (inward & outward), trenches, diversion channel (ii). vegetative field boundaries: bunds with grasses, shrubs, grass strips (iii). bush / tree (fuel & fodder) on field boundaries and (iv). gabion structure at gully head and in non-arable lands includes: Gully stabilization and stream Bank Protection.

The identification of suitable sites for these conservation measures are very important for successful implementation of watershed development planning. Thematic information derived from remote sensing (soil, land use / land cover, soil erosion severity etc.) and terrain information (slope, elevation, drainage pattern, drainage density etc.) derived from digital elevation model (DEM) can be very vital in this regard. GIS helps in integration of the information and derive information for planning.

5. Watershed Monitoring and Evaluation

Monitoring & Evaluation (M & E) of Watershed activities using Geospatial technology, under the Integrated Watershed Development Program (IWMP) of Department of Land Resources (DOLR), is facilitated through Bhuvan GeoICT tools by National Remote Sensing Centre (NRSC), ISRO. The package facilitates Decision makers at National and State level to monitor program implementation at different levels, including at the local level on the geoportal, while State Level Nodal Agencies (SLNA) and Watershed Cell Development Centres (WCDC) are facilitated with necessary tools on the package to provide specific inputs on implementation of the program at micro-watershed level. NRSC has designed, developed and deployed the Bhuvan GeoICT tools in the name of Srishti and Drishti for IWMP in the form of Geoportal to help the stakeholders in the effective implementation of the program.

Application of GIS, remote sensing and use of GPS for monitoring and evaluating watershed projects is a recent development. Monitoring and evaluation of progress of developmental activities in an expeditious manner for watershed management requires array of state-of-the-art of geo-spatial technologies. Fine resolution satellite data available from satellite sensors such as Panchromatic and LISS III/IV can be successfully utilized for observing water use patterns, changes in cropped area, improvement in permanent vegetation, cessation of land degradation etc. A Web based GIS application (Geoportal) enabling the monitoring and evaluation of IWMP watersheds, using satellite remote sensing and sample field data using mobile smart phone applications has been realised. This Geoportal facilitates M&E of all IWMP watersheds for 10 states and 50 special watersheds in 16 states.

Web based interface providing GIS service in terms of image coupled with thematic mapping as well as analysis is termed as **SRISHTI**, which connotes the entirety of Natural Resource Management envisaged through Watershed Management Concept. While the field information collecting mechanism executed through ANDROID based smart phone application is aptly termed as **DRISHTI**, which refers to the ability of view everything on the field situation and reporting it. Drishti images, collects, geo-codes, archives and relays field information in terms of photographs organised under specific implementation classes.

6. Watershed sustainability and Ecosystem Services

Commonly, watershed sustainability is quantified by the analysis of water resources and its quality. Health watershed supports many ecosystem services such as nutrient cycling, carbon storage, erosion/ sedimentation control, flood control, water storage, water quality, biodiversity, wild life movement, risk of invasion species etc. climate change may adversely affect and invite vulnerability and disruption to these services. These services are essential to social, environment and economic well-being. Achieving sustainability of watershed required involvement of formal and non-formal institutions, participation of people especially of local community for mutual reinforce of the activities of watershed management (David Raj et al., 2022).

Sustainability entails preserving natural resources for future generations while also allocating them fairly among present generations (WCED, 1987). Sustainable development, it was agreed, should not just encourage economic progress, but also promote equitable wealth distribution, prioritise environmental concerns, and empower individuals instead of just exclude them. The susceptibility of a watershed (soil erosion, hydrologic functions, species richness, habitat, and so on) must be assessed for soil resources and long-term sustainability. The spatial and temporal distribution of watershed processes which can generate the more critical source area or vulnerable area. The monitoring and identifying the vulnerable areas are very much necessitated for attaining the sustainability. The implementation of the conservation and mitigation measures is only possible after the proper understanding of the vulnerability. Hence, the vulnerable watershed can be transformed into sustainable by proper vulnerability analysis and measures.

7. Conclusions

Remote sensing and GIS provide promising tools for preparing thematic maps of natural resources at desired scale for watershed development planning. Remote sensing and other ancillary information can be obtained from ISRO-BHUVAN portal. RS and GIS enable us to extract information on soils, land use / land cover, geomorphology and terrain parameters. The thematic maps are used to derive soil erosion factors maps. These factor maps serve as spatial input to the soil erosion models. Employing erosion models in GIS environment allows the prediction of erosion. GIS has distinct advantages in identifying the suitable sites for various conservation measures within a watershed. A Web based GIS application (Geoportal) enabling the monitoring and evaluation of IWMP watersheds, using satellite remote sensing and sample field data using mobile smart phone applications has been realised. These results on watershed in GIS platform help in better decision support to the development agencies and government for planning of rural development. Geospatial technologies support in proper planning and in decisions for sustainable agricultural development.

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Chapter 6

Geospatial Applications for Agricultural Drought Assessment and Food security

1. Introduction

The need for addressing World's food security in coming decades and the present century is critical and urgent. However, for this to happen, one of the primary requirements will be to have an advanced geospatial information system. Such a system should be global, consistent across nations and regions, and in the least, provide such critical information as: (a) crop types, (b) precise location of crops, (c) cropping intensities (e.g., single crop, double crop), (d) cropping calendar, (e) crop health\vigor, (f) watering methods (e.g., irrigated, supplemental irrigated, rainfed), (g) flood and drought information, (h) water use assessments, and (g) yield or productivity (expressed per unit of land and\or unit of water). Possibility of such system can be set-up at global level through geo-spatial integration of information from various sources e.g. advanced remote sensing (e.g., fusion of Landsat, Resourcesat, MODIS) in combination with national statistics, meteorology & ancillary data (e.g., elevation, precipitation, temperature), and field level ground observations data. There is a substantial progress in this effort in last few years. A comprehensive remote sensing based global agricultural monitoring system has been realized by Group on Earth Observation Global Agriculture Monitoring Project (GEOGLAM)—a joint effort of NASA, USDA, UMD and SDSU. This system presents remote sensing data, derived products, and analysis tools of GLAM for agricultural crop-condition monitoring and production assessment at global level (Becker-Reshef et al., 2010). GEOGLAM aims to provide timely forecasts of crop production and early warnings of potentially significant harvest shortfalls on a national, regional, and international basis.

Agriculture in developing countries like India is often an information-poor sector of the economy. The generation and use of relevant, timely and accurate information in this sector is quite complex and challenging. The products emanating from remote sensing are nothing but 'information' with certain levels of quality, coverage and timeliness. With these backdrops in India, some of the key remote sensing applications in agriculture demonstrate how if it is used strategically in well-knit institutional framework could help in crucial policy decisions especially in food security context. India exemplifies a variety of remote sensing enabled products and services, which have formed the basis to enhance the information base in agriculture and to facilitate well-informed decision making processes with regards to food security issues. Present day satellite systems can support food security issue for supplying information and services through village resource centres, distance education, communications on crop mapping, crop monitoring, production forecasting, early warning & crop-insurance (pests/disease, drought and extreme events) and weather and climate observation etc.

1.1 Advantages of remote sensing based agricultural resource survey over traditional survey

- The potential for accelerated survey;
- Capability to achieve synoptic view under relatively uniform illumination conditions;
- Availability of multi-spectral data providing increased information;
- Capability of repetitive coverage to depict seasonal and long term changes;
- Permitting direct measurement of several important agro-physical parameters which are used in crop growth assessment and yield prediction;
- Relatively inexpensive - monitoring from space;
- Remotely sensed data provide a permanent record.

2. Crop Acreage Estimation

Crop discrimination is based on differential spectral response of various crops in a multi-dimensional feature space produced by different spectral bands, or time domain or both. The crop acreage estimation procedure broadly consists of: i) complete enumeration, and ii) or sample segment approach. All these approaches use current season's ground truth data and supervised classification algorithm(s) on digital image processing system. In the complete enumeration approach (for small study area), the study area (Blocks, or district boundary is super-imposed on the satellite data and all the pixels within this boundary are analysed. Estimation of crop acreage for large areas requires handling of a very large volume of data, larger efforts in ground truth data collection. To overcome this problem, stratification sampling technique sample segment based procedures have been developed under CAPE. The stratification is done using GIS, based on Crop concentration statistics, agro-physical and/or agro-climatic. Each stratum is divided into number of segments of 5 x 5 km, 7.5 x 7.5 km or 10 x 10 km size depending on field sizes and number of crops grown in each stratum. 10% of the segments in each stratum, selected randomly is digitally processed to estimate crop acreage per segment. These segment-wise estimates are aggregated at each stratum and finally at state level. A large of variables such as choice of spectral bands, spatial and radiometric resolution of the sensor, acquisition date of satellite data, and image classification techniques, influence the results of crop identification using RS data.

The satellite based studies on crop inventory graduated from visual to digital analysis and by launch of IRS-1A (Indian Remote Sensing Satellite) in 1988, large crop inventory project called CAPE (Crop Acreage and Production Estimation) sponsored by Ministry of Agriculture, was implemented covering large area crop acreage, yield prediction and condition assessment for important crops such as wheat, rice, cotton, groundnut, mustard and sorghum (Anonymous, 1995). The two major objectives of CAPE project were: (i) to develop methodology for state level acreage and production estimation of important crops and (ii) to transfer technology to state level agencies for its operational applications. Under CAPE mainly IRS-1A, 1B, 1C & 1D LISS-I, II & III digital data were being used for district and state levels acreage estimation of dominant crop growing state (Table 1). The CAPE procedure is being continuously revised and upgraded to improve upon accuracy and timeliness of crop estimates. These efforts are related to improving sample design; ground truth data collection; optimizing date of acquisition; including data from additional spectral regions in the digital analysis; use of higher spatial resolution satellite data; use of microwave data for crop inventory in Kharif (rainy) season; adopting different classification procedures.

Table 2. Study crops, areas and geographic area coverage in Crop Acreage and Production Estimation (CAPE) Project Phase I and II.

Crops	**Phase –I**		**Phase -II**	
	State* (No. of districts; F = Full)	**Geographica lArea (Sq.Km)**	**State* (No. of districts; F = Full)**	**Geographical Area (Sq.Km)**
Wheat	HARyana (F), PUNjab (F), Madhya Pradesh (8), RAJasthan (8), Uttar Pradesh (24)	352582	HAR (F), PUN (F), MP (32), RAJ (17), UP (F), BIHar (27), Himachal Pradesh (5)	1068692

Crops	Phase –I		Phase -II	
	State* (No. of districts; F = Full)	**GeographicalArea (Sq.Km)**	**State* (No. of districts; F = Full)**	**Geographical Area (Sq.Km)**
Rice	ORIssa (F), Tamil Nadu (F)	285469	ORI (F), TN (F), Andhra Pradesh (12), ASSam (F), BIH (F), HAR (9) KARnataka (12), MP (17), PUN (F), UP (39), West Bengal (F)	1339770
Sorghum (R)	MAHarashtra (3)	47696	MAH (6), KAR (7), AP (5)	339006
Mustard	GUJarat (2), MP (1), RAJ (6), UP (2)	128822	UP (8), ASS (10), HAR (5), PUN (3), WB (9)	272107
Ground nut (K)	GUJ (2)	28570	GUJ (6), AP (7), KAR (6), MAH (5), TN (11)	364603
Cotton	AP (3), GUJ (1), HAR (2), MP (2), MAH (6), PUN (4)	176039	AP (7), GUJ (8), HAR (3), KAR (5), MP (4), MAH (12), ORI (1), PUN (5), RAJ (2), TN (5), UP (1)	512354
TOTAL		**1019178**		**3896532**

3. Crop Production Forecasting: FASAL

In 1998, country lost heavily by taking a late decision about wheat import. It was felt that the ountry should have the capability for in-season multiple crop forecasting system, which could provide advance information on the possible shortfalls, if any, in production of major crops, and the systems must be objective and scientific. The Ministry of Agriculture, Govt of India used CAPE experiences to develop Forecasting Agricultural Output using Space Agrometeorology and Land-based Observations (FASAL). FASAL aims at (a) Institutionalizing the operational use of RS data for diverse applications in agriculture, (b) Developing a system for multiple in-season crop assessment and forecasting in near real-time, and (c) Integrated use of tools such as GIS, large databases, modelling and networking. FASAL enables crop forecast by integrating econometrics, agrometeorology and land-based observations (Fig. 1), FASAL captures even the unforeseen minor impacts of unusual high temperatures during harvesting period of the crop; revises the forecast accordingly; and highlights the areas from where shortfalls are expected. Mid-season assessments can be supplemented with multi-temporal coarse resolution data based analysis. In the latter half of crop growth period, direct contribution of remote sensing in form of acreage estimates and yield forecasts is available. However, in this case also, the addition of more extensive field information and weather inputs would increase the forecast accuracy (Dadhwal et al., 2002). The advantage lies in timelines, as FASAL forecasts are one-month in advance (before harvest of the crop). Components of FASAL have been developed and tested for making multiple in-season crop acreage and production forecasts (Parihar and Oza, 2006).

Crop production forecasting activities has been a regular practice to provide information on acreage and production of major crops (kharif rice, rabi rice, wheat, jute, potato, mustard) and at district level (wheat, cotton, mustard, sorghum, sugarcane), in the country. The methodology includes analyses of Remote sensing data acquired during crop season using limited field observations for crop identification and use of stratified random sampling (5*5 km land area) with 15-20% sample size of population for acreage estimation. Spectral-yield model, Agromet model, time trend and crop simulation models are used for crop yield prediction. Similarly like FASAL, both developing and developed countries have emphasized the need of early warning system for advance know-how on any short-fall in crop output during growing season and subsequently support food security. Some of the examples listed as:

Early Warning Systems

- FEWS Net - USAID Famine Early Warning System
- GIEWS - FAO Global Information and Early Warning System
- VAM - WFP Vulnerability Analysis and Mapping
- MARS FOOD – Monitoring Agriculture with Remote Sensing (EC/JRC)
- EARS-EWBS: Environmental Analysis and Remote Sensing-Energy and water balance system
- SADC - Regional Early Warning System for Food Security
- USDA - Production Estimate and Crop Assessment Division (PECAD)

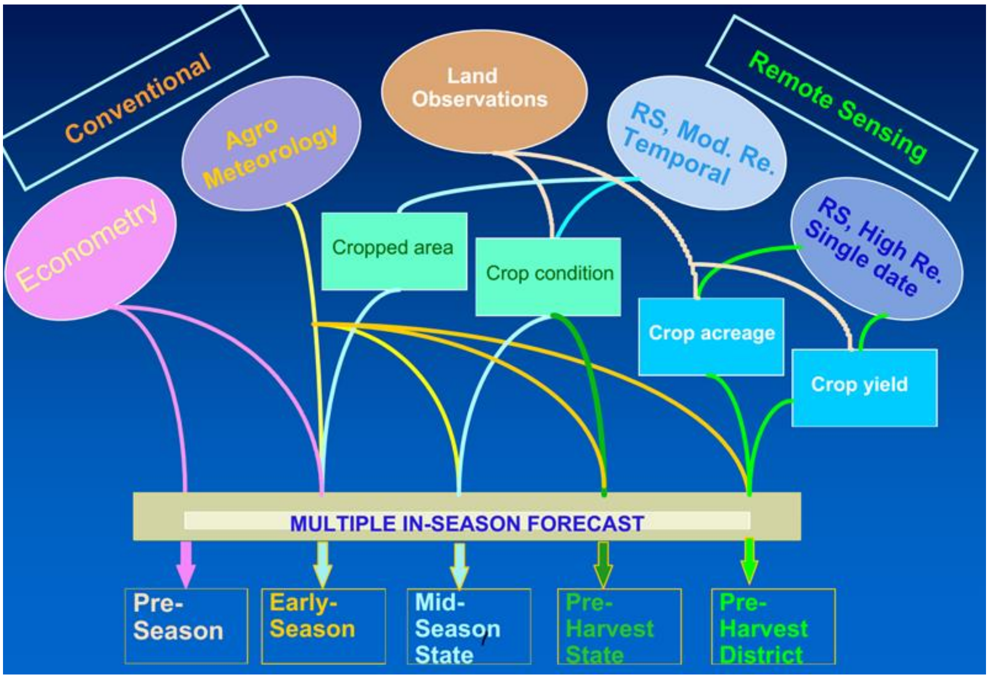

Figure 1. Conceptual diagram of forecasting agricultural output using space, agro-meteorology and land-based observations (FASAL)

4. Geospatial Technology for Drought Management

Remote Sensing technology in its current state of art can help in predicting, mitigating and monitoring all the five different types of drought. Data from various satellites can be utilized for the purpose depending on the perspective that a researcher has towards drought, whether it is agricultural, meteorological, hydrological, socio-economic or ecological. It enables to understand the manifestations of drought in a larger area more directly than the conventional methods, which used to utilize indirect methods for assessing the various impacts of drought. Drought monitoring mechanisms exist in most of the countries that use ground based information on drought related parameters such as rainfall, weather, crop conditions and water availability. Earth observations from satellites are highly complementary to those collected by in-situ systems. Satellites are often necessary for the provision of synoptic, wide-area coverage and provision of the frequent information required putting in-situ information into broader spatial monitoring of drought conditions. Geospatial technology enables two fundamental requisites for reinforcing drought mitigation and preparedness in the long term are: i) an accurate drought risk assessment quantifying the degree of hazard and the vulnerability of the different regions; and ii) real-time information concerns the development of drought conditions and providing forecasts of the likely evolution of the drought. Conventional drought indicators may assimilate information on rainfall, stored soil moisture, or water supply, typically they do not express much local spatial detail. The nature of sparse ground observations and delay in data availability make it difficult to assess near-real time and spatially representative drought conditions. New geospatial information are available from various sources (e.g. satellite, measurement network, resource inventory and land records and crop census) to determine the risk and vulnerability of a system to a drought and to develop monitoring and early warning systems based on real-time information to support decision making.

4.1 National Agricultural Drought Assessment & Monitoring System (NADAMS)

In India, operational agricultural drought assessment using remote sensing data is carried under a major programme called National Agricultural Drought Assessment & Monitoring System (NADAMS). NADAMS project, developed by National Remote Sensing Centre, provides near real-time information on prevalence, severity level and persistence of agricultural drought at state/ district/sub-district level (Murthy & Sesha Sai, 2011). Currently, it covers 13 states of India (Andhra Pradesh, Bihar, Chattisgarh, Gujarat, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, and Uttar Pradesh), which are predominantly agriculture based and prone to drought situation. In four states (Andhra Pradesh, Karnataka, Haryana and Maharashtra), the assessment is carried out at subdistrict level. The remote sensing data of NOAA AVHRR (for district level), MODIS and Resourcesat-2 Advanced Wide Field Sensor, AWiFS (for sub-district level) along with rainfall data are used for drought assessment. Various spectral indices, such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) & Shortwave Angle Slope Index (SASI) are computed and integrated with Soil Moisture Index and District Level Rainfall to assess the drought condition. Agricultural conditions are monitored at state/district level using daily NOAA AVHRR/ MODIS data. Fortnightly/monthly report of drought condition is provided to all the concerned central and state government agencies under NADAMS. MNCFC has started providing periodic Drought Assessment Reports from the Kharif season of 2012 (Ray et al., 2014).

4.2 Drought Monitoring by Satellite Remote Sensing

Satellite remote offers potential advantage of providing timely and spatially continuous data for monitoring drought-impacted vegetation condition. Since 1981, Advanced Very High Resolution Radiometer (AVHRR) sensor on board NOAA routinely provides information about terrestrial vegetation condition over the globe (Tucker, 1986). The normalized difference vegetation index (NDVI), calculated as numerical transform of visible and near-infrared reluctances derived from AVHRR has been widely used to monitor terrestrial vegetation stress, biomass and predicts crop yields. The NDVI was introduced by Rouse et al. (1974) and can be obtained using near-infrared (NIR) and red channels as (ρNIR−ρRED)/(ρNIR+ρRED), where ρ represents the spectral reflectance.

4.2.1Vegetation Condition Index (VCI)

It was first suggested by Kogan (1997) and subsequently used elsewhere (Thenkabail et al.2004). VCI is an indicator of the status of the vegetation cover as a function of the NDVI minimum and maxima encountered for a given ecosystem over many years. VCI is defined as:

$$VCI_j = (NDVI_j - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) * 100$$

Where, $NDVI_{max}$ $NDVI_{min}$ is calculated from long-term record for a particular month and j is the index of the current month. The condition of the ground vegetation presented by VCI is measured in percent. The VCI values between 50% to 100% indicate optimal or above normal conditions whereas VCI values close to zero percent reflects an extreme dry month.VCI has been used by (Kogan and Unganani,1998) for estimation of corn yield in South Africa and drought monitoring over India (Singh et al.2002). VCI captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas. Also, VCI values indicate how much the vegetation has advanced or deteriorated in response to weather. It was concluded from the above studies that VCI has provided an assessment of spatial characteristics of drought, as well as its duration and severity and were in good agreement with precipitation patterns.

4.2.2Temperature Condition Index (TCI)

The TCI was also suggested by Kogan (1997). It was developed to reflect vegetation response to temperature i.e. higher the temperature the more extreme the drought. TCI is based on brightness temperature and represents the deviation of the current month's value from the recorded maximum. TCI is defined as:

$$TCI_j = (BT_{max} - BT_j) / (BT_{max} - BT_{min}) * 100$$

where, BT is brightness temperature. Maximum and minimum BT values are calculated from the long-term record of remote sensing images for a particular period j. low TCI values indicate very hot weather. TCI has been used for drought monitoring in the USA, China, Zimbabwe and the Former Soviet Union. A study in Argentina for drought detection revealed that TCI was useful to assess the spatial characteristics, the duration and severity of droughts, and were in good agreement in precipitation patterns. TCI has been related to recent regional scale drought patterns in South Africa. (Kogan, 1998) and India (Singh and Kogan, 2002).

By integrating VCI and TCI for particular period, vegetation health (VT) is formulated as (Figure 2)

$$VT = a*VCI + b*TCI$$

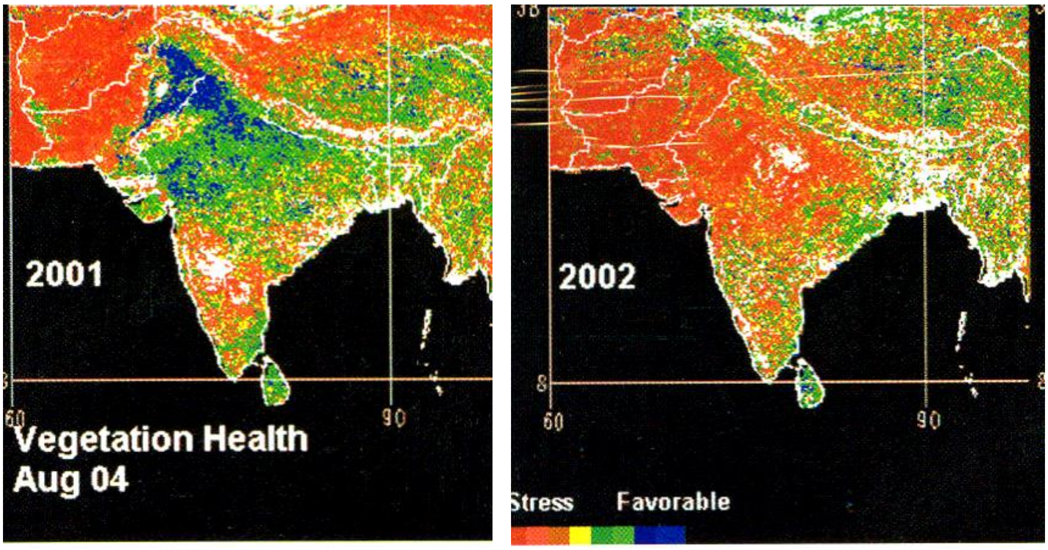

Figure 2. VT image of non-drought year-2001 and VT image of drought year-2002 (Source: Singh & Roy et al., 2003)

4.2.3Remotely Sensed Indices Based on VI-Ts Triangle

The most commonly used Normalized Difference Vegetation Index (NDVI) from remote sensing often fall short in real time drought monitoring (Patel et al., 2009). Due to a lagged vegetation response to drought, NDVI cannot detect drought events instantaneously. On the other hand, surface temperature (Ts) is sensitive to water stress and has been identified as good indicator of water stress. Thus, accurate and real time drought monitoring needs combination of the thermal and visible/near infrared wavelength to provide information on vegetation and moisture condition simultaneously. The scatter plot of remotely sensed temperature and spectral vegetation index often exhibits a triangular or trapezoidal (Moran *et al.*1994) shape and is called the Ts-NDVI space if a full range of fractional vegetation cover and soil moisture content is represented. Recently, this Ts-NDVI space has been widely exploited to derive various types of hydrological information such as air temperature, evapotranspiration and soil moisture (Patel et al., 2009). Drought stress effects on agriculture are closely linked to actual evapotranspiration by crop canopies throughout the growth period. Therefore, drought index which is closely related to crop water status holds a key place in drought monitoring. Recently, many drought indices like Temperature-Vegetation Dryness Index (TVDI), Vegetation Temperature Condition Index (VTCI), Water Deficit Index (WDI), and the Crop Water Stress Index (CWSI) have been defined for quantification and real-time monitoring of the spatial extent and magnitude of drought

The VTCI index has been used to monitor the drought occurrences in 8 days composite basis in Gujarat (Patel et al., 2012). Mathematically it can be written as,

$$VTCI = \frac{LST_{NDVIi\max} - LST_{NDVIi}}{LST_{NDVIi\max} - LST_{NDVIi\min}}$$

where $LST_{NDVIimax} = a + b\ NDVIi$

$LST_{NDVIimin} = a' + b'\ NDVIi$

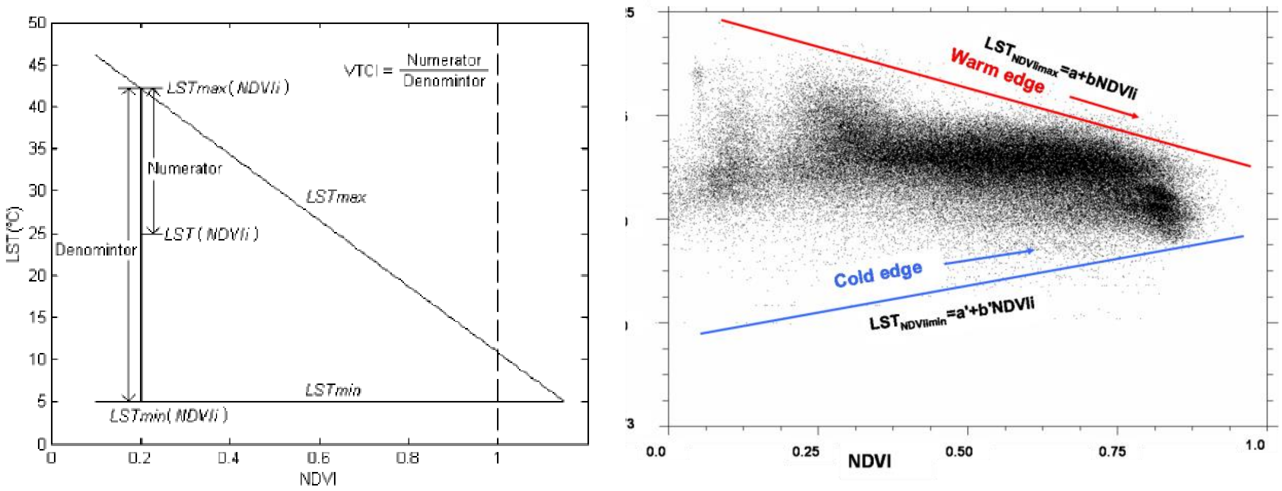

Figure 3. Parameterization of $LST_{NDVImax}$ and $LST_{NDVImin}$ from LST/NDVI triangle

The $LST_{NDVIimax}$ and $LST_{NDVIimin}$ are maximum and minimum LSTs of pixels, which have same NDVI value in a study region on each ith date or period of image, respectively, and LST_{NDVIi} denotes actual LST of one pixels whose NDVI value is NDVIi (Fig. 3). The shape of the scatter plot is normally triangular at a regional scale (Gillies, 1997) and (Wang, 2001), provided the study area is large enough to provide a wide range of NDVI and surface moisture conditions, where in $LST_{NDVImax}$ and $LST_{NDVImin}$ represents "warm edge" (no water limitation) and "cold edge" (water stress restriction). The value of VTCI ranges from 0 to 1. In general, the lower the value of VTCI, the higher the magnitude of drought stress. This index was found to have positive relationship with crop moisture index. It was observed that the VTCI is an ideal index to monitor agricultural drought because it is highly sensitive to short-term changes in crop moisture status in terms of CMI. Besides this, the VTCI was found to be related crop yield anomalies occurs due to drought conditions. Furthermore, interpretation of drought duration from time series of VTCI can clearly depicts severity of drought stress effects on crop performance (Fig. 4). The major advantage of VTCI is that it can captures information about drought stress condition solely on satellite measurements. However, this index has limited applicability in presence of cloudy condition since surface temperature is highly sensitive to cloud cover.

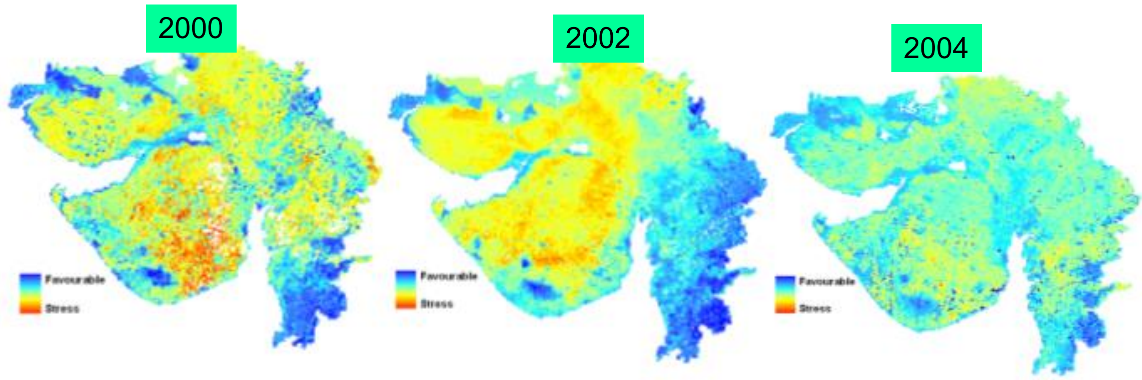

Figure 3. Spatial pattern of VTCI on 242-249 Julian day period

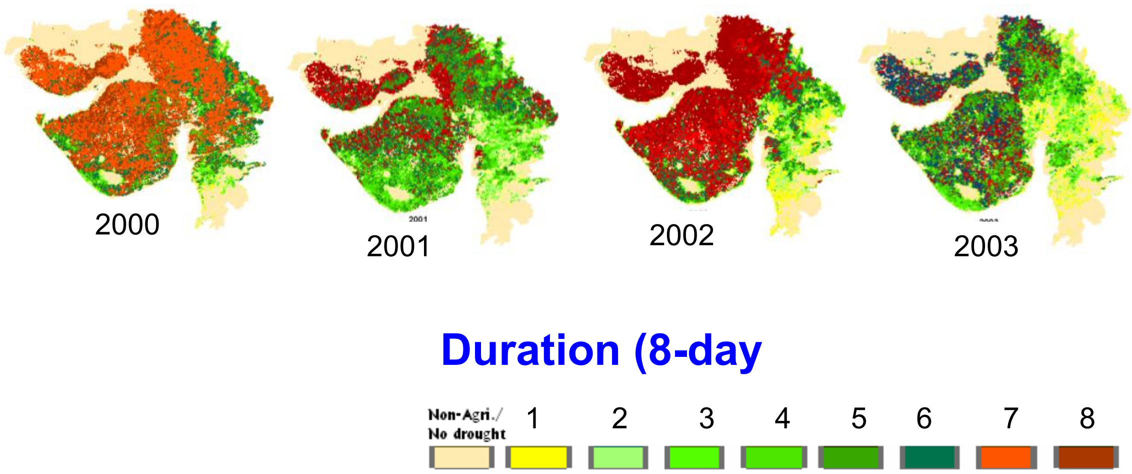

Figure 4. Spatial pattern of drought duration based on VTCI in Gujarat (Patel et al., 2012)

4.3 Drought risk zonation using geoinformatics

The integration of remote sensing, geo-computation and geographic information techniques helps overcome the problem of lack of ground truth data to provide a method for quick spatial drought assessment. Drought risk methodology forms the basis for estimating the spatial extent of the area of drought risk, thus making possible assessment of various drought management alternatives. The remote-sensing based method for identification of drought prone areas (Jeyaseelan *et al.*, 2002) uses historical vegetation index data derived from NOAA satellite series and provides spatial information on drought prone area depending on the trend in vegetation development, frequency of low development and their standard deviations. Drought risk can be better addressed by integration of spatial information on adaptive capacity of a region e.g. irrigation potential, soil moisture storage capacity and cropping pattern practiced with satellite derived vegetation stress indicators and meteorological drought indices. As of now, weighting and ranking method following multi-criteria applied to various drought severity classes of each drought risk type viz., meteorological drought risk, agricultural drought risk and hydrological is common way of geo-informatics application. Various case studies were attempted to map agricultural drought hazard from frequency occurrence of drought severity derived based on NDVI anomaly. When agricultural drought hazard integrated in GIS environment with meteorological drought risk (based on either probability occurrence of meteorological drought based on either rainfall departure or standardized precipitation index) can lead to generation of composite drought risk (Fig. 5).

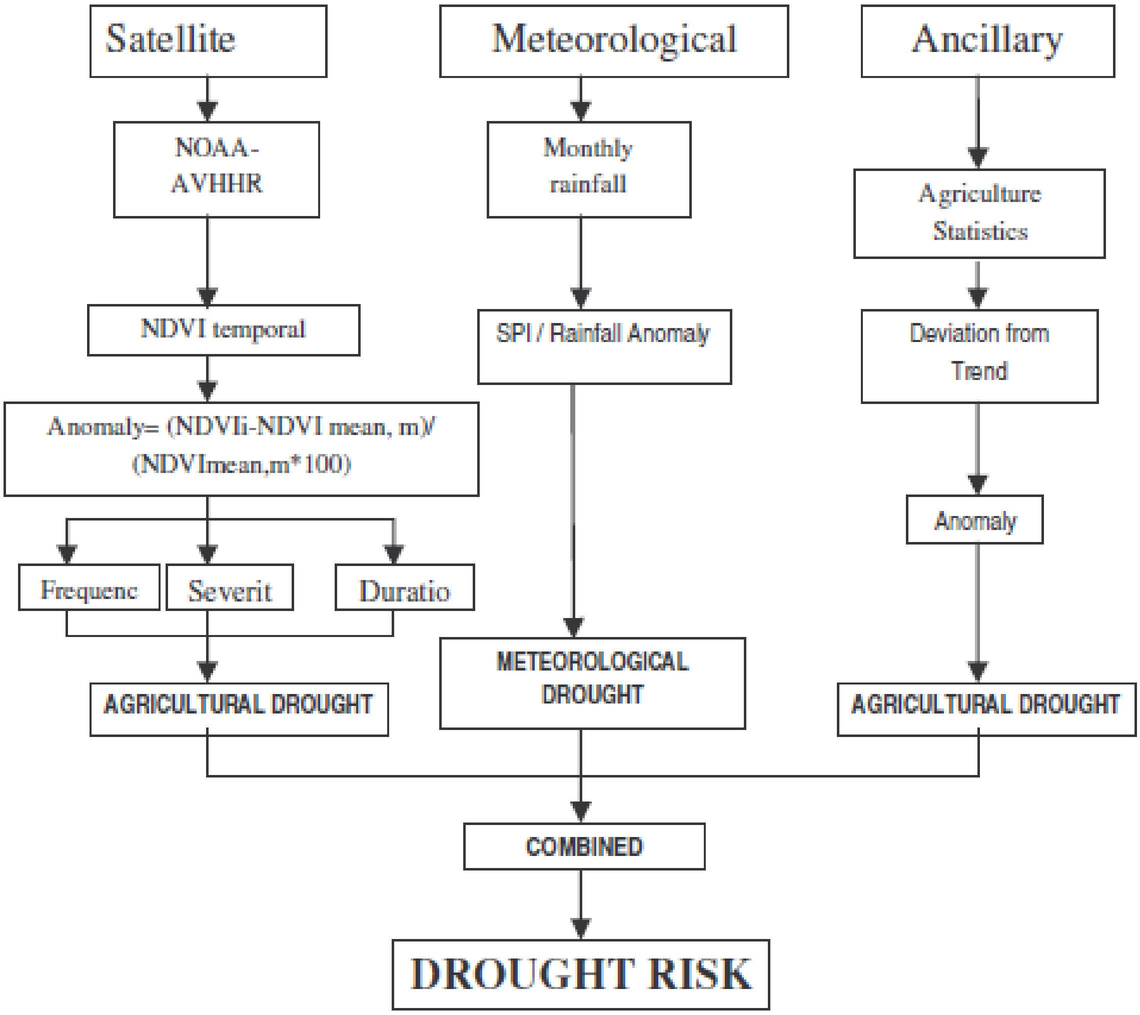

Figure 5. Drought risk zonation based on RS, rainfall and ancillary data

4.4 Drought Prediction

At present, drought forecasting can be fully embedded in the seasonal forecasting provided by Global Climate Models (GCMs). The European Centre for Medium-Range Weather Forecasts (ECMWF), an independent organization supported by 31 states across Europe, has extended the model's predictions to other regions of the world. Now, the European centre maintains a seasonal forecast up to four months lead in time.. The prediction is based on an ensemble of GCMs, which provides a reasonable prediction for large scale drought warning. Thus, an ensemble mean and associated probabilities associated with temperature, precipitation and other climatic variables which make computing drought indicators possible (http://www.ecmwf.int/products/forecasts/d/charts/)

The quality of seasonal predictions of temperature and precipitation anomalies by various centres such as the National Climate Research Centre (NCRC) of United States, the European Centre for Medium Range Weather Forecasts (ECMWF), the India Meteorological Department (IMD), the National Centre for Medium Range Weather Forecast of India (NCMRWF) is a function of the quality and amount of satellite data assimilated into the starting fields (e.g., SST from AVHRR and profiles from TOVS on NOAA satellites, ERS-2 scatterometer winds, SSM/I on DMSP satellites and all geostationary weather satellites: Geostationary Operational Environmental Satellites (GOES), i.e. GOES-East, GOES-West of USA, METeorological SATellite (METEOSAT) of Europe, Geostationary Meteorological Satellites (GMS) of Japan, Indian National Satellites (INSAT) of India etc.).

Empirically based methods for drought forecasting have been developed based on the current values of drought indicators, the historical frequency of rains and some external factors as predictors. One of the common predictor is El Nino Southern Oscillation (ENSO) as it is good indicator of inter-annual climate variability. A strong relationship between ENSO and the Asian monsoon was established in past decades. In India, few studies have also demonstrated ENSO linkages with summer monsoon rainfall (Mohanty and Ramesh 1993), vegetation patterns and food grain production (Parthasarathy et al., 1992) at country level. Furthermore, on smaller regional scale, ENSO activity and their linkage with satellite NDVI anomaly and rainfall established (Patel et al., 2006). This study showed that there is a clear association between ENSO warm and cold phase events and inter-annual fluctuations in seasonal (*kharif)* NDVI and rainfall in arid - semi arid region of India (Gujarat). Warm phase events were associated with negative anomaly in NDVI and rainfall, except in 1997 ENSO warm event which have positive anomaly. While cold phase events were in general led to an increase vegetation and rainfall activity.

4.5 Technological Developments for Decision Support on Drought

4.5.1 Agricultural Drought Monitoring through Exploitation of Satellite Derived Soil Moisture

The full potential of state-of-the-art satellite-derived soil moisture measurements from space-based microwave sensors needs to be exploited for agricultural drought monitoring It indicates plant water deficiencies earlier than conventional products estimating the vegetation status such as the Normalized Difference Vegetation Index. Although space-based microwave sensors is limited to a few centimeters, it is possible to estimate the soil moisture conditions in the root zone. Radar measurements are carried out independent from weather conditions and sunlight. Afterwards, they can either be used directly as an input for drought indicators or incorporated into advanced models via data assimilation. Soil moisture information available are freely and in near –real time from various sensors on board satellite from various agencies (e.g. ASCAT, AMSR-E, SMOS etc).

4.5.2 Long-term Weather Forecasts and its Integration with Satellite Information

The weather forecast information can be integrated with satellite-derived information (soil moisture, ET) and crop models for improved decision making and drought risk reduction. In addition to large scale picture of present crop state and conditions, decision-makers require estimates of future conditions, preferably over the duration of a season. Forecasts on seasonal scale are often generated by dynamic or statistical down scaling of GCM outputs. Once the outputs of forecasting models are calibrated to regional conditions, seasonal predictions can then provide an added-value. Seasonal forecasts (e. g. of rainfall) are usually based on a multitude of model outputs that ideally agree on a future trend. The retrospective analysis of forecasts, so-called “hindcasts”, can help to identify their performance with respect to past drought events. If the forecast of one variable shows an added-value compared to its historic trend, it can potentially be considered as the input for an operational decision-support system.

Since seasonal forecasts for rainfall, temperature or soil moisture are available from different centers around the world, the strong vegetation and rainfall relationship could allow estimation of future vegetation based on rainfall or standardized precipitation index or actual soil moisture predictions.

4.5.3 Mobile Applications

The integration of non-environmental information via smartphones could help to reduced drought risk and finally food insecurity. The mobile applications can directly link end users to drought-relevant information. On one hand, local farmers and aid organizations need to be able to understand and access all the above-mentioned information. On the other hand, these people are indispensable for validating satellite-derived drought indicators (e.g. GPS-tagged pictures of crops and its stages, or to collect information about socio-economic condition). One example of such mobile application is “crowd-sourcing”. Now-a-days crowd-sourcing has become versatile applications for damage assessment due to landslides or cyclone. Recently, through crow-sourcing , in a couple of days informations on landslide affected villages in Kedarnath and crop damage due to HudHud cyclone in Andhra Pradesh being gathered for rescue and relief management.

A smartphone application that concentrates on food security could help to complement traditional in-depth household assessments with more frequent monitoring of food prices, the availability of fertilizers and drought-resistant seeds. It could help to gather vital information about access to potable water, the level of malnutrition, the current prevalence of diseases or even incorporate local knowledge about recurring events.

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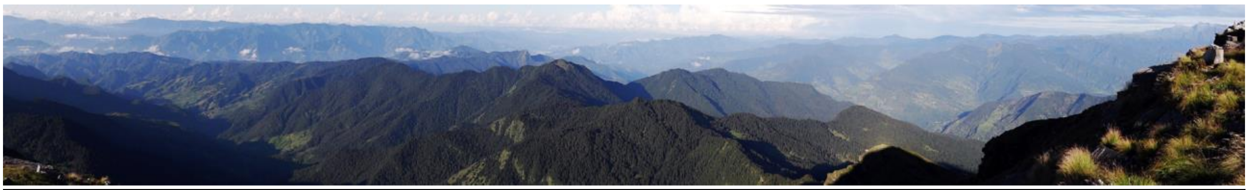
Chapter 7

Geospatial Applications in Forestry, Ecology and Environment Security



Chapter 7- Geospatial Applications in Forestry, Ecology and Environment Security

1. Introduction

The forestry sector in India plays a key role in maintaining the ecological balance along with meeting the direct needs of a large rural human and livestock population in the country. The development aspirations of the growing population and the additional pressure of climate change have called for the improvement of scientific and technical management of forests. India is among the leading countries in harnessing space technologies for periodic monitoring of forests. India has 12 per cent of global plant and animal wealth and much of it is possessed by the forests. Forest cover in India has fairly stabilized after early eighties because of the strict legislative control on the use of forestland for non-forestry purposes. Remote sensing has played a role in checking deforestation and degradation by multiple factors by supporting effective implementation of forest protection laws. The diversion of forestland for various developmental purposes with prior approval from Government of India, however, still continues. Forest degradation is a major issue currently.

The conventional methods of forest resources assessment and monitoring are time consuming and fraught with various inadequacies. Many a times they do not match with the forest dynamism and hence, become obsolete by the time the results are available. The reliability of the results obtained through such methods is often considerably less. The remote sensing, GIS and GPS technologies have positively impacted the process of forest resource assessment, monitoring and management. Remote sensing has greatly reduced the tedious groundwork in addition to bringing higher accuracy. It is perhaps the only of its kind tool, which allows retrospective monitoring of the forests. Forest management is a multi-faceted activity involving forest change monitoring, forest fire prevention and monitoring, biodiversity assessment, protected area management, terrestrial biomass/carbon assessment, eco-development planning, forest damage detection and forest development planning.

In view of the immense possibilities of geospatial technologies in forest management, its extensive use has been emphasized in the current forest management plans (e.g. Forest Working Plans). India's national forest monitoring system executed by Forest Survey of India (FSI) is expanding through advanced and innovative forest applications of remote sensing and geoinformatics techniques. The Indian space program has been the backbone in providing a continuous supply of remote sensing data to the National Forest Monitoring System, demonstration of technical methods and sharing of expertise. India's future satellite projects include missions like NISAR, TRISNA, High Resolution Sampler, Advanced LISS etc. to address the challenges of better monitoring of forests. In this article, an attempt is made to share the progress and emerging applications of Remote Sensing and Geonformatics in the field of forestry with the participants of Decision Makers Course in a concise manner.

2. Forest Cover Change Monitoring

The temporal aerial photographs and satellite image interpretation facilitates forest change detection and monitoring over time. This was demonstrated by National Remote Sensing Agency (1983) using Landsat MSS data when entire country was mapped on 1:1M scale for two periods i.e. 1972-75 and 1980-82 using visual interpretation. This was the first-ever nationwide mapping involving satellite imagery by ISRO/DOS or forestry sector. The technology has been used by Forest Survey of India since then for biennial forest monitoring and change detection. Knowing the changes in the cover and density of forests in India from satellite data provided by FSI, this information helps in making policies and plans for the management of forests at the national and state levels.

Under the Natural Resource Census program of ISRO, regular monitoring of forest cover along with changes in land use outside forests is being done at five year intervals using Indian remote sensing satellite data. With increasing pressure on forests, there is a need to monitor forest cover on a finer scale and at shorter intervals, especially in areas with chronic problems of encroachment and clear-cutting. Very high resolution satellite image from online portals (ISRO Bhuvan, GoogleEarth) are already used in rapid assessment of forest status and performance evaluation of plantation programs (e.g. e-Green Watch by FSI). IIRS has developed techniques for historical and near real-time monitoring of forest disturbances, such as clear-cutting, from optical and radar images. It has become technically possible to provide deforestation information to forest managers in near real time or subannual basis by analysing dense time series of high-revisit satellites (AWiFS, Sentinel-1 & 2 and Planetscope). Increased the availability of very high resolution radar data of submeter scale is poised to improve the monitoring of illicit felling incidences during the rainy season.

Forests are vulnerable to the damage caused by the insects and pests infestation. Teak plantations are often infested by insect, which eats away its leaves. The defoliation reduces tree productivity and vigour. Teak defoliation is easily discernible on satellite imagery and hence, could be monitored. The coconut wilt disease in Kerala was detected using colour infrared aerial photographs in early eighties. The borer infested sal forest in Doon valley could be identified and mapped for remedial action by IIRS. The spectral behaviour of the borer-infested sal forest is distinct from that of healthy one and hence, ease in interpretation, mapping and monitoring.

3. Tracking Phenology

Seasonal changes in phenology (leaf emergence, bud bursting, flowering, fruiting and senescence etc.) are effective indicators vegetated ecosystem functioning (e.g. the arrival of pollinating insects, wildlife migration, the availability of valuable forest products and environmental changes (e.g. summer water stress)). The blossoming of flowers in a plant and the arrival of bees for pollination is a unique example of biological interaction. Tropical mixed forest supplies a wide variety of leaves, flowers and fruits that have livelihood and commercial value but these are available at a particular time and place. Long-term phenological observations in some parts of the world have revealed changes in regional climate. Remote sensing has key role in tracking phenology changes in space and time. Satellite data for mapping phenology requires high resolution, frequency and swath. Since the 1980s satellite remote sensing (for example AVHRR) has been used extensively to track vegetation cover and leaf fall phases on a global scale. With improved resolution and high revisit sensors (e.g. MODIS, MERIS, AWiFS), accurate determination of start of leaf emergence, peak foliage time and foliage senescence time has become possible. In recent years it has been possible to map flowering and fruiting timings at least at local scale for many forest species using very high resolution remote sensing data supported by field based phenocam obervations, either from satellite (e.g. Planetscope) and drone images.

4. Phytodiversity Distribution and Mapping

Biodiversity is assessed by remote sensing both directly and indirectly. In direct assessment, the emphasis is on the spectral differentiation of forest types, communities and species, and understanding the configuration and arrangement of their spatial patterns (e.g. habitat fragmentation). Indirect assessment uses field inventory data, remote sensing and ancillary data and ecological principles through geospatial modeling to understand various facets of biodiversity such as biorich and vulnerable areas, potential distribution of species, etc. IIRS has taken a lead role in mapping India's biome types and distribution using WiFS data at 1:2,50,000 scale.

Country's first vegetation type map was also prepared from IRS LISS-3 satellite data in which mixed forest formations, gregarious formations, local specific forests including grasslands and degradation types were mapped at 1:50,000 scale. IIRS has recently demonstrated mapping of vegetation communities and species at 1:20,000 scale using Sentinel-2 data for subalpine and alpine areas of Western Himalaya. A nationwide project on biodiversity characterization covering India was carried out by IIRS between 1998 and 2007. Using indirect approach through multicriteria geospatial modelling, the biological richness map of the entire country has been generated combining vascular plant diversity and its economic value, vegetation type and landscape matrices for different anthropogenic disturbance levels. A number of studies in recent years have used ecological niche approach to model potential distribution of plant species of conservation concern or threatened in nature.

5. Biomass and Carbons Stock Assessment

The amount of carbon stored in Indian forests is estimated every two years by the Forest Survey of India (FSI) under the National Forest Inventory (NFI), but this information is not generated spatially. However, for the first time in the latest report of FSI (ISFR, 2021), this effort has been made in collaboration with ISRO. In a national project funded by ISRO-GBP, biomass carbon density map of Indian forests for the year 2010 has been prepared at 250 spatial scale by combining intensive field inventory and remote sensing data. The carbon pools and fluxes including vegetation carbon, soil carbon, carbon exchange between forest/vegetation canopies and the atmosphere were the focus of this programme. Space agencies have plan several advanced and ambitious microwave satellite missions (NISAR by ISRO & NASA, BIOMASS by ESA, TanDEM-L by Germany, ALOS-3&4 by Japan) in the coming years to comprehensively quantify and understand the carbon cycle of forests. Realizing the special importance of radar data in forest biomass estimation, ISRO and NASA are going to launch a joint satellite NISAR in early 2024. The NISAR satellite will not only perform high resolution imaging but with the help of its short revisit time of 12 days and longer image frames will ensure data availability of radar data for monitoring biomass and forest disturbance in humid and cloudy areas. In recent years, LiDAR from space platforms (GEDI, IceSat-2) has also become available from NASA for almost all forest areas of the world. Canopy height is a key parameter for estimating the growing stock, biomass and carbon of forests. Therefore, temporal LiDAR data will be helpful in keeping a close watch on the growth and development of forests. IIRS has developed methodologies for biomass modelling, especially for high biomass densities, using advanced LiDAR and radar data It is important to emphasize the fact that regional, national and global level biomass and carbon stock estimation is possible with the synergistic use of multiple technologies (optical, LiDAR and microwave remote sensing), thus overcoming the shortcomings of one technology over the other. Volume equations need to be developed for the trees found in natural forest and agroforestry systems in addition to for better quantification of plot biomass. In the coming years, the information about the change in biomass from the satellites is planned to be made available at appropriate scale on a regular basis by the space agencies, which will benefit in the appraisal of forestry programs (afforestation / reforestation) and carbon trading mechanisms like REDD+.

6. Vegetation Productivity Assessment

The assessment of the productivity of forests is necessary to understand the continuous supply of a number of goods and services obtained from forests. IIRS has quantified annual and inter-seasonal productivity trends of Himalayan vegetation, which includes a variety of forests and grasslands, using remote sensing and radiation efficiency models. These studies have highlighted the role of environmental factors in controlling the productivity of the vegetation. For example: Soil moisture has the most decisive role in controlling the productivity of moist and dry deciduous forests in the north-western Himalayan foothills. Sal dominated broadleaf deciduous forests in the Doon Valley act as a net sink of atm. carbon. However, it also behaves as a net source of carbon during a few weeks during the months of April and May.

7. Forest Fire Prevention and Management

Forest fires are a major cause of degradation of India's forests. Forests are about 21% of the total area of India but their spread is in almost every part of the country though not contiguous. Deciduous and coniferous forests experience more fires than other types. Among various floristic regions, the north-eastern region suffers maximum from the fires due to the age-old practice of shifting cultivation and spread of fires from jhum fields. About 90 per cent forest fires in India are started by humans. Forest fires cause wide ranging adverse ecological, economic and social impacts. Due to increasing population and mobility, the incidence of man-made fire in forests has increased and fire incidences have become much more widespread in recent decades. Identifying areas susceptible to fire, issuing warnings of high-risk areas, identifying active fire occurrence and monitoring spread, monitoring burn area and burn severity, and monitoring burn recovery are the major applications areas of satellite remote sensing. Fire could be monitored during day and night using thermal infrared bands. Forest Survey India provides the active forest fire events detected from MODIS and Suomi NPP satellites thermal detectors in near real time to the field staff of the all the state forest departments thereby controlling the spread of fire and preventing further damage to forest wealth and ecology. A quick assessment of the forest area that gets burnt due to incidents of major forest fires is also done. Satellite data are also making it possible to explain changes in forest fire regimes, concentrations of emitted pollutants and positive feedback on regional climate in recent years.

8. Climate Change Impacts

Long-term satellite archives play a vital role in understanding climate change's impact on global forests. Satellite data indicate upslope shift and intensification of temperate vegetation due to the effect of global warming in the mountains of higher latitudes. Severe depletion of soil moisture due to prolonged drought in tropical forests is causing tree death. Mass mortality of trees has been observed using satellite NDVI in severe El Nino years. IIRS’s researchers are trying to understand the future state of forests by calibrating and validating dynamic global vegetation models with regional specific vegetation characteristics derived from satellite data and field inventory and through in-situ climatic and forest physiological observations (e.g. eddy flux observations). From these studies, carbon sequestration capacity of forests, water use efficiency and shift in geographical boundaries and many other aspects of the Himalayan forests can be understood in the event of increasing GHGs in the atmosphere in the coming decades.

9. Movement Ecology

Satellite telemetry is a unique way to understand the movement ecology of mobile organisms. In particular, species that come within line of sight of satellites during their transits and that can bear the weight of available satellite collars or tags can be targeted for satellite telemetry observations. Valuable information has been obtained on the habitat, movement and behaviour of endangered (vultures) and species in conflict with humans (elephants) in India using satellite telemetry. The ARGOS satellite constellation, which is operated by France and includes Indian satellites, facilitates animal tracking through satellite telemetry technology. Recently WII and IIRS tagged the cuckoo bird which is considered to be the harbinger of monsoon rains in India with a transmitter weighing as little as 5 grams and its movement was tracked between the Doon Valley and the Arabian Sea. The spatial ranging pattern of species obtained from satellite telemetry, combined with the habitat factors of species obtained from remote sensing and other sources, is helping to plan for their conservation and to address human pressures.

10. Protected Area Management and Ecodevelopment Planning

Remote sensing provides state-of-art information on bio-physical parameters of the wildlife habitat, which significantly helps in the monitoring and evaluation of the habitat for a particular wild animal. The USDA has developed more than 200 habitat models mainly for Amphibians. Alfred et al. (2001) used a remote sensing and GIS-based model to find out the habitat suitability for chinkara (Gazella bennetti) in Rajasthan. Kushwaha and Roy (2002) have reviewed the contemporary research on wildlife habitat evaluation. A web-enabled wildlife information system (WILIS) is needed to enable the people interested in similar studies as well as for exchange of information on wildlife-related issues. The wildlife Institute of India and IIRS have collaborated in various wildlife habitat studies since early eighties.

Protected areas (PAs) in India are under tremendous pressure due to ever-growing needs of an over-growing human population. Ecological development of the areas surrounding the PAs is considered as one of the effective measures to reduce the dependability of the people on the PAs. World Bank in 1984 sanctioned an eco-development planning project for some PAs with guidelines to use remote sensing and GIS for database creation on PAs and surroundings. The IIRS participated in this programme and created spatial database for Ranthambhore N.P. in Rajasthan. The field staff was specially trained by IIRS for continuity of the programme. Some states have taken keen interest in the programme and demonstrated encouraging results. Needless to mention that RS and GIS plays an important role to play in the eco-development planning.

11. Environmental Impact Assessment/ Ecosensitive Area Zonation

In the past decade, data from remote sensing and geoinformatics have been increasingly used to guide decision-making at national and state level in the country for the protection and conservation of sensitive landscapes and species. For example, the natural area to be affected by the proposed development projects (e.g. mining and hydroelectric projects) for EIA approval, a decision support system developed by FSI, is used to evaluate the impacts on forest cover, density, biological richness and ecosystem integrity. The Kasturirangan Committee (2012), which was constituted by the MoEFCC, to delineate ecologically sensitive zones in the Western Ghats, used spatial outputs of the national level biodiversity projects conducted by IIRS such as vegetation type, forest fragmentation and biological richness.

12. Conclusion

Space agencies have made impressive progress in the availability and cost-effectiveness of multiscale remote sensing data to address problems in the forestry sector. At present the emphasis is on providing analysis ready data and value added science products to ensure their effective use. In addition to optical remote sensing data, new applications are being fuelled by data from other wavelengths of the electromagnetic spectrum, such as microwave and thermal regions. Space borne LiDAR is helping to unravel the vertical characteristics of Indian forests. Research is being done in the direction of improving both near real time monitoring as well as long term forest dynamics prediction. Along with this, massive scale capacity building and training programs are also being conducted by the Department of Space, MoEFCC Institutions like FSI, ICFRE and State Remote Sensing Centers to effectively utilize the developments in technology by forest managers and other stakeholders.

Chapter 8

Geospatial Applications for Geosciences

1. Introduction

Present day Earth observation satellites carry a variety of imaging sensors, which are capable of generating an image of the objects on the earth's surface in a particular wavelength range of the electromagnetic spectrum. Using such images, it is possible to map, monitor and measure many geological processes and associated features. Geographic Information Systems (GIS) offers a powerful toolbox to create maps, integrate information, visualize scenarios, solve complicated problems, and develop effective solutions. Recent advances in EO and Global Positioning Systems integrated with GIS, can provide valuable information on earth surface features and processes involved. In the last few decades, there has been a spectacular growth in the field of RS and GIS, primarily due to revolution in IT and success of the earth observing systems. It is important to note that since the earlier days of remote sensing using aerial photographs to modern EO using high spectral and spatial resolution data sets, various innovative attempts have made to demonstrate the role of RS & GIS in geological applications starting from basic geological mapping to planetary geology

(Siegal and Gillespie, 1980; Rao, 1999; Drury, 2001; Gupta, 2003; Sabins, 2007). The established technique of geologic remote sensing is still improving day by day due to recent advances and newer challenges in view of issues related to sustainable development, climate change and disaster management. The RS and GIS can be applied in the following areas and some of which are described in the following sections.

- Geological and geomorphological mapping (terrain evaluation/analysis)
- Mineral/ oil/ gas exploration
- Ground water exploration and management
- Engineering geological studies- Dam site selection, road alignment, site investigation
- Geological hazards: Landslides, earthquakes, mining related hazards and subsidence
- Environmental geology
- Planetary geological exploration

2. The Optical, Microwave and Hyperspectral imaging

Primarily, optical remote sensing techniques have been used for geological applications. However, in recent years there has been tremendous progress in the field of space-borne SAR due to its technical superiority and application potential in various fields. In particular SAR has found its role in geological remote sensing due to (i) the enhanced sensitivity of SAR to topography; (ii) the sensitivity of SAR to surface roughness of exposed terrain and the composition of vegetation and/or other ground cover material; and (iii) the sensitivity of SAR to dielectric properties indicative of moisture content, related to geomorphology, lithology, structure and geobotanical aspects. Due to the above basic reasons there has been significant research and application in the field of SAR application to geological mapping, mineral exploration and structural studies.

Multispectral sensors with selected spectral bands provide very useful information that can be put to multitude of applications. However, these have been found wanting in capturing subtle spectral variation across electromagnetic spectrum in a contiguous manner, which is crucial for discrimination of features/ objects based on spectral properties.

Hyperspectral imaging consists of spectral measurements using hundreds of narrow contiguous bands providing very useful information hitherto not possible in multispectral imaging. Hyperspectral imaging is also referred to as imaging spectrometry as it generates continuous spectra for each pixel. Hyperspectral systems effectively discriminate different types of surface materials that have absorption and reflection characteristic over narrow wavelength intervals. Thus, Hyperspectral sensors can gather data of sufficient spectral resolution for direct identification and discrimination of materials in consideration.

Owing to these advantages, Hyperspectral data/images have been used in the study of surface mineralogy, water quality, bathymetry, soil type and erosion, vegetation type, plant stress, leaf water content, canopy chemistry, crop type / condition and snow / ice properties. In recent years, newer applications and methodology have been developed to analyse and derive useful information from Hyperspectral images. These new techniques and unique data sets have tremendous application potential in surface mineralogy mapping, mineral exploration and general geological applications.

3. Geological and Geomorphological Mapping

This is one of the most fundamental applications of remote sensing in which rock types, structures (lineaments etc.) and geomorphological features are identified and mapped using synoptic coverage and 3-D perceptions as available from different types of satellite and aerial data products. The most fundamental keys of image/photo interpretation such as tone, texture, shape, size, shadow, associationship etc. are used along with very advanced spectral signature of rocks and minerals to identify and map features. Recent advances such as availability of DEM from satellite data products and 3-D data visualization in GIS have further helped to interpret and map rock types, alteration zones, subtle topographic changes and structural features.

4. Mineral and oil exploration

The use of RS and GIS in mineral exploration has been demonstrated by several case examples. The strategic benefit of using EO is that it provides most authentic, timely and at a fraction of cost required for obtaining similar information by ground-based observations. Therefore, in the recent past there have been tremendous advances in the application of earth observation in mineral/oil/gas exploration and management.

The role of remote sensing in mineral/oil industry can be explained with respect to on-shore mineral/oil/gas exploration using optical and radar remote sensing, off-shore oil seepage detection, off-shore gravity analysis and Interferometric Synthetic Aperture Radar study for analyzing subsidence due to oil extraction. Ever since the launch of ERTS-1 in 1972 and landsat-4 (TM) in 1982, the optical remote sensing products have been used by geologists to produce geologic information that aid in virtually all aspects of exploration. Landsat satellite imagery helped in discovery of many oil/gas fields like giant Haters Pond field, Citronelle field near Missisipi and Alabama (Halbouty, 1976), Ghawar in Saudi Arabia, Kettleman Hills in California (Halbouty, 1980), Carpathian oil/gas field in Poland including the largest oil field in USA Prudhoe Bay field in Alaska (Halbouty, 1980). Other successful examples can be cited from the pioneering work of Dr. Floyd F. Sabins, Chevron Remote Sensing Research Group (http:// www.geology.sdsu.edu/ activities/ seminar/ spring00/ sabins/). In India, Oil and Natural Gas Company Ltd. (ONGC) its inception is using remote sensing as one of the basic tools for petroleum exploration (Mitra and Agrawal, 1991).

In exploration geology, the preferred approach is to compile all of the available geoscientific data within the GIS in the context of an exploration model in order to produce a mineral potential map. Careful consideration must be given in developing the model such that all of the relevant, important aspects of the deposit being sought are represented. The model is also very important in deciding what weightages to apply to each of these aspects. In the final analysis, these weightages may be applied by a geologist, with an intimate knowledge of the model and the deposit, who decides which factors related to the deposit are most important, ranging down to those of least importance (a knowledge based approach). The final result is a combination of all of the weighted values, producing a map which ranks the study area by degrees of perceived prospects. One of the widely used statistical data integration technique is the Weights of evidence method suggested by Bonham-Carter et al. (1989) and Bonham-Carter (1994) in which the quantitative relationships between data sets representing the deposit recognition criteria and known mineral occurrences is analyzed using Bayesian weights of evidence probability analysis. In this method the predictor maps are used as input maps and the end product is an output map showing the probability of occurrence and the associated uncertainty of the probability estimates of mineral deposits. In ample number of case examples, this approach has been applied using various GIS packages.

GIS are increasingly important in customizing and integrating a broad range of exploration data consisting of information on drill holes with summary stratigraphic logs, rock sample and drill hole sample geochemistry, mineral occurrences, magnetic and gravity images, digital geology, current and historic exploration details, roads and railways, localities, parks and reserve forests, restricted areas and integrated bibliography. IIRS has attempted to develop such a system i.e. Mineral Resource Information System, which is a database on mineral deposits, mainly iron and manganese ore deposits of the Iron Ore belt of Keonjhar and Singhbhum region of Orissa and Jharkhand, India. It contains all relevant information on mining activities of the region. Although it is developed based on the concept of Geographical Information Systems, it runs independent of any commercial GIS and allows data updating, querying, report generation and access to GIS if present.

5. Ground Water Exploration and Management

RS and GIS can be used for almost all application related to groundwater exploration and management such as groundwater targeting, resource estimation, groundwater recharge estimation, evaluation of ground water exploitation impact on environment (runoff, soil moisture, vegetation growth conditions etc.), evaluation of groundwater resources for urban and rural fresh water supplies. Ground water pollution and vulnerability assessment, environmental impact assessment and human activity affecting ground water etc. IIRS has prodcued groundwater prospect maps for entire National Capital Region of India covering around 67 topo-sheets on 1:50,000 scale. Geological, geomorphological and groundwater quality data were integrated and results were produced on 1:50,000 scale using ARC/INFO GIS software. Similar efforts are also going on at national level under Rajeev Gandhi National Drinking Water Mission to prepare ground water prospect maps on 1:50,000 scale in most drought prone districts of India.

6. Engineering Geological Applications

Remote sensing plays an important role in hydropower development: starting from dam site selection to comprehensive geotechnical evaluation and reservoir monitoring. Following are some of the studies carried out by IIRS for hydro power development in Himalaya using mainly aerial photographs and satellite images. In recent times, high resolution data products and derived terrain information like DEM are used for dam site selection, alignment of HRT etc. and reservoir rim survey and analysis.

- Geotechnical survey of Parbati Hydel Project area, H.P.
- Geotechnical investigation for Srinagar Hydel Scheme, Garhwal, U.K.
- Geotechnical studies of Bowala-Nandprayag Hydel Scheme, U.K.
- Geotechnical studies of Tapoban-Vishnugad Hydel Scheme, U.K.
- Geotechnical investigation for Lakhwar-Vyasi Hydel Project, U.K.
- Photogeological study of Kotli-Bhel Hydel Project, U.K.
- Photogeological study of Pabar-Tons Hydel Project, U.K.
- Remote Sensing and GIS based studies for Kishau Dam Project, U.K.

7. Landslides Hazard Assessment

Aerial photographs and high-resolution satellite images have been used extensively by many researchers and agencies to map, monitor and predict landslide hazard prone areas in different mountainous regions of the world. The faculty of Geoinformation Sciences and Earth Observation (formerly known as ITC), University of Twente, The Netherlands had developed specialized GIS package, GISSIZ, for landslide hazard Zonation at different scales with aerospace inputs (vanWesten, 1993). In the recent past Geosciences Division at IIRS has experimented with various quantitative methods for spatial prediction of landslides in Himalayan region using remotely sensed data products and other ancillary information in GIS environment (Champati ray, 1996). The results of such studies indicate that RS data products can be utilised for deriving various informations related to landslide studies and the information can be utilised for landslide hazard assessment and prediction in GIS.

Subsequent to Malpa and Okhimath tragedy, at the behest of the Cabinet Secretary (Government of India), Department of Space, launched a major project titled as

"National Landslide Project" on landslide hazard zonation along major tourist and strategic routes covering 1800 km of road length in UP and HP Himalayas. The project was carried out with the collaboration of eleven Government organisations and generated Landslide Hazard Zonation maps along with management plans on 1:25,000 scale. Based on the experience and recent advances in the technology, it is realized that the following EO based service can be of immense help in mitigating landslide related disasters.

1. Using remote sensing and GIS techniques, landslide hazard zonation maps can be prepared on 1: 25,000 and larger scale in a more consistent, efficient and cost effective manner within very limited time.
2. Landslide incidence map can also be prepared and updated on a regular basis on 1:25,000 scale and larger scale with availability of high resolution data.
3. Prediction of landslides based on deterministic modeling and factor of safety analysis is very site specific and data requirements are enormous. However, RS and GIS can play a role in such analysis, as demonstrated by recent studies.
4. Surface displacement due to landslides can be determined using differential interferometry (DInSAR) and permanent scatter (PS) techniques.
5. Landslide triggering factors (precipitation and earthquake) can be analysed and landslide hazard based on precipitation, earthquake intensity and reservoir inundation can be anaysed.

8. Landslide Hazard Zonation

The main purpose of various data integration techniques or models is to combine spatial data from diverse sources together to describe and analyse interactions, to make predictions with models, and to provide support to decision-makers (Chung and Fabbri, 1993; Fabbri, 1994; Westen, 1993). Towards this end GIS offers numerous tools to input, organise, process spatial data and to make predictions using modelling techniques. In the recent past various models or methods were developed independently for many applications mainly using non-spatial data. Now with the advent of GIS, various attempts are being made to emulate or simulate similar procedures on spatial data for prediction purposes. Although models were not originally developed for landslide hazard zonation, the underlying principle is same in many respects. Hence various statistical models /techniques which can be used as a methodology or can be integrated in a methodology for landslide hazard zonation were tried in the recent past at IIRS.

- **Spatial statistical prediction model (SSPM) for landslide hazard analysis in Western Himalayan (around Sataun, HP)**

GIS based spatial statistical modelling techniques were applied to predict landslides around Sataun in Himachal Pradesh, a structurally disturbed zone of western Himalaya (Champati ray, 1996). Various geoenviromental parameters such as lithology, structure, slope, aspect, land-use, drainage, road excavations, vegetation cover and mass wasting areas were considered. Information on these parameters were derived from remotely sensed data products by using digital image processing techniques, such as principal component analysis, image classification, vegetation coverage estimation (NDVI) and ortho-rectification. Terrain parameters such as slope and aspect were derived from DEM.

Statistical relationship between landslide occurrences and geoenviromental factors was established using information value (Yin and Yan, 1988) and weights of evidence. Finally, landslide hazard zonation maps were prepared using information value and weights of evidence modelling methods. It was observed that models predict around 60-65% of actual landslides in 17% of the predicted high hazardous area. Two important conclusions could be made from this study - 1) information from remotely sensed data products can be integrated directly in a GIS based spatial predictive model; 2) the information value method and weights evidence modelling can predict reasonable number of landslides with the help of parameters derived from remotely sensed data products. In order to incorporate human knowledge in the model, fuzzy membership values were defined based on expert knowledge and information value. Finally data layers were integrated using fuzzy gamma operator. Although the result shows same level of accuracy, but the reliability is much higher.

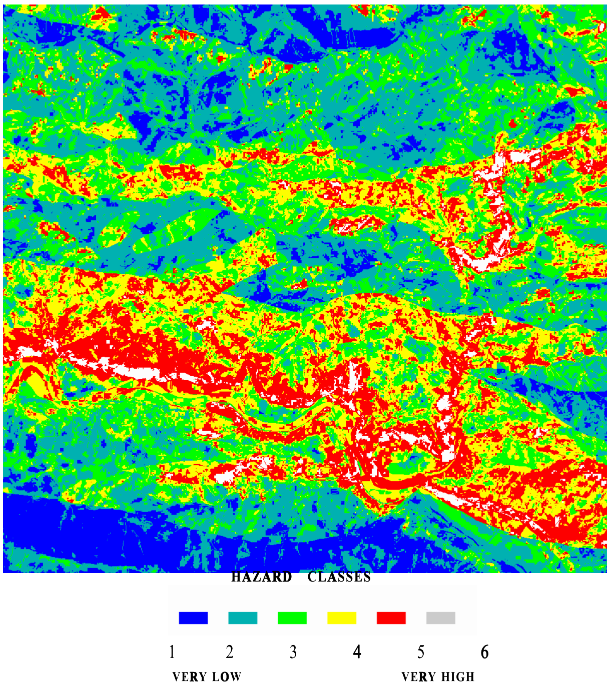


Figure 1. LHZ map of Pandoh area (HP) using weights and ranking method

- **Landslide Hazard Zonation and Mitigation Measures in Northeastern region of India**

Landslide is considered as one of the potentially most damaging phenomena affecting human lives, property and natural environment of northeast Himalaya. Therefore, a project was undertaken to identify, map and assess geo-environmental parameters and predict areas prone to landslides using remotely sensed data and Geographic Information System (GIS) in a priority sector, namely Shillong-Silchar-Aizawl Highway corridor in the states of Meghalaya, Assam and Mizoram (IIRS, 2008). The project was carried out in a collaborative mode by scientists from Central Building Research Institute (CBRI, CSIR), IIRS, and North Eastern Space Applications Centre (NESAC). Landslide Hazard Zonation (LHZ) maps were prepared on 1:25,000 scale for the entire road corridor showing the probable areas of landslide hazard based on geological, geomorphological, terrain and geo-environmental parametersa using knowledge-driven approach verified with statistical approach.

Landslide mitigation measures have been suggested for slope stabilisation and environmental protection. Digital as well as large format Atlas consisting of 64 pages of textual and spatial information have been generated and distributed among collaborators for further use by line departments. The resultant maps have high utility value in regard to planning and developmental activities in northeastern region of

India, particularly with respect to infrastructure development and natural resources management.

9. Earthquake Hazard Assessment

The devastating earthquakes of recent past have emphasised the need to explore technological advancements including space technology for better understanding of the phenomena and its impact in terms of regional and local risk. Although the prediction of seismic events remains as an elusive goal even today after much technological advancement, the main value of scientific investigation lies in the potential for identification of hazard prone areas where proper preventive measures can be taken well before the fatal shock strikes. Secondly dynamic seismic hazard assessment over a range of spatial and temporal scale will allow a more systematic approach to prioritizing the areas for retrofitting of vulnerable structures, relocating populations at risk, protecting lifelines, preparing for disasters, and educating the public.

In recent time, space technology has made significant contributions. The most significant observation from space has been made possible by deployment of dense geodetic network of Global Positioning Systems (GPSs) in seismic active regions, acquisition of synthetic aperture radar (SAR), thermal and many other data for deriving geophysical parameters and post processing capability such as sub-pixel correlation (of optical images) and interferometric SAR (InSAR) processing for deformation mapping to understand the kinematics of fault rupture and transient stress built up. A review of the literature reveals significant progress in the application of Earth Observation in earthquake studies in the following areas.

1. Neotectonic and morphotectonic study to identify active faults
2. Surface deformation through SAR Interferometry and optical remote sensing
3. Liquefacation study using optical remote sensing
4. Seismic microzoning using GIS based modelling with remote sensing inputs
5. Damage assessment using high resolution satellite (HRS) data
6. Thermal and electro-magnetic (EM) anomaly observation

In the initial phase of earthquake hazard studies, the most significant contribution is made by monitoring the subtle neotectonic changes often expressed in the form of diagnostic landform and relief changes. In one case study, the evidences of curstal deformation and its manifestation on surface geomorphology in the recent past (1972-2003) has been reported from a seismically active Himalayan Frontal Thrust (HFT) zone at Dehradun reentrant, India by comparative analysis of Landsat images of 1972 and Indian Remote Sensing (IRS) Satellite-Panchromatic image and Linear Imaging Self Scanning (LISS)-III images of 2003. Terrain analysis using Shuttle Radar Topography Mission (SRTM) data also reveals tectonic influence on landform development. The eastward shifting of rivers, reversal of the drainage direction, straightening of the course, shifting of the water divide, development of close meanders, uneven bank erosion point towards strong tectonic influence, which has also been confirmed by supportive evidences given by other workers. The detection of recent tectonic activity using satellite remote sensing provides very important input for seismic hazard assessment of the Dehradun valley and similar techniques can be applied for delineating active tectonic zones in other parts of 2500 km long HFT zone for more detailed study.

In another case example, the extent of the causative fault of the Kashmir earthquake of 2005 has been mapped based on sub-pixel registration, image interpretation, damage assessment and field investigation. Multi-resolution satellite data products from ASTER (15m resolution), IRS-LISS-IV(5.8m resolution) and Cartosat-1(2.5m resolution) were used to analyse the satellite observations in conjunction with ground deformation and to decipher the nature of the causative fault and its influence on the ground deformation and landslides in the region (Champati ray et al., 2007).

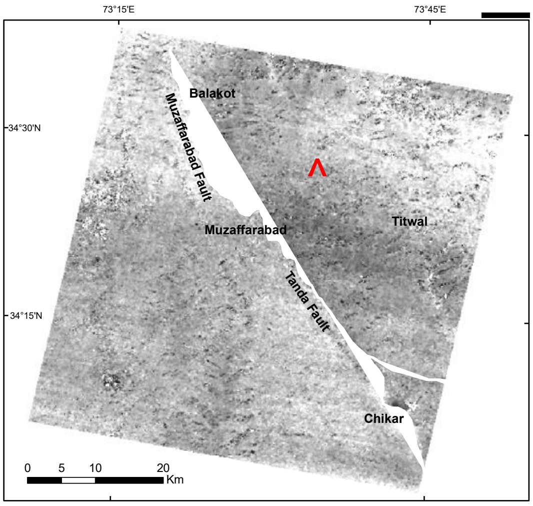


Figure 2. Nature of the causative fault and its influence on the ground deformation

Currently the interferometric SAR (InSAR) processing has been one of the important and effective techniques for mapping deformation related to earthquakes. The most promising application of InSAR is to extract two-dimensional patterns of land displacement caused by earthquake (e.g. Massonnet et al., 1993, Massonnet and Feigl, 1995). This was first demonstrated during the 7.3 magnitude Landers earthquake of 28 June 1992 that ruptured over 85 km along a complex fault system in the Mojave Desert of California. Since then many earthquakes and associated surface deformation have been studied using InSAR and differential InSAR techniques.

Liquefaction is a soil behavior phenomenon in which a saturated soil looses a substantial amount of strength due to high pore-water pressure generated by and accumulated during strong earthquake ground shaking. The liquefaction phenomenon can be very damaging or hazardous when accompanied by strong ground displacement or ground failure as was observed during Bhuj earthquake of 2001 (Champati ray et al., 2001). Using image processing on pre- and post- LISS III data sets it was possible to delineate precisely earthquake induced liquefaction areas indicated by liquid emanation. In the event of an earthquake, the liquefaction probability can be estimated based on the geotechnical characteristics of soil, earthquake strong motion in terms of Peak Ground Acceleration (PGA) and ground water table. For Bhuj earthquake, liquefaction probability has been modeled which corresponds well with the actual observation as revealed on satellite image and in the field.

Satellite remote sensing technology is also unsed for gathering damage information on built up areas due to earthquakes (Yamazaki et al., 1998; Matsuoka and Yamazaki, 2000). The damage of 2001 Bhuj earthquake was studied using high-resolution satellite imagery (Chiroiu et al., 2002). Damage to large built up areas and surface deformation could be detected using IRS PAN images. Special band combination of pre and post earthquake data as well as PAN data merged with LISS III data by IHS transformation revealed damages to large built up areas (Champati ray et al., 2001).

Various measurements related to earthquakes can be performed in GIS, and the role of GIS in earthquake monitoring and prediction is well attempted by Towers and Gittings (1995). For example, the magnitude of early earthquakes can be assessed from the extent of the area over which the shock was felt with given intensity, and from the fault rupture and displacement which can then be calibrated against macroseismic information about similar earthquakes for which instrumental data are available. The assessment of the peak horizontal ground acceleration and velocities at certain distance from the causative fault can be simulated by using the attenuation law in GIS (Joyner and Boore, 1981; Ambraseys, 1990). This enables to assess the magnitude of disaster well before the event for different levels of earthquake magnitudes. In this regard, Brabb (1995) has reported how a GIS based geologic-hazard data base in California has been used in an innovative way to produce maps, such as - a map showing the seismic-shaking intensities in a repeat of the 1906 San Francisco earthquake; maps showing cumulative damage potential to different types of buildings; a map showing where earthquake-triggered landslides will impact the county during a repeat of 1906 earthquake; map showing debris flow probability and a map of liquefaction susceptibility.

In one example from Dehradun valley, seismic microzonation has been attempted by site response analysis which takes into account soil profile and its thickness, depth to bedrock, geotechnical properties of the soil, shear wave velocity and input earthquake data. The shear wave velocity and soil thickness was obtained by using Multi channel Analysis of Surface Waves (MASW) method. SHAKE 2000 has been used for site response modelling using Chamoli and Uttarkashi earthquake data recorded at Tehri as input motion. On the basis of present analysis, whole city has been classified in to different zones of shear wave velocity and spectral acceleration has been estimated at critical frequencies to assess vulnerability of urban built up (Mahajan et al., 2007).

Many claims have been made concerning the correlation of thermal IR anomalies and Earthquakes. It is assumed that pressure built-up due to tectonic activities and also associated subsurface degassing might create changes in thermal regime and if by any technique this change is detected, it can provide very important clues about future earthquake activities. Thermal satellite remote sensing which can sense the earth's surface emissivity at regular interval provides new opportunity for analyzing this phenomenon. Using NOAA-AVHRR thermal infrared time series datasets, major past earthquakes in India and Iran were analyzed for studying the thermal changes before and after the earthquakes. The study was successful in detecting pre-earthquake thermal anomalies prior to all these earthquakes (Saraf and Choudhary, 2005; Choudhury et al., 2006). The current Advanced Spaceborne Thermal Emission Radiometer (ASTER) and Landsat ETM+ instruments have good spatial resolution, and provide better data to test existing hypotheses.

Changes in land, oceanic, and atmospheric parameters have also been observed prior to large earthquakes using remote-sensing data. These changes suggest the existence of a strong coupling between land, ocean, atmosphere, and ionosphere associated with earthquake processes. Recent studies using remote-sensing data have shown that such strong coupling is associated with the build-up of stress in the earthquake hypocentral region The analysis of multi-sensor data has shown that the associated parameters change significantly with earthquakes of magnitude 5.5 and greater with a focal depth up to 35km (Cervone et al. 2004; Singh et al. 2007). In case of Sumatra earthquake and tsunami of 26 December 2004, as reported by Singh et al. (2007), sea surface temperature (SST) was found to increase anomalously before the earthquake (6–8 December), decrease anomalously prior to and soon after the earthquake (24–29 December), and to recover its normal value 5 days after the earthquake. Over the last 20 years, many scientific publications have discussed the existence of precursor signs in the ionosphere before major earthquakes. However there is a lot of uncertainty and controversy about whether these signs are actually related to seismic activity. This is because variations in the characteristics of the ionosphere depend on many factors and in particular on solar activity.

10. Interferometry SAR Applications

Spaceborne interferometric SAR (InSAR) has been found to be an efficient tool for measuring high precision digital topography and ground displacements occurring due to a variety of natural causes such as earthquake, landslide, volcano, glacier and solution activities of rocks, and anthropogenic causes like underground mining, hydrocarbon extraction and groundwater overdraft. The precise digital elevation model (DEM) generated from SAR interferometric data pair along with amplitude and coherence information of the InSAR data pair can be used for monitoring environmental hazards.

Recently, the problem of ravine erosion with consequent loss of usable land has received much attention worldwide. The characterization of ravines as a function of their erosion potential expressed through ravine density, ravine depth and ravine surface cover is possible in quantitative terms exploiting the preferential characteristics of side-looking, long-wavelength, coherent SAR signal and precision measurements associated with InSAR technique (Chatterjee et al., 2009). Similarly, from the high precision InSAR DEM and InSAR coherence image, opencast mining areas (including abandoned, closed and non-operational categories), mine dumps, and abandoned or closed non-operational opencast mines could be successfully delineated (Chatterjee et al., 2010).

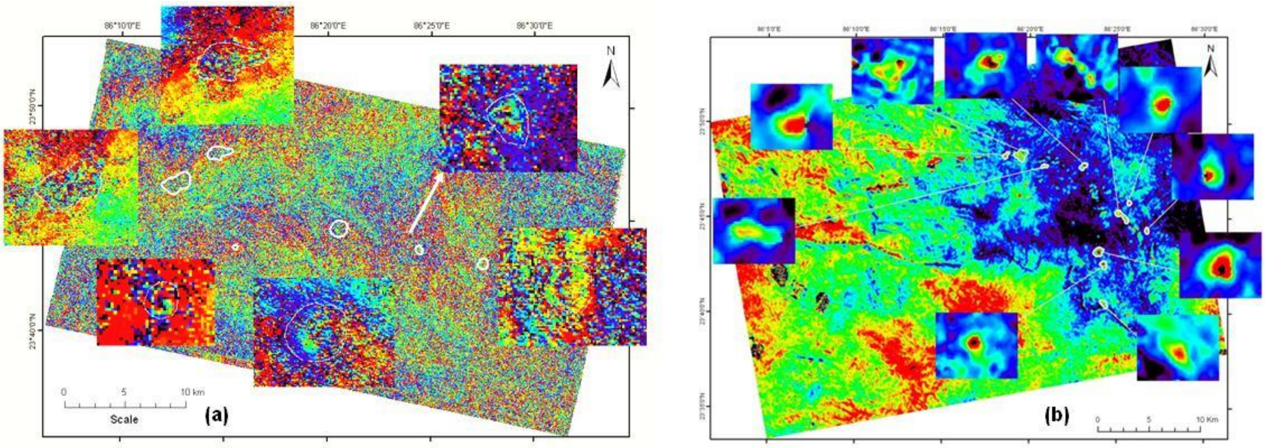


Figure 3. Differential interferograms of C-band ENVISAT ASAR (a) and L-band ALOS PALSAR (b) data pairs showing subsidence fringes during the observation period.

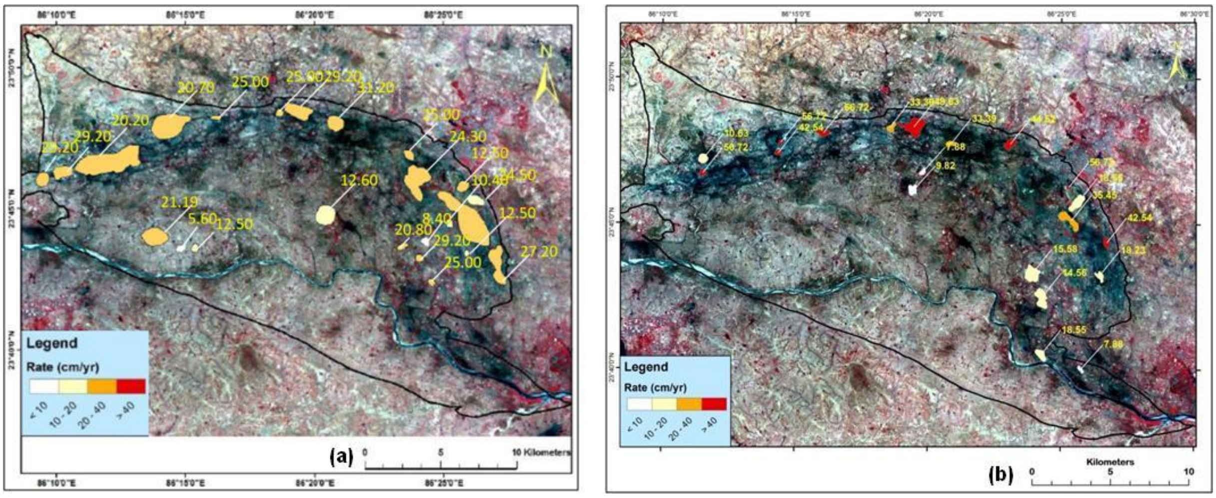


Figure 4. DInSAR based land subsidence maps of Jharia Coalfield from C-band ENVISAT ASAR data pairs of 2003-2007 (a) and L-band ALOS PALSAR data pairs of 2007-2008(b).

Spaceborne differential interferometric SAR (DInSAR) has been used for detection and measuring subtle movements associated with landslides in the Garhwal Himalayas. Although early results are very encouraging, various limitations were encountered in analyzing such phenomena due to topographic errors and lack of adequate SAR data sets with favorable geometry and frequency. Attempts are under way to monitor slope deformation in and around Tehri dam area using L and C band interferometric data sets and GNSS based ground deformation measurements.

Various studies were also carried out for detection, mapping and modeling of land subsidence occurring primarily due to the anthropogenic causes like groundwater over-extraction, underground mining of coal and petroleum. In areas like Kolkata city where the rate of groundwater induced land subsidence is very slow, it is a challenging task to separate the areas of ground subsidence from heterogeneous atmospheric effects (Chatterjee et al., 2006, 2007a). In a moderate to highly subsiding areas, where land subsidence is potentially occurring due to a number of factors such as seismicity, volcanic movement and exorbitant groundwater overdraft, as in the case of Bandung city, Indonesia, it is more important to characterize the nature of subsidence and predictive modeling of groundwater-induced land subsidence phenomena (Chatterjee et al, 2012). On the other hand, in coal mining areas like Jharia Coalfield, India, it appeared quite difficult to map and measure land subsidence phenomena due to dynamic nature of mining operations, adverse land cover and complex deformation pattern. Predictive modeling of mining-induced land subsidence is another area of research to differentiate land subsidence occurring due to active underground mining, vulnerability of old mine workings and/or subsurface coal fire propagation (Figure 1 and 2; Chatterjee, 2006; Chatterjee et al., 2007b). Spaceborne DInSAR successfully delineated new and unreported land subsidence areas and facilitate to characterize the nature of subsidence in association with collateral measurements and ancillary information (Chatterjee et al, 2013).

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Chapter 9

Geospatial Data Access and Visualization using Geoportals

1. Introduction

Advancements in Information and Communication Technologies (ICT) has facilitated a new way for sharing and dissemination of Geospatial data and information. The online data repositories and web applications are providing various means of data access by using internet and related technologies. Today, the users of geospatial data and information can use internet platform for various geoscientific activities such as spatial queries, geo-visualization and simple to complex computations for decision-making and virtual reality. Considering the importance of spatial data for humanitarian response during natural disasters many agencies and individuals are hosting their data sets online, which has enhanced the outreach of geospatial data many folds. These open geo-data sets can be used for various thematic applications either as a geo-web service or as a data product(s).

The open online data repositories and geo-web services are providing data and information by using web service standards published by Open Geospatial Consortium (OGC). The websites are available either as geo-portal or online data archive. The web portals are dynamic web applications which serves data and information to its user (s) by using database server technology. In web portal applications, the data is accessed and processed using an additional middle tier at server end using any web programming language such as PHP, C#, JAVA, Python, etc. This middle tier is also known as business logic or application server. In case of GIS data, the database servers hosts the raster and vector data in addition to attribute data sets in a database server. The geo-portals are developed based on GIS servers which are also known as Map server (s). The GIS servers typically act as middle tier in software application architecture to make geospatial data compatible with internet client software applications such web browsers.

The most of online data repositories are providing free and open geo-data in public domain. Some of the popular geoportals and online data repositories are discussed in this chapter. One of the important source of data in GIS is crowdsourcing or public participation. The popular geo-portals such as Open Street Map (OSM) and ISRO Bhuvan has successfully demonstrated the power of public participation in GIS data creation and sharing. Today, you can download large scale maps in original GIS format of entire globe from OSM website. OSM also provides online mapping utility to its users in web platforms where many individuals can be engaged in mapping activities simultaneously so that the task is completed in very short time. The ISRO Bhuvan geoportal provides various mobile apps and online mapping utilities to create data repository of ground data. In India, the Bhuvan geoportal is used by many government departments and ministries to generate the geo-tagged inventory of their assets. In this chapter some of the examples are discussed.

2. Geospatial Data access from GIS Portals or Geoportals

2.1 Global

2.1.1 Google Maps and Google Earth

The mapping applications (https://maps.google.com) from Google (www.google.com) are one of the most popular GIS application available in public domain. The map data from google can be accessed through variety of ways like as web application in web browser, Google Earth as standalone desktop application, mobile application and Application Programing Interface (API) for custom web mapping. The mapping applications from google provides satellite imagery, street maps, and Street View perspectives, as well as many GIS tools such as a route planner for traveling by foot, car, bicycle, or with public transportation, locator for urban businesses and other organizations in numerous countries around the world. In some cities, Google Maps offers street views comprising photographs taken from moving vehicles in different direction.

The maps and satellite images available in google mapping applications are not up-to-date or real time data. However the maps are being updated on frequent basis by using public participation in data creation. The satellite imageries are available at various spatial resolution which allows geo-visualization at street level with spatial resolution of less than a meter. Google Maps uses a close variant of the Mercator projection, and therefore cannot accurately show areas around the poles. A related product is Google Earth, a stand-alone program which offers more globe-viewing features, including showing polar areas. Google Maps for mobile is the world's most popular app for smartphones, with over 54% of global smartphone owners using it at least once during the month of August 2013 (Business Insider, 2013). Some of the popular services available in google maps are:

- A route planner offers directions for drivers, bikers, walkers, and users of public transportation who want to take a trip from one specific location to another. This route planner application is one of the popular mapping application used by majority of google users across the globe.

- The Google Maps application program interface (API) makes it possible for Web site developers and administrators to embed Google Maps into their websites. The mapping applications developed using google map API allows overlay of site specific data i.e. user's data on google maps. The specific and custom mapping application can be build using these API. As per google developers website (googlegeodevelopers.google.com, 2013) approximately 1,000,000 web sites using Google Maps API which makes it the most heavily used web application development API (www.programmableweb.com, 2013). The Google Maps API is free for commercial use, provided that the site on which it is being used is publicly accessible and does not charge for access, and is not generating more than 25 000 map accesses a day (Google Maps API FAQ, 2014). Web Sites that do not meet these requirements can purchase the Google Maps API for Business (Google Maps API for Business, 2014).
- The map services of Google for mobile user offers location based services using Global Positioning System (GPS) of mobile devices and data from wireless and cellular networks.
- Google Street View enables users to view and navigate through horizontal and vertical panoramic street level images of various cities around the world.
- In addition to the above services google maps also offer images of the moon, Mars, and the heavens for hobby astronomers. These services are available as additional components of google map service.

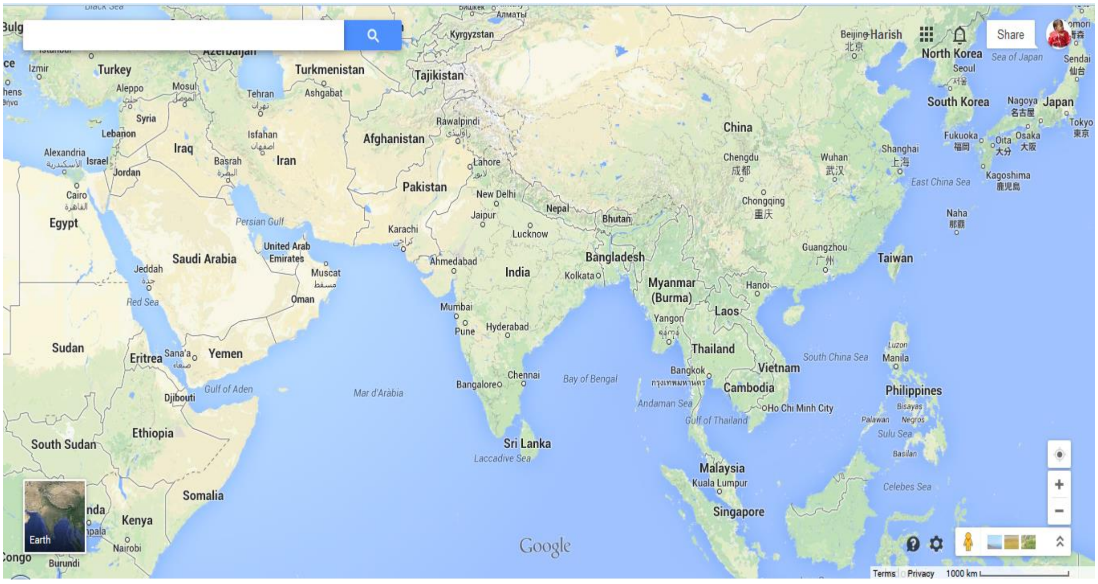

Figure 1. Map view of http://maps.google.com

The development and implementation of google map application is based on web 2.0 technology where AJAX based architecture is implemented for interactive mapping applications. The google map application uses JavaScript extensively. As the user drags the map, the grid squares are downloaded from the server and inserted into the page (Gautham, 2012). When a user searches for a business, the results are downloaded in the background for insertion into the side panel and map; the page is not reloaded. Locations are drawn dynamically by positioning a red pin (composed of several partially transparent PNGs) on top of the map images. A hidden IFrame with form submission is used because it preserves browser history. The google map website also uses JSON for data transfer rather than XML, for performance reasons. Google maps has also introduced MapsGL for 3D rendering of geospatial data using WebGL. The WebGL based mapping applications allows 3D visualization of geo-spatial data using javascript without having any additional plug-in or software components at client end.

2.1.2 Bing Maps

Bing map is a web based mapping service provided by Microsoft. Bing is a search service from Microsoft, which includes the 'Bing Maps' platform, which was previously known as Microsoft Virtual Earth. The Bing map platform includes map tiles, map embedding APIs, routing, and many more map applications. It makes use of proprietary datasets, often licensed from third party geo-data providers, and its use is therefore bound by copyright restrictions. The Bing map provide global coverage of maps and satellite data for geo-visualization and development of custom web mapping applications.

This mapping service provides browse and search the locations in topographically-shaded street maps for majority of cities worldwide. The maps includes certain Points of Interest (POI) such as metro stations, stadiums, hospitals, and other amenities. It also provide facility to locate and add new POI by the users. Searches can cover public collections, businesses or types of business, locations, or people. Bing map provides five primary types of street map views:

- **Road View**: Road view is the default map viewer which allows display of vector maps of roads, buildings, amenities, and geography features. The data from which the default road map is rendered is licensed from NAVTEQ which is an American Chicago-based provider of GIS data and a major provider of base electronic navigable maps. In addition to this the road data from OpenStreetMap is also allowed to overlay and visualized.

- **Aerial View:** Aerial view is a map viewer provided by Bing to allow overlay of satellite imagery onto the map and highlights roads and major landmarks for easy identification. The satellite data of different spatial resolution are available which can be used for identification of geographical features at street level. The satellite images of Bing aerial view are also used by OpenStreetMap for its mapping applications.
- **Bird's Eye View:** Bird's-eye view displays aerial imagery captured from low-flying aircraft (http://www.bing.com). According to Bing Maps Imagery Release in April 2010 the Bird's-eye images are taken at an oblique, 45-degree angle. They show the sides of buildings, not just the roofs, and give better depth perception for geography. Bird's-eye view is available in selected locations across the globe (Bing Maps Imagery Release, 2010). Bird's-Eye images for a location may be viewed from all four cardinal directions.
- **StreetSide View**: StreetSide of Bing provides 360-degree photos of street-level scenes taken from special cameras mounted on moving vehicles. It is similar to Google Street view but have less number cities covered for 360-degree visualizations.
- **3D View:** The 3D View of Bing provides ability to rotate and tilt the angle in addition to panning and zooming in satellite imagery and map data. To attempt to achieve near-photorealism, the 3D buildings available in this view are textured using composites of aerial photography and ground photograph. To view the 3D maps, users must install a plugin available freely in the website, then enable the "3D" option on "Bing Maps". In addition to exploring the maps using a mouse and keyboard, it is possible to navigate the 3D environment using an Xbox 360 controller or another game controller in Windows operating system.

Another important initiative taken by Microsoft under Bing Ma is generation of Global Ortho data. In July 2010, Microsoft and DigitalGlobe, a leading global content provider of high-resolution earth imagery solutions, announced the collection of the first imagery from the company's Advanced Ortho Aerial Program. Through a special agreement with Microsoft, the Advanced Ortho Aerial Program will provide wall-to-wall 30 cm aerial coverage for entire globe.

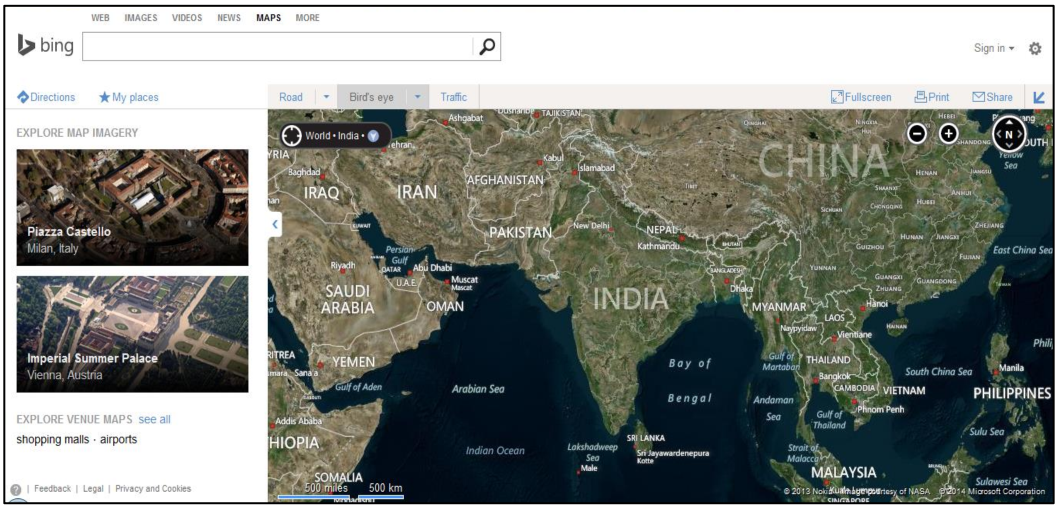

Figure 2- Bird eye view from Bing- http://www.bing.com/maps/?mkt=en-in)

2.1.3 OpenStreet Map- An approach using crowdsourcing

OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world using concept of crowdsourcing. The project was initiated by Steve Coast of UK in 2004. Since then, it has grown to over more than one million registered users who can collect data using GPS devices, aerial photography, and other free sources (Neis et al, 2012). The data generated through public participation is made available under the Open Database License. The site is supported by the OpenStreetMap Foundation, a non-profit organization registered in England.

In the initial phase the map data were originally collected from scratch by volunteers performing systematic ground surveys using a handheld GPS unit and a notebook, digital camera, or a voice recorder. The data were then entered into the OpenStreetMap database. Now OSM provides variety of tools and mode to create and update map data directly through internet by the registered users. Editing of maps can be done using the default web browser editor called iD which a HTML5 application written by MapBox. Another OSM editor which is Flash-based application and known as Potlatch is also available for web users. The desktop version of map creator and editor are known as JOSM and Merkaartor which are more powerful desktop editing applications and are better suited for advanced users.

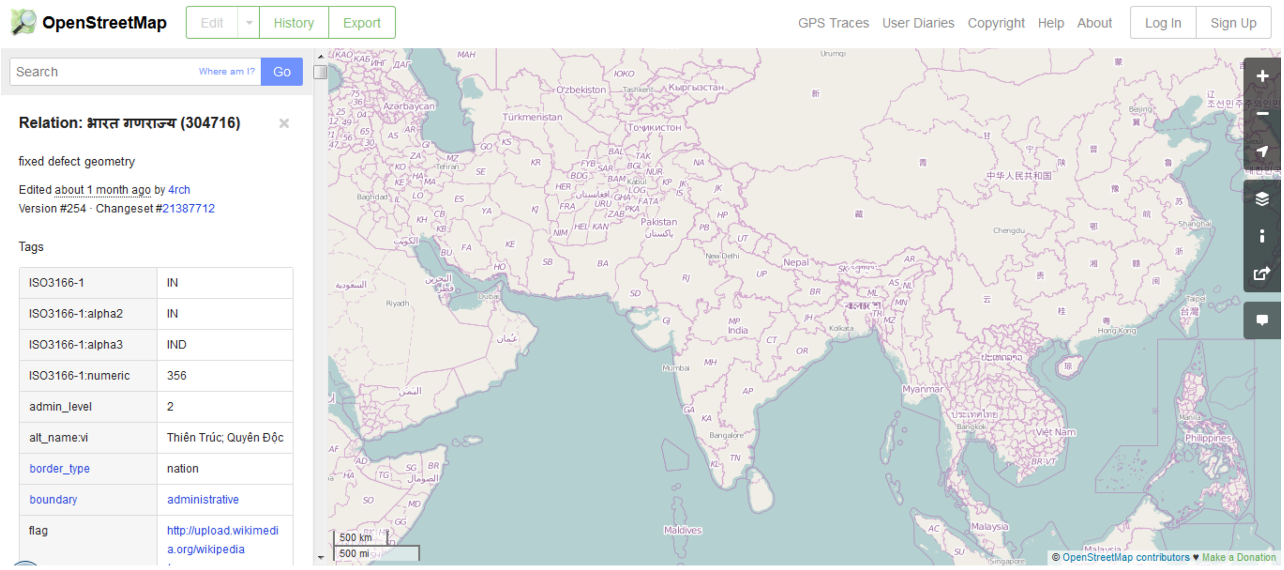

Figure 3. Home page of OpenStreetMap- http://www.openstreetmap.org

The satellite imagery from Bing Maps are available freely as background image for all the mapping applications of OSM by using which the geographic features are identified by the map creator.

The online mapping platform using concept of crowdsourcing or public participation is a key element of Openstreet map. Any user can create his/her account in the website and can start contributing the map creation as shown in Figure 4. In the online map editing tool, the three basic geometry types are provide to create the vector map. The spatial data structure is designed to create various map features and their attributes. The online mapping application provides the mapping utilities in multi-user environment so that many users can do mapping simultaneously. This participatory approach seems to be one of the best approach of mapping at large scale.

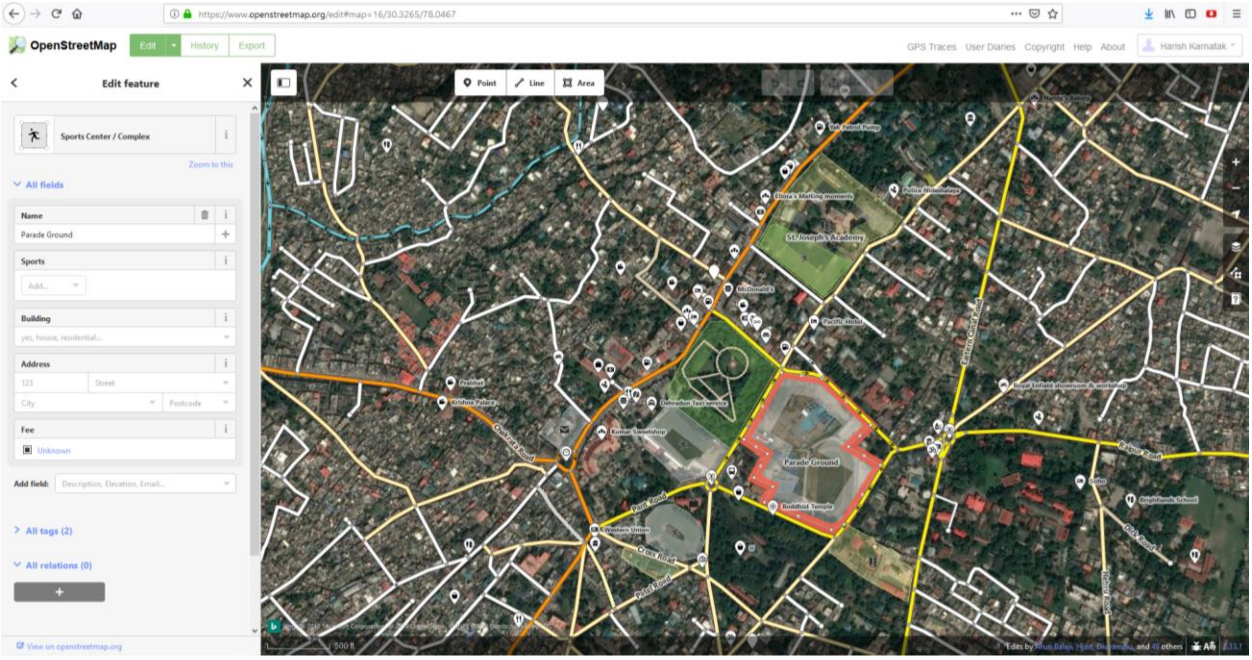

Figure 4. Map creation/editing for Dehradun city.

The OSM has designed a data models for different map features. The maps can be created for these predefined data models. For detail structure of OSM map feature please visit- http://wiki.openstreetmap.org/wiki/Map_Features .

The large scale maps can be downloaded from OSM website as .osm file which is a XML document and can be converted as vector data by using any third party software product like QGIS. Some of open service providers such as https://download.geofabrik.de/ are providing cloud based services to download the OSM data.

2.1.4 ArcGIS Online

ArcGIS online (www.esri.com/software/arcgis/arcgisonline) is a mapping service from ESRI. According to ESRI website, it is a collaborative, cloud-based platform that allows members of an organization to use, create, and share maps, apps, and data, including authoritative base maps published by ESRI. In ArcGIS online portal the user can use and create maps, access GIS layers and tools, publish data as web service, collaborate and share, access maps from any device, create spatial data using attribute data available in MS Excel, customize the ArcGIS Online website, and view status reports of their data. The ArcGIS Online can also be used as a platform to build custom location-based applications for mobile devices.

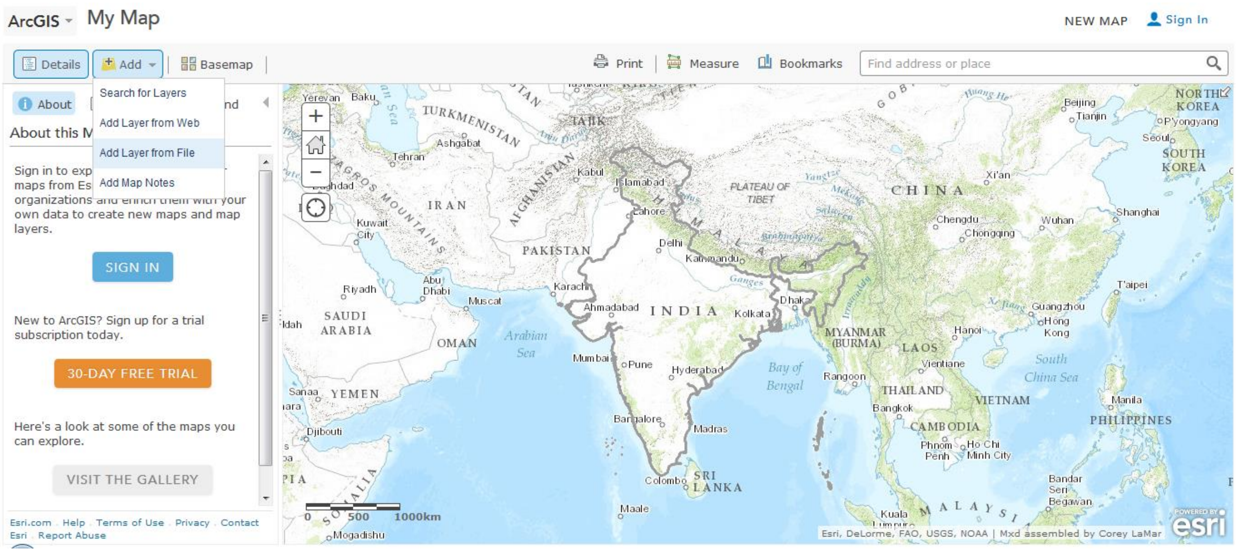

Figure 5. Map viewer of ArcGIS Online- http://www.arcgis.com

This mapping service is commercial, however the trial access for 30 days is available free of cost for any users. The users can access ArcGIS Online through web browsers, mobile devices, and desktop map viewers, as well as directly through other components of the ArcGIS system, for example, the web APIs and ArcGIS for Desktop.

2.1.5 GIS Cloud

GIS Cloud (www. giscloud.com) is the web based GIS developed based on cloud computing. It provides features and capabilities of desktop GIS through internet. GIS Cloud offers easy and efficient visualization, analysis and exploration of geographic information. The primary goals of the GIS Cloud platform are as follows; to simplify exchange of geographical information between users and offer an easy way to analyze this information regardless of the location of its users (www.giscloud.com). By using this mapping service the users can access the capabilities of desktop GIS such as geospatial analysis, spatial intelligence, the creation of customized mapping reports and publishing geographic analysis on the Web. The main differentiating characteristic of GIS cloud website is its unique vector visualization engine and vector based data analysis in web browser environment. It also supports wide range of vector and raster file and database formats.

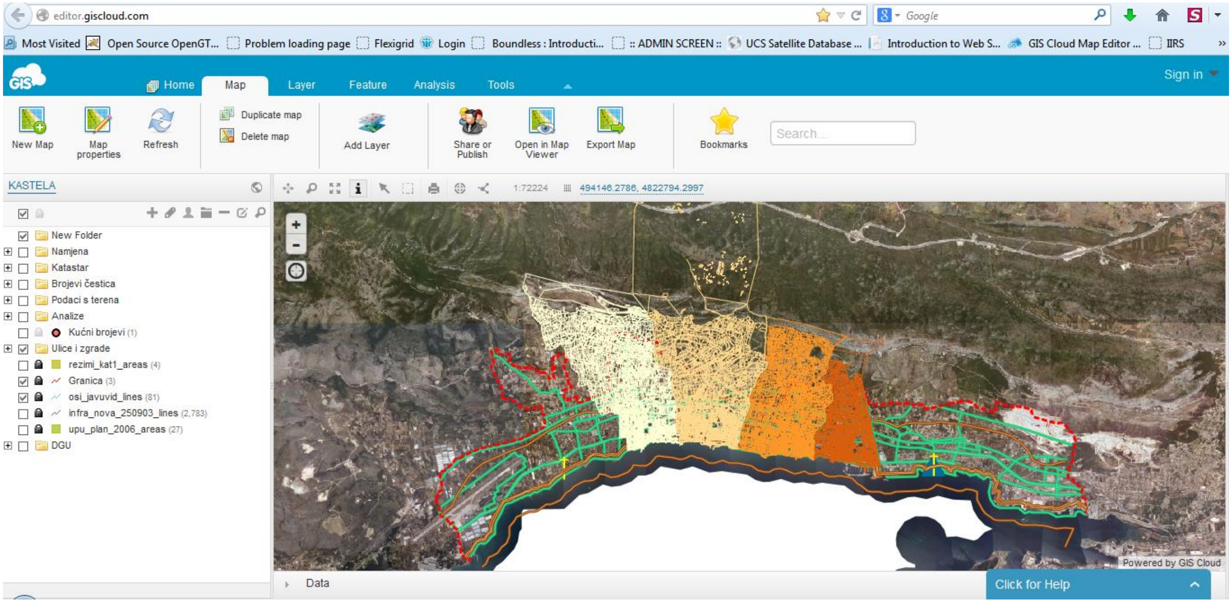

Figure 6. GIS cloud environment- http://www.giscloud.com

The Graphical User Interface (GUI) provides various tools and functionalities for GIS operations as shown in Figure 6. The various tabs are available like 'Map', 'Layer', 'feature', 'Analysis', and 'Tools'. The GUI looks like a standard desktop based GIS software. In addition to GIS data creation, analysis and processing, the GIS cloud also provide various utilities for location based services and mobile GIS. Mobile GIS based data collection system is freely available to the users however many other features are available under commercial mode. This mapping service also provide free trial version for 30 days for all the features of GIS cloud.

The complete operating manual of GIS cloud is available at http://www.giscloud.com/docs/GIS_Cloud_User_Manual.pdf.

2.2 Indian Geoportals and Geo-data repositories

2.2.1 ISRO Bhuvan

Bhuvan (the name is derived from the Sanskrit word which means Earth), a Geoportal of ISRO and Gateway to Indian Earth Observation Data Products and Services (http://bhuvan.nrsc.gov.in or www.bhuvan.nrsc.gov.in), is an initiative of Indian Space

Research Organisation (ISRO), Department of Space, Government of India, to evince the Indian Earth Observation capabilities from the Indian Remote Sensing (IRS) series of satellites. Buvan is hosted at National Remote Sensing Centre (NRSC) Hyderabad India. The satellite images showcased on Bhuvan are from Multi-sensor, Multi-platform and Multi-temporal domains with capabilities to overlay thematic information, derived from such satellite imageries, as vector layers on virtual globe for the benefit of user community. Apart from its unique visualization capabilities, Bhuvan also facilitates the users to download the satellite data and products through its Open EO Data Archive (NOEDA).

The unique features of Bhuvan are availability of uniform high resolution data (6 m spatial resolution from LISS IV and 2.5 meter spatial resolution from Cartosat) for entire Indian territory, multi-sensor temporal data from IRS series of satellites, rich thematic data and information (Soil, Land use Land Cover (LULC), wasteland, water resources etc), visualization of ISRO's AWS (Automatic Weather Stations) data/information in a graphic view and use tabular weather data of user choice, Ocean Services, Disaster Services (timely support and services from space systems), Collaboration/Sharing/Community Participation (Volunteered Geographic Information), OGC Web Services, Mobile Compatibility (supports Android, Symbian, iOS and Windows Operating Systems). The major components of Bhuvan geo-portal are:

2.2.1.1 Visualization

This component focused on geo-visualization of satellite images and thematic maps.

- **Bhuvan 3D:** This map viewer is available for geo-visualization of three dimensional data sets including digital elevation model (DEM) and other 3D features. Developed based on commercial software product known as skylineGlobe and freely available for download as plugin at user end. This map viewer provides various tools for spatial analysis such as terrain profile, terrain analysis, horizontal and vertical distance measurement, flood analysis, urban design etc,. As on April 2014, this 3D map viewer is compatible with windows operating system, however NRSC has also released beta version of 3D map viewer using JavaScript based WebGL which is compatible with all the operating systems.

- **Bhuvan 2D:** This map viewer is available as browser based web GIS application which developed using open source GIS software solutions. The OGC web service specifications are published for satellite images and thematic data sets. The map viewer provide seamless visualization of map layers at different zoom level. The spatial data up-to 1 meter spatial resolution is available in open public domain. Bhuvan2D also provides various tools such draw tool for map feature creation, measurement tool for area and distance, navigation tools, WMS manager etc.

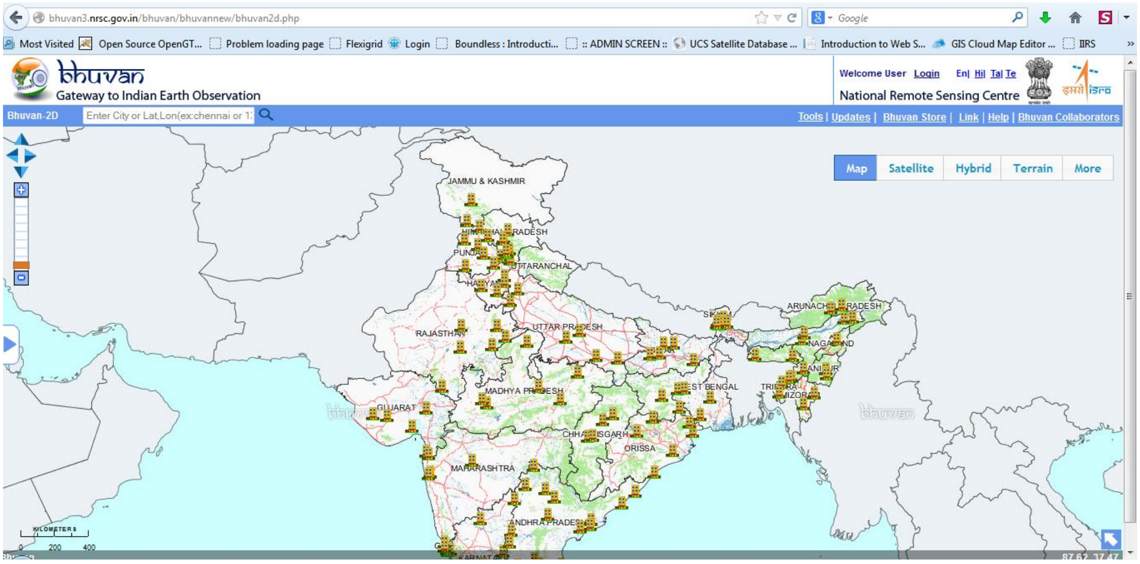

Figure 7. Bhuvan 2D map viewer- http://bhuvan.nrsc.gov.in

- **Pocket Bhuvan (Mobile Version of Bhuvan):** This is a mobile version of Bhuvan 2D geo-visualization. This application is compatable with all the mobile based web browsers. However Bhuvan also provides specific map application for Android and windows mobile operating system.

2.2.1.2 Services

This component provides access to various specialized services like:

- **Open Data Archive -**Allows download of free satellite data and products of specified period and resolution. This component is developed based on Remote Sensing Data Policy (RSPD)-2011 of ISRO.
- **Thematic Services -** To display and analyze thematic maps using WMS / WMTS (OGC web Services). The maps for different themes like LULC,

wasteland, urban land use, Geomorphology, Lineament, Flood inundation etc., are available with various tools and services.

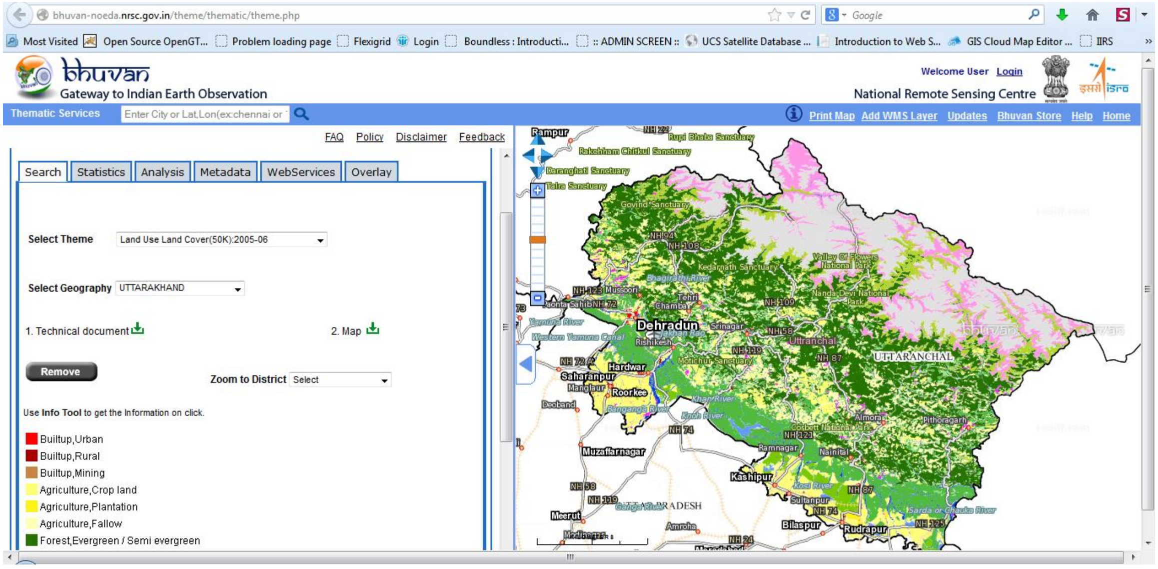

Figure 8. Map viewer for Bhuvan thematic services- http://bhuvan-noeda.nrsc.gov.in

- **Disaster Services-** To provide timely information on various disasters for better decision making. This component is developed based on ISRO disaster management support programme which address six natural disasters viz. Flood, Drought, Cyclone, landslide, Forest fire and Earthquake. The disaster event based historical data for above disasters are available under disaster services.
- **Weather Services- This component provide v**isualization of data from Automatic Weather Station (AWS) of ISRO in near real time as well as archived mode.
- **Ocean Services -** Visualization of Potential Fishing Zone, Sea Surface Temperature, Chlorophyll information.
- **Mapping Services-** Comprehensive application facilitating user to embed their local knowledge and create value added maps through association.

2.2.1.3 Application Sectors

This component provides platform to create, visualize, share, analyze Geospatial data products and services towards various applications areas such as Agriculture, E-

Governance, Events based spatial data and information, Forestry, Irrigation, Tourism, Urban etc.

Figure 9. WebGL based 3D map viewer of Bhuvan

In the recent past, Bhuvan geoportal is used as g-governance dashboard by various government departments and Ministries in India. ISRO has developed quite good number of mobile apps and online mapping applications to generated geo-tagged attribute data and thematic maps using crowdsourcing.

Geospatial Governance Dashboard- https://bhuvan-app1.nrsc.gov.in/sitemap/

Figure 10. Geospatial Governance Dashboard in Bhuvan Geoportal

The crowdsourcing has become one of the important source of data and information Bhuvan Geoportal. The geo-tagging in Bhuvan platform under various government flagship programme is successfully implemented in India. The Figure 11 shows the various geo-tagged assets under Mahatma Gandhi Rural Employment Guaranty Scheme (MGNREGA) of Ministry of Rural Development for Suyalbari Village Panchayat in Nainital District of Uttarakhand state:

Figure 11. Geo-tagged assets under MGNREGA programme in Bhuvan Geoportal

Similarly you can also search for your own village in Bhuvan geoportal. You can also look for any other flagship programme of government of India where the crowdsourcing successfully implemented.

2.2.2 National Spatial Data Infrastructure (NSDI)

In India the geo-spatial data is available with diverse organizations like Survey of India, National Remote Sensing Centre, Geological Survey of India, Forest Survey of India, etc in different data standard and formats. Department of Science and technology (DST) in collaboration with Department of Space Government of India (DOS) has taken up an initiative to establish a Indian National Spatial Data Infrastructure (NSDI) for public domain in participation of other government organizations, private sectors, academia, research centers and NGO's. The Indian NSDI is available as a web portal under URL *https://nsdiindia.gov.in*. The India NSDI Portal makes data access and sharing of geo-spatial data easier, faster, and less expensive for all levels of government and the public. Indian NSDI focuses on de-centralized approach with the major emphasis on:

- Development and maintenance of standard digital collections;
- Development of common solutions for discovery, access and use of spatial data;
- Building relationships among organizations;
- Increase the awareness and understanding of the vision, concepts and the benefits.

In the NSDI framework the data providers of geo-spatial data provides their data under single web portal as a web service. There is a NSDI clearing house for browsing and accessing the geo-spatial data.

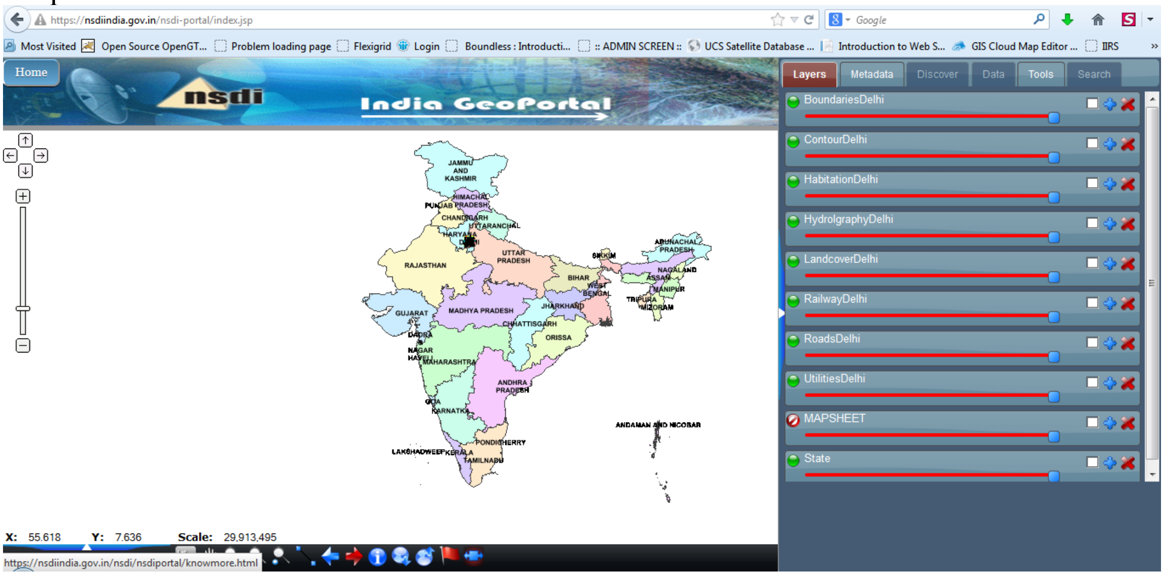

Figure 12. Map viewer and metadata search engine of Indian NSDI

The NSDI portal provides browser based map viewer to visualize and search the spatial data available with different NSDI partners. The main focus is on metadata creation and development of metadata search engine. The metadata for various spatial layers is created based on NSDI metadata standard. The NSDI portal acts as a gateway or clearing house for searching the spatial data available in the country with different mapping organizations.

2.2.3 Biodiversity Information System (BIS)

National Biodiversity Characterization at Landscape Level, a project jointly executed by Department of Biotechnology and Department of Space, was implemented to identify and map the potential biodiversity rich areas in India. This project has generated spatial information at three levels viz. Satellite based primary information (Vegetation Type map, spatial locations of road & village, Fire occurrence); geospatially derived or modeled information (Disturbance Index, Fragmentation, Biological Richness) and geospatially referenced field samples plots. This relatively large spatial information on the above-mentioned facets of biodiversity has been organized in a web based Biodiversity Information System (BIS) (http://bis.iirs.gov.in) for prioritization, conservation and bio-prospecting.

The spatial data available in BIS web portal is as following:

- Spatial Data on 1:50,000 scale for entire India
    - Vegetation Type map
    - Fragmentation map
    - Disturbance Index map an
    - Biological Richness map
- Species Database: Phytosociological database for 16,000+ sample plots for entire India

The portal provides information of high disturbance and high biological richness areas which are suggesting future management strategies and formulating action plans.

The BIS web portal provides data and information services under two major categories i.e. 'Biodiversity Spatial Viewer' and "Data Download.'. The Biodiversity spatial viewer provides the utility to visualize all the spatial maps available in the BIS portal along with many base layers and administrative boundaries. The data is available in original scale. The WMS and WFS based quires are available which can generate many user defined map outputs. The portal also integrates the satellite data from Bhuvan geo-portal as background image directly accessed as WMS layer from Bhuvan geo-portal.

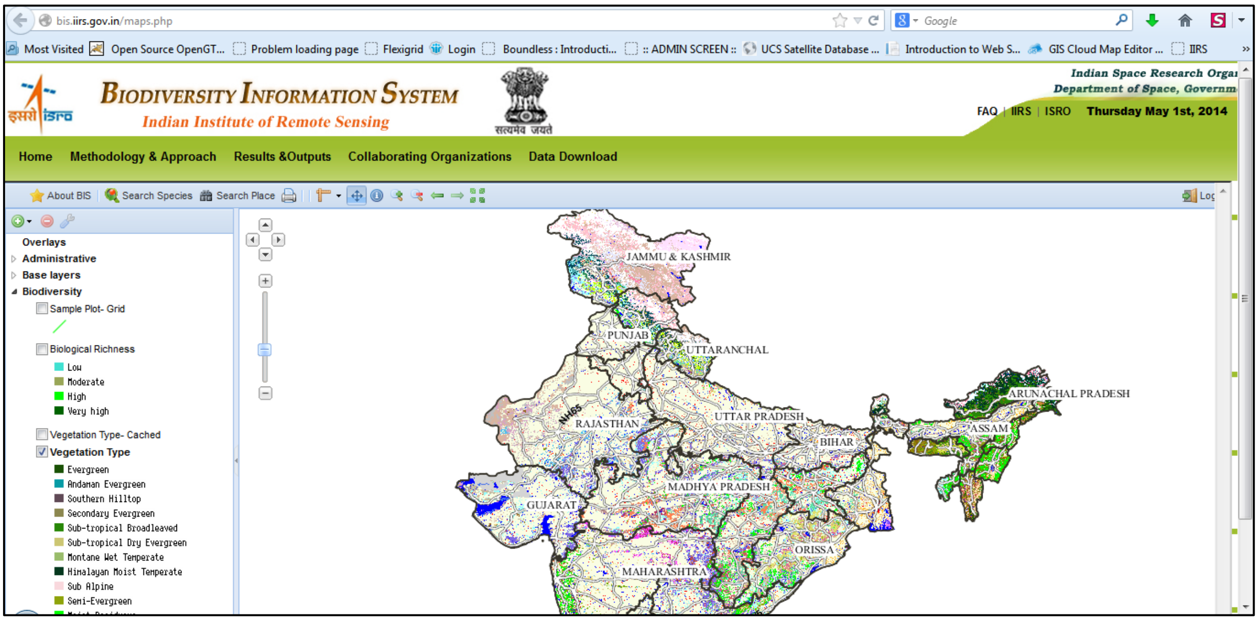

Figure 13. Biodiversity spatial viewer of BIS- https://bis.iirs.gov.in

Many unique features are available in biodiversity spatial viewer like overlay of local and remote maps through WMS URL, layer swiping utility for maps, WFS based query builder and filter utility etc. In addition to spatial data viewer BIS web portal also provide a data download utility in public domain. All the biodiversity data sets available in this website are freely downloadable through data download section. The user can define an Area of Interest (AOI) and select the map layer to download. The data download application will extract the data online and generate a quick data analysis report in real time mode.

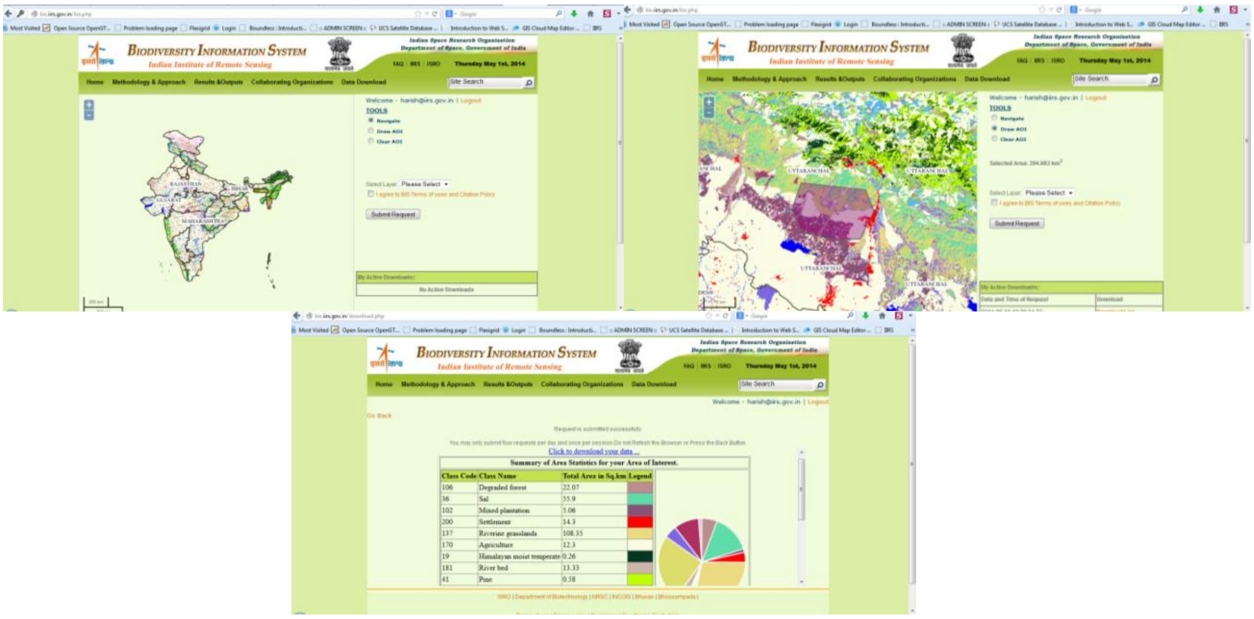

Figure 14. Data download and online analysis - https://bis.iirs.gov.in

The online data extraction and analysis for raster data are some of the unique features of Biodiversity Information System. This web portal is hosted at Indian Institute of Remote Sensing (IIRS), ISRO Dehradun India.

2.2.4 Indian Bioresource Information Network (IBIN)

Indian Bioresource Information Network (IBIN) (*www.ibin.gov.in*) is developed as a distributed national infrastructure to serve relevant information on diverse range of issues of bio-resources of India. IBIN web portal aims to offer a platform for all the data holders in the country to host their data at the same time maintaining their ownership on it. 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. IBIN portal provides platform to the diverse data providers in a mutually sharable environment with full ownership protocols. It aims at expanding the IBIN program through:

- Creation of an inter-communicating network of databases,
- Promoting an open ended and collaborative growth of participant digital databases and,
- Serving value added information on issues related to biological diversity and associated knowledge in multiple languages.

Data and information available in IBIN portal can be categories in two major categories:

- **Spatial Data Sets:** Under this category the maps generated in various projects on Bio-resources of India are hosted. The spatial data is available is an interactive map viewer with various queries and services developed on top of OGC web service specifications. The spatial data node provides access to primarily spatial data services. The browsing of different spatial and species data services is through biodiversity metadata catalogue.
- **Species Data Sets**: The species data is an attribute data available from various sources and different categories including plants, animals, microbes etc. Based on a common but flexible and indigenously developed inputting system, information was compiled from secondary sources. Suitable querying and outputting systems are also developed to retrieve different linkages among these databases. The data size of the compiled databases of all the groups till date accounts to about 6.8 GB on 39,000 species with 82,00,000 records.

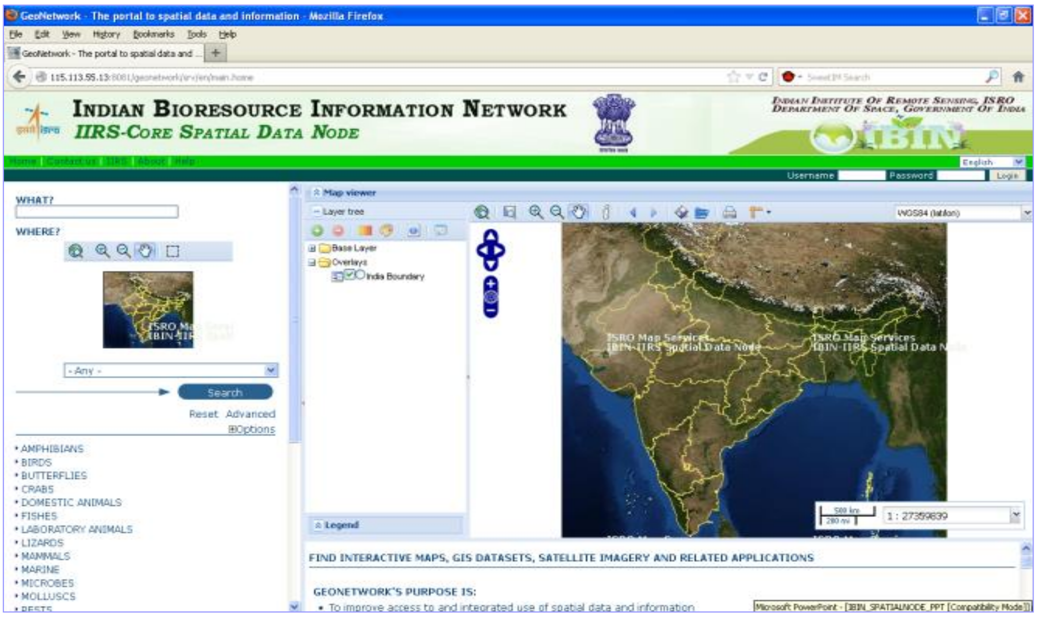

Figure 15. IBIN spatial node- www.ibin.gov.in

One of the unique feature of IBIN web portal is availability of different types of data related to Indian bio-resources in a single window. The spatial data is also available as a GIS data catalogue which allows various data search mechanism with good documentation in standard national framework.

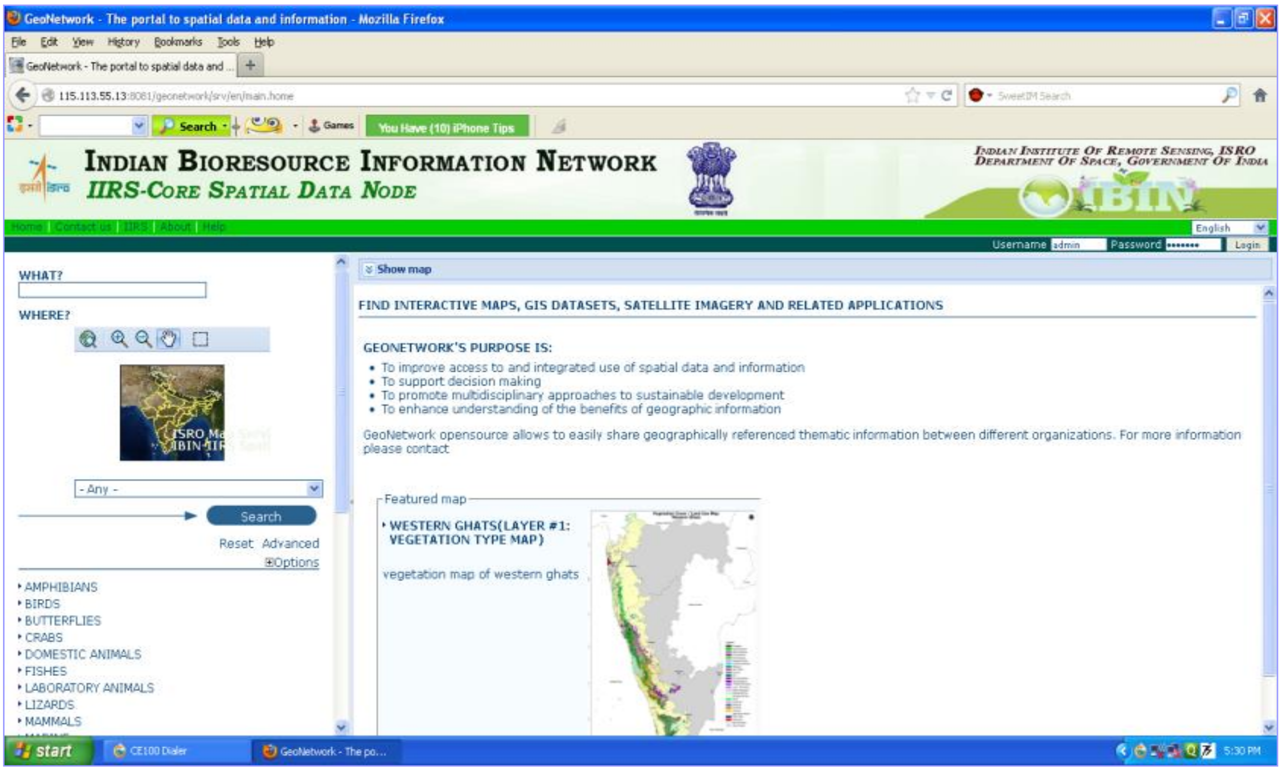

Figure 16. Metadata catalogue of IBIN geo-portal- www.ibin.gov.in

2.2.5 India-WRIS

India-WRIS WebGIS (https://indiawris.gov.in/wris/) Water information in Public domain - Initiative of India-WRIS Project with the aim of dissemination of data in public domain constitute the most important aspects of the water resources management. Information on the state of water resources is must for planning and water resources management strategy. Considering the challenges involved in the water resources sector, Government of India took an initiative for developing a centralised platform to act as a repository of water resources and related data at National level with administrative granularity up to the smaller units of governance at state level as well as hydrological level such as basin and sub basins. India-WRIS focuses on ensuring increase in public and stakeholders awareness about the present status of water resources and the need for its effective management by attracting their interest in leading towards the holistic goal of water security. New technologies like GIS and Remote sensing together with Water resources domain skills has proven its application in successful mapping, evaluation and management strategizing of the asset. This includes all varied sources data collection, standardization, and storage of the entire gamete of information on a nationalized scale. Hence, providing an operational system for all kind of users with increased visibility and global standard platform on public domain.

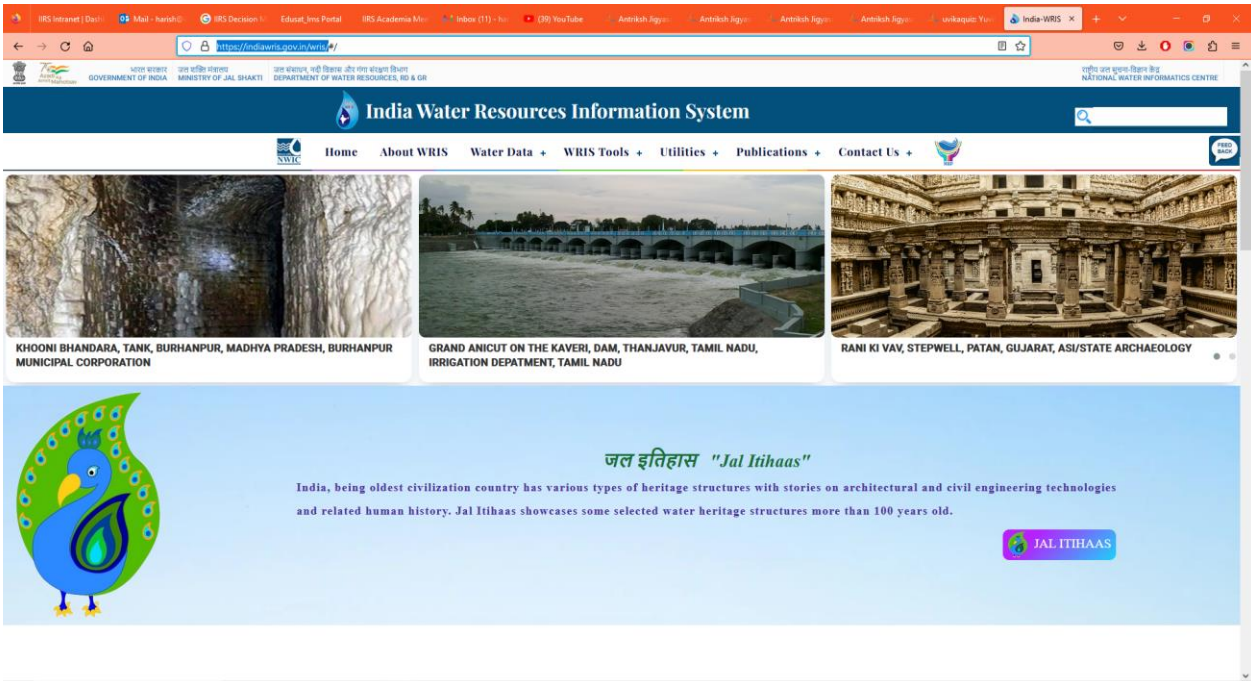

Figure 17. Home page of India-WRIS Web GIS portal- https://indiawris.gov.in/wris/

The generation of a database and the implementation of a web enabled Water Resources Information System popularly known as India-WRIS was initiated through a Memorandum of Understanding signed on December 3rd, 2008 between the Central Water Commission (CWC), Ministry of Water Resources, River Development and Ganga Rejuvenation (now Ministry of Jal Shakti) and the Indian Space Research Organization (ISRO), Department of Space. This project was funded by the Central Water Commission.

Under the National Hydrology Project, a central sector scheme approved by the Cabinet on April 6th, 2016 with the objective to improve the state of information on water resources, India WRIS has been fundamentally revised and improved, new modules and functionalities have been added and technologies have been updated. India-WRIS provides a single window solution for all water resources data and information in a standardized national GIS framework. It allows users to Search, Access, Visualize, Understand and Analyse comprehensive and contextual water data for the assessment, monitoring, planning and development of water resources in the context of Integrated Water Resources Management (IWRM).

India has 16% of the World's population, 2.4% of the World's land area and 4% of the World's fresh water resources. On an average, every year India receives 4,000 billion cubic meters (BCM, 1 BCM = 1 cubic km) of water by mostly rainfall and some snowfall. However, there are considerable spatial and temporal variations in the distribution of rainfall and hence in the availability of water in the country. It is estimated that out of the 4000 BCM of water, 1869 BCM are "available water resources". Out of this quantity only 1123 BCM (690 BCM from surface water resources and 433 BCM from ground water) can be put to use ("usable water resources"). The water demand in the year 2000 was 634 BCM and demand is expected to be 1093 BCM by the year 2025. Therefore, efforts need to be made to increase the utilizable quantity and manage demand by conservation, improving efficiencies and increasing supply sources. We are facing many challenges in the water sector. India WRIS is an important element to address these challenges, bringing all relevant water data on one nation-wide platform, making information available to users and creating the basis for a better management of our water resources.

The National Water Policy (2002) and (2012) recognizes that the development and the management of water resources need to be governed by national perspectives and aims to develop and conserve the scarce water resources in an integrated and environmentally sound way. The policy emphasizes the need for effective and economical management of our water resources by intensifying research efforts in the use of remote sensing technologies and developing an information system. The National Water Policy 2002, para 2 on Information System states:

A well-developed information system, for water related data in its entirety, at the national/ state level, is a prime requisite for resource planning. A standardized national information system should be established with a network of data banks and databases, integrating and strengthening the existing central and state agencies and improving the quality of data and the processing capabilities.

Standards for coding, classification, processing of data and methods / procedures for its collection should be adopted. Advances in information technology must be introduced to create a modern information system promoting free exchange of data among various agencies. Special efforts should be made to develop and continuously upgrade technological capability to collect process and disseminate reliable data in the desired time frame.

Apart from the data regarding water availability and actual water use, the system should also include comprehensive and reliable projections of future demands of water for diverse purposes.

The National Water Policy 2012 in its section 14 stipulates:

All hydrological data, other than those classified on national security consideration, should be in the public domain. However, a periodic review for further declassification of data may be carried out. A National Water Informatics Center should be established to collect, collate and process hydrologic data regularly from all over the country, conduct the preliminary processing, and maintain in open and transparent manner on a GIS platform.

In view of the likely climate change, much more data about snow and glaciers, evaporation, tidal hydrology and hydraulics, river geometry changes, erosion, sedimentation, etc. needs to be collected. A programme of such data collection needs to be developed and implemented.

All water related data, like rainfall, snowfall, geo-morphological, climatic, geological, surface water, ground water, water quality, ecological, water extraction and use, irrigated area, glaciers, etc., should be integrated with well-defined procedures and formats to ensure online updating and transfer of data to facilitate development of database for informed decision making in the management of water. The vision of a pan-India Water Resources Information System is also in line with the Hydro-Meteorological Data Dissemination Policy, formulated by the Ministry of Jal Shakti in November 2018, which has the objective to make non-sensitive data collected through the use of public funds available for legitimate use, enabling better decision making and meeting society's needs.

The vision of a Pan-India Water Resources Information System is also consistent with the Hydro-Meteorological Data Dissemination Policy, formulated by the Ministry of Jal Shakti in November 2018, which has the objective to make non-sensitive data collected through the use of public funds available for legitimate use, enabling better decision making and meeting society's needs.

India WRIS is managed by the National Water Informatics Centre (NWIC), a unit of the Ministry of Jal Shakti which has been created upon Cabinet approval by the Ministry of Water Resources, River Development and Ganga Rejuvenation (now Jal Shakti) vide notification of March 28th, 2018 to be a repository of nation-wide water resources data, providing a 'Single Window' source of updated data on water resources & allied themes. NWIC's mandate also is to provide value added products and services to all stake holders for its management and sustainable development.

3. Summary

The GIS based websites or web portals has attracted the attentions of GIS users in last one decades. The mapping organizations has started to publish their data as web service which allows various exciting new applications at user end. The GIS portals display geo-data on maps and gives tools to interact with the data. There are several mapping portals available in internet either in public domain or in closed domain. Most of the web portals are compatible with majority of web browsers such as Mozilla Firefox, Google chrome, Internet explorer, Safari etc. These web portals also allows GIS users to connect to one another and to share their geographic knowledge. The popular GIS portal are summarized here:

S. No.	Web Portal	URL	Specialty
1	Google maps	http://maps.google.com	Global satellite images and maps (2D and 3D) at street level with various applications
2	Bing Map	http://www.bing.com/maps/	Global satellite images and maps (roads and POI).
3	Openstreet Map	http://www.openstreetmap.org	Open and free vector data and collaborative mapping.
4	Wikimapia	http://wikimapia.org	Crowdsourcing approach for tagging ground information.
5	ISRO Bhuvan	http://bhuvan.nrsc.gov.in	Rich contents and seamless availability of multi-temporal, multi-resolution satellite data for entire Indian region. Thematic and disaster services.
6	MapMyIndia	http://www.maps.mapmyindia.com	Rich POI and detailed maps of India.
7	Indian NSDI	https://nsdiindia.gov.in	Metadata catalogue and policy document.
8	Biodiversity Information System	http://bis.iirs.gov.in	Biodiversity spatial viewer and data download utility. Rich data contents on plant biodiversity of India.
9	Indian Bio-resource Information Network	http://ibin.gov.in	Rich data contents for Indian Bio-resource information. System of distributed database.
10	India-WRIS	https://indiawris.gov.in/wris/	Rich data contents for water resources of India.
11	NIC GIS	http://gis.nic.in	Village level tagging of information in GIS domain.

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Chapter 10

Remote Sensing and GIS Applications in Marine Sciences

1. Introduction

The coastal zone is the interface where the land meets the ocean, encompassing shoreline environments as well as adjacent coastal water. Its components can include river deltas, coastal plains, wetlands, beaches and dunes, reefs, mangrove forests, lagoons, and other coastal features. The limit of coastal zone is often arbitrarily defined, differing widely among nations, and are often based on jurisdictional limits or demarcated by reasons of administrative ease. It has often been argued the coastal zone should include the land area from the watershed to the sea, which theoretically would make sense, as this is the zone where biophysical interactions are strongest.

For practical planning purposes, the coastal zone is a *special area*, endowed with special characteristics, whose boundaries are often determined by the specific problems to be tackled. Its characteristics are:

- It is a dynamic area with frequently changing biological, chemical, and geologic attributes.
- It includes highly productive and biologically diverse ecosystems that offer crucial nursery habitats for many reasons.
- Coastal zone features such as coral reefs, mangrove forests, and beach and dune systems serve as critical natural defenses against storms, flooding and erosion.
- Coastal ecosystems may act to moderate the impacts of pollution originating from land (for example, wetlands absorbing excess nutrients, sediments, human waste).
- The coast attracts vast human settlements due to its proximity to ocean's living and nonliving resources, as well as marine transportation and recreation.

2. Problems and issues in coastal developments

The coastal zones throughout the world are very precious and delicate ecological environments, both for man and for nature. Since they have often fertile soils, and are in favor by man through their location near the sea (ports, fisheries), the pressure on the yet undisturbed coastal zones is great. In addition, the coastal zones already inhabited and cultivated encounter often difficulties caused by the complex nature of the environment and conflicts of interest between the different inhabitants and users.

There are many coastal activities laying their own claims to the coastal zone. Main activities are transport, aquaculture, fishery, agriculture, forestry, human settlement, mining, recreation and tourism. For guiding and monitoring, the development of activities and their effects on the coastal zone, planning and management is needed to sustain coastal resources.

Some major problems encountered in coastal developments are:

- the deterioration of coastal resources by destruction, over-exploitation and un-economical use.
- development activities along the coast, which create many adverse affects on coastal resources.

- upland development activities having negative impact upon the downstream coastal areas.
- sea level rise and land fall resulting in inundation of coastal lowlands.

3. Critical issues of coastal zone management

The following issues are critical in context of coastal zone management

a) Coastal Habitat Conservation related

- Availability of benchmark or reference data (base line data)
- Preservation, conservation and monitoring of vital and critical habitats, e.g. coral reefs, mangroves, etc.
- Appropriate site selection for industries, landfall points, aquaculture, recreational activities, etc.
- Assessment of conditions in regulation zones, areas under construction set-back –lines, megacities
- Reclamation of wetland for agricultural and industrial purposes

b) Coastal Processes related

- Planning and implementation of coastal protection work (erosion, flood protection, salt water intrusion, etc.)
- Interactions between developmental activities and modification of coastal processes.
- Impact of dam construction on shoreline equilibrium
- Suspended sediment dynamics
- Changes in bottom topography

c) Coastal Hazards

- Cyclones, storm surges
- Coastal erosion
- Sea-level rise and possible effects
- Non-point and point pollution
- Phytoplankton blooms

d) Availability of resource and its utilisation (sand mining, fisheries).

4. Primary Applications of Remote Sensing for Coastal zone Study

Remote Sensing is used to address a wide variety of management and scientific issues in the coastal zone. Due to its repetitive, multispectral and synoptic nature, remote sensing data has proved to be extremely useful in providing multi-spectral information on various components of the coastal environment, viz. Coastal wetland conditions, mangrove and coral reef degradation, coastal landforms and shoreline changes, tidal boundaries, brackish water areas, suspended sediment dynamics, coastal currents, air pollution etc.

Different wavebands of light penetrate water to varying degrees; red light attenuates rapidly in water and does not penetrate deeper than 5 m or so, whereas blue light penetrates much further (15 m), and in clear water, the seabed will reflect enough light to be detected by a satellite sensor even when the depth of water approaches 30 m. The green light penetrates as far as 15 m in clear waters. NIR (0.7- 0.8 μm) penetrates to a maximum depth of 0.5 m and IR (0.8- 1.1μm) is fully absorbed (Mumby and Edwards 2000).

Importance of remotely sensed data for inventorying, mapping, monitoring of coastal zone was realized early. Due to its repetitive, multi-spectral and synoptic nature, remote sensing data has proved to be extremely useful in providing information on various components of the coastal environment, viz., coastal wetland conditions, mangroves and coral reefs degradation, coastal landforms and shoreline changes, tidal boundaries, suspended sediments dynamics, coastal currents, etc. IRS-1C/1D has LISS III and PAN which have proved to be extremely useful in the discrimination of dominant mangrove community zones, mapping details of ports and harbour areas as well as in assessing damage due to cyclones in the coastal areas, delineation of coastal regulation zone, shoreline changes, etc. (Nayak et al 1996, Mitra et al 2000).

Erosion/accretion and Shoreline changes and can be seen from the Figure 1

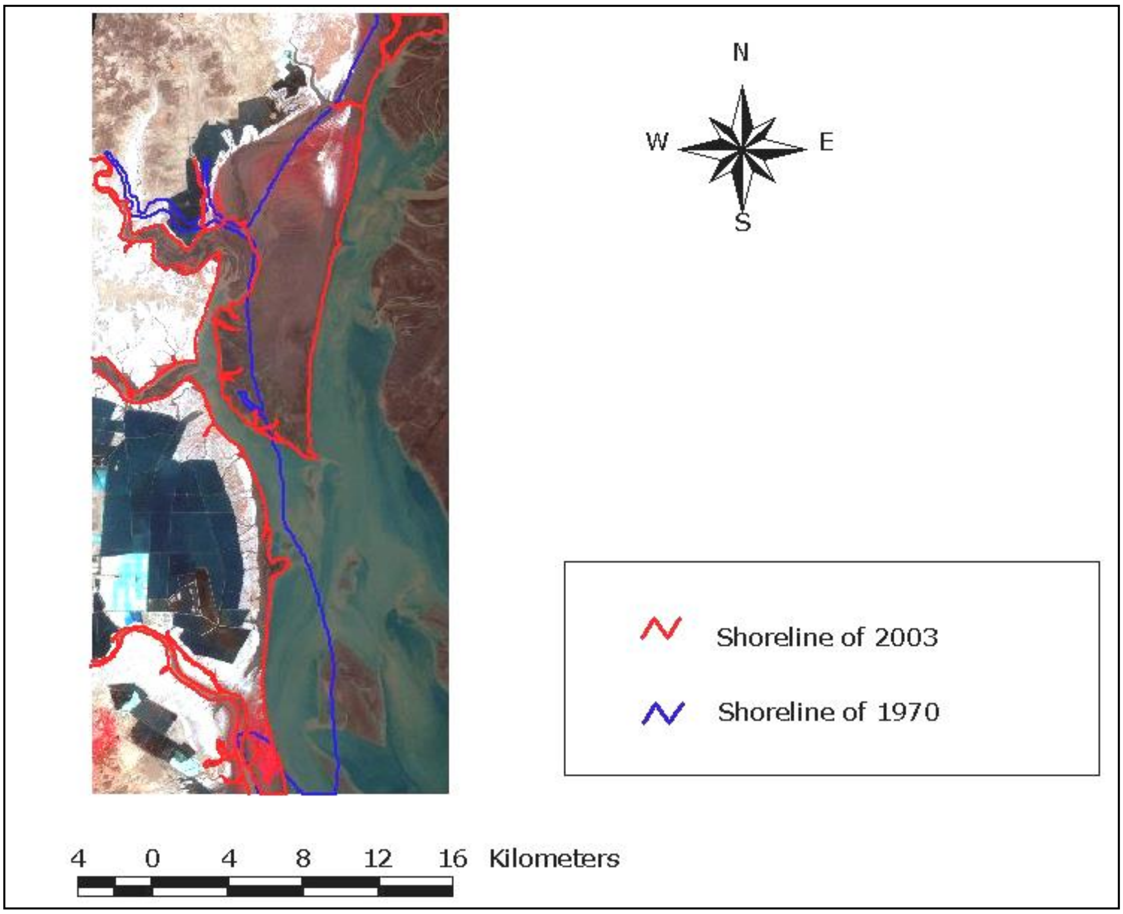

Figure 1. Shoreline Changes in a part of Khambhat, Gujarat

5. Ocean Colour

Phytoplankton forms the first link in the ocean food chain and gives an indication about the standing stock of green biomass, which helps in predicting the third level productivity. The varying levels of phytoplankton pigment (Chlorophyll-a) and other constituents impart colour varying from bluish to greenish to brownish. Hence, a satellite-based observing system having narrow spectral bands in the visible region is providing better insight into our understanding of the ocean productivity. It will also provide better understanding of the role played by ocean productivity in the uptake of carbon dioxide from atmosphere. IRS P4 OCM has been providing ocean colour data every two days for the Indian regions (Figure 2). Various models are under development to estimate primary productivity.

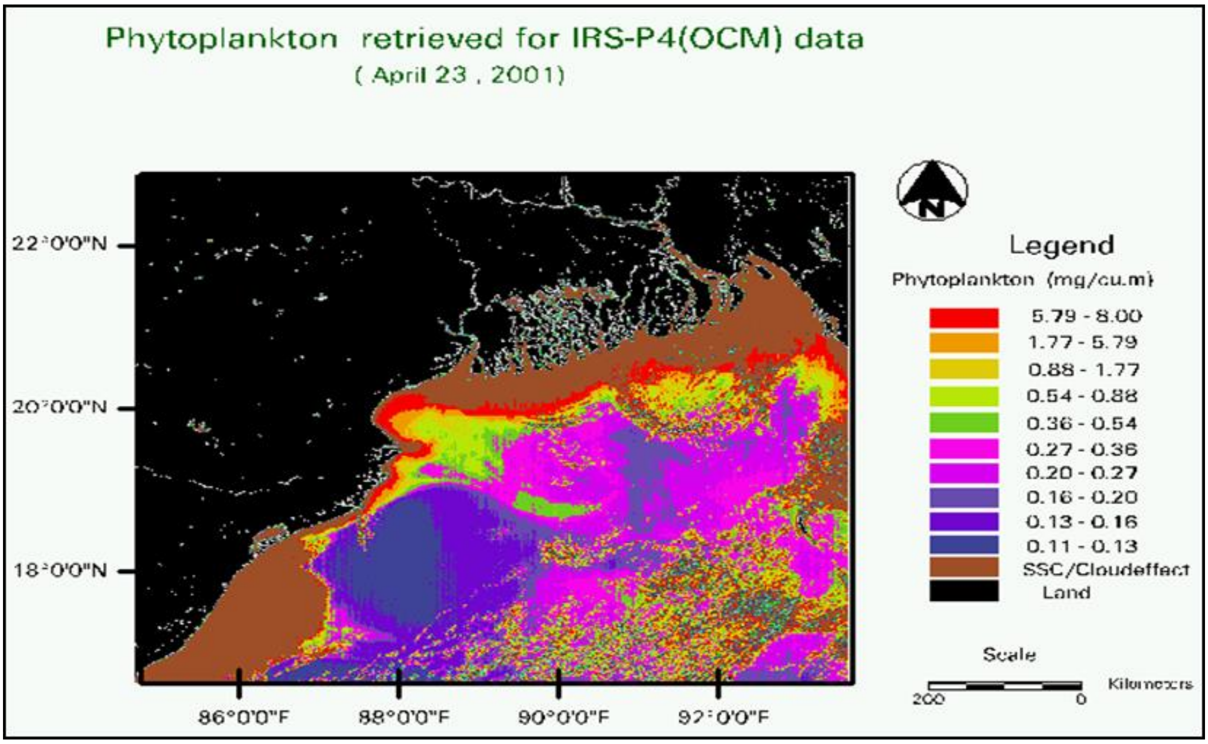

Figure 2. Phytoplankton map of part of East Coast of India

6. Bathymetry

The knowledge about depth values is important for coastal zone managers and navigators, for exploration and exploitation of non-living and living resources, operations on engineering structures and ocean circulation studies. Tides and currents constantly modify the submerged land-mass which prove hazardous for navigators. Updating the bathymetric charts by conventional methods is time consuming and expensive. Remote sensing is relatively cheap and fast method for periodically updating navigational routes. It is also useful technique for detecting new reefs and shoals. The water depth that permits detection of the bottom depends upon water colour, turbidity, bottom reflectance and intensity of incident light (Polcyn, 1976). The principal advantage of satellite data is the repetitive coverage. IRS data can be used for updating medium and small scales nautical charts (Figure 3). Techniques have been developed to retrieve depth values using high-resolution satellite data in shallow parts of sea (Vyas and Andharia, 1988) and

Synthetic Aperture Radar (SAR) image data in coastal regions (Rajkumar et al. 1998). It was observed that inferred depths vary about 10-15 % as compared to published charts. However, these methods are not routinely used for updating navigational charts.

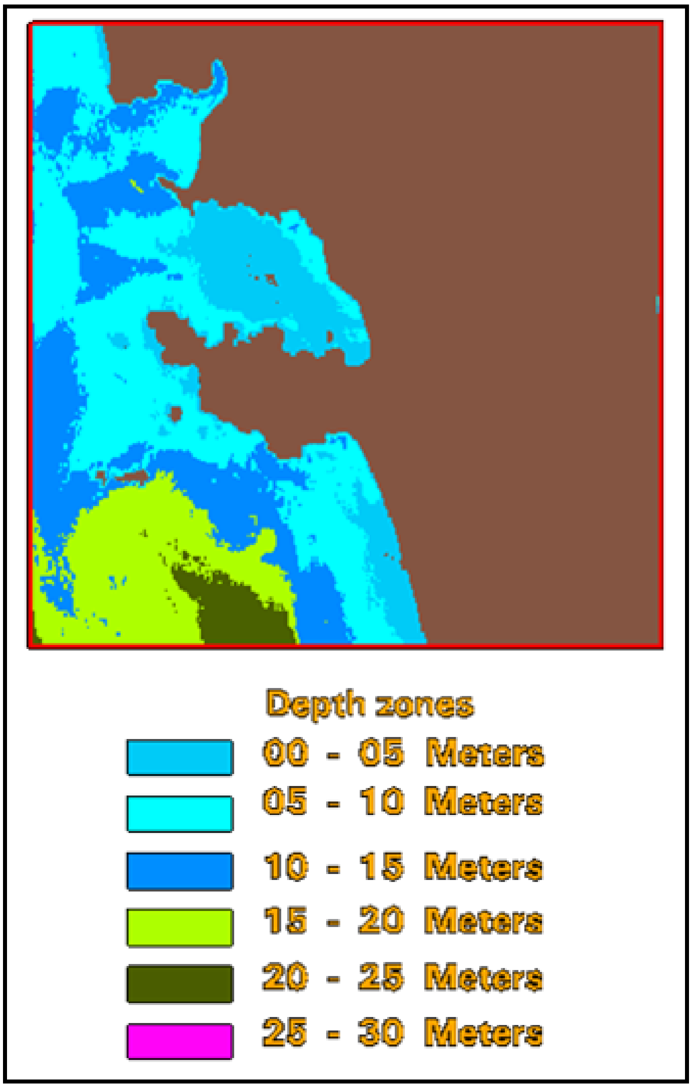

Figure 3. Bathymetry predictions through satellite data in parts of Goa region

7. Tsunami warning system in India

India unveiled its own tsunami early warning system put together by its scientists, three years after being caught off guard by the giant killer waves that wreaked havoc along the country's southern coastline. The tsunami warning centre, which has taken shape at the Indian National Centre for Ocean Information Services (INCOIS), will issue alerts for the killer waves within 30 minutes of an earthquake. The Centre will generate and give timely advisories to the Ministry of Home Affairs for dissemination to the public for which a satellite-based virtual private network for disaster management support has been established.

8. Potential Fishing Zones

India has high potential for marine fisheries development. The present fish production in the country is mainly from the coastal waters (up to depth of 50 m). The remote sensing satellites with their capability to monitor large spatial areas over oceans on a routine- basis, have proven to be of substantial economic benefit, particularly for a nation like India having a long coastline and extensive EEZ. The AVHRR data from NOAA satellites are being used in India to determine SST at 1.1 km^2 pixel level over Indian oceanic region on daily and weekly (composite) basis by the National Remote Sensing Agency, Hyderabad. The potential Fishing Zone (PFZ) maps are generated based on oceanographic features such as thermal boundaries, fronts, eddies, rings, gyres, meanders and upwelling regions visible on 3-4 days composite map of SST. The extensive validation of these SST estimates with data collected by research vessels/drifting buoys has shown an accuracy of measurement of $\pm$ 0.7^o C (NRSA, 1992). The major inadequacy of thermal infrared sensors is that it will measure ocean surface temperature only through a cloud-free atmosphere and strictly, the ocean skin temperature.

Currently, efforts are on-going to provide integrated fishery forecasting with the scenario of availability of new sensors optimised for deriving various other ocean features in the coming years. The relationship between chlorophyll and SST is being studied (Solanki et al. 1998). The data from Ocean Colour Monitor (OCM) sensor, launched in May 1999 on-board IRS-P4 (Oceansat-1) has been used to develop model to integrate chlorophyll information along with SST as a first step towards providing fishery forecast to predict likely availability of fishes more accurately (Figure 4). The information on surface wave, wind, topography, coastal circulation using microwave data that will become operationally available from planned series by different space-faring nations will also assist in developing an integrated model for fishery forecasting.

Apart from this, new resources through sea ranching and mariculture in enclosed and semi-enclosed bodies will have to be tapped.

An approach for integration of chlorophyll concentration and sea surface temperature features for fishery resources exploration using Ocean Colour Monitor (OCM)- derived CC and AVHRR-derived SST was developed by Solanki et al. (2000). The methodology for integration of CC and SST were validated through direct fishing and a ~70% success rate was observed (Solanki et al. 2003). Wind-induced ocean flow affects oceanographic processes through surface-layer transport and vertical transport of water mass. The knowledge of the surface layer transport processes is important in fisheries because the dispersal mechanism controls the distribution of early life stages, thereby influencing the recruitment and fishery stock. Wind velocity also affects the formation, persistence and decay of different types of oceanographic features. The shift in the oceanographic features due to wind was observed in OCM chlorophyll images (Chandran et al. 2004, Solanki et al. 2005a). Eslinger and Iverson (1986) studied the wind effect on Coastal Zone Colour Scanner (CZCS) chlorophyll patterns in the Mid-Atlantic Bight. They observed that increased chlorophyll concentration in the offshore waters was associated with high wind speeds during May when a deep chlorophyll maximum was present. An improved PFZ forecast approach was developed by Solanki et al. (2005a) with inclusion of QuikSCAT/SeaWinds derived sea surface winds (SSW). The present study investigates synergistic application of CC, SST and SSW to generate PFZ forecasts, with concurrent validation of experimental PFZ forecasts carried out during 2004 and 2005 by direct fishing and analysis of fishing operations data and their statistical significance.

Figure 4. Potential Fishing Zone Map derived from satellite data

9. Status on Utilization of Remote Sensing data for coastal studies in India

Resources/Parameters/Processes	Remote Sensing compliances	Status
Mangrove, Coral reefs, Salt pans, Aquaculture, wetlands, Other coastal inland resources	Mapping and monitoring in different scale.	Operational using high resolutions multispectral sensors data from IRS series.
Fisheries	Forecasting and monitoring	Semi operational with NOAA and IRS-P4
Mineral and Energy	Exploration and Monitoring	R & D stage with existing RS data
Coastal Geomorphology and shoreline changes	Mapping and Monitoring in different scales	Operational High Resolution Data from IRS Series
SST, Winds, Waves, Water vapour content etc.	Fishery forecasting, Monsoon, Ocean and atmospheric studies	Operational with IRS –P4 and other foreign satellites
Upwelling, Eddies, Gyres etc	Fishery and Ocean Dynamics studies	Operational with IRS-P4 and others
Coastal Regulation Zone	Mapping and monitoring in 1:50,000 and 1:25,000 scale	Operational using IRS 1C and IRS 1D
Suspended sediment Concentration	Mapping and Monitoring	Semi operational with IRS –P4
Oil Slicks	Mapping and monitoring	Semi operational with IRS series and

Resources/Parameters/Processes	Remote Sensing compliances	Status
		other foreign satellites
Chlorophyll concentration	Mapping and monitoring	Semi operational with IRS P4
Currents and Surface Circulation Patterns	Mapping and Monitoring	Semi operational with IRS series and other foreign satellites

10. Major Projects carried out along the Indian Coast using remote sensing data

With the availability of Landsat sensors data in India, Government of India initiated a major programme for mapping of coastal resources and for sustainable utilization. With the launch of IRS satellites coastal zone mapping and monitoring at National Level became an imperative for planning and administrative purposes. Space Application Centre (SAC) in association with Regional Remote Sensing Service Centres and State Remote Sensing Application Centres carried out several projects as follows:

i. Coastal zone mapping for the entire country in 1:250,000 and 1:50,000 scale
ii. Wetland Mapping in 1:250,000 scale for the entire country and 1:50,000 scale in selected areas
iii. Coral reefs and Mangroves area mapping in 1:50,000 scale
iv. Shoreline changes for the entire Indian coast in 1:250,000 scale and 1:50,000 scale in selected areas
v. Coastal land form studies in 1:250,000 for the entire Indian coast and 1:50,000 in selected areas
vi. Lagoonal/Lake studies in 1:50,000 scale

vii. Mapping of Coastal Regulation Zone (CRZ) in 1:25,000 scale for the entire Indian Coast using high resolution data from IRS and SPOT
viii. Integrated Coastal Management studies
ix. Identification of suitable sites for brackish water aquaculture

11. Future Prospect and Challenges for remote sensing for Marine Science

The major gap areas in the field of ocean applications are in observations of ocean salinity, surface pressure, wave spectra, sea level anomaly and more frequent observations of wind vector and coastal ocean parameters and estimation of SST with better resolution especially in the Indian Ocean region. The major task in biological ocean application is algorithm development for case II waters and validation of ocean colour products and estimation of primary productivity and fish stock assessment. There is a need to carry out coastal processes study and develop coastal zone information system (CZIS). Major gap area in this field is simultaneous observation of ocean colour and sea surface temperature.

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Important Websites

http://www.nesdis.noaa.gov/

http://www.ioccg.org/

http://www.nodc.noaa.gov/SatelliteData/

http://www.environment.sa.gov.au/coasts/management.html

http://shorelines.dnr.state.md.us/coastalProcesses.asp

http://www.oceanexplorer.noaa.gov/technology/tools/mapping/mapping.html

Chapter 11

Geospatial applications in Urban and Regional Planning

1. Introduction

Urbanization is inevitable, when pressure on land is high, agriculture incomes are low and population increases are excessive, as is the case in most of the developing countries of the world. Urbanization has been both, one of the principal manifestation as well as an engine of change, and it has been the 20th and also the 21st century which have witnessed the maximum urban transition for human society. In a way, urbanization is desirable for human development. However, uncontrolled urbanization has been responsible for many of the problems, our cities face today, resulting in substandard living environment, acute problems of drinking water, noise and air pollution, disposal of waste, traffic congestion, etc. A large population of the cities in the developing countries live in poverty and under miserable conditions. The city is no longer the exclusive habitat of the educated and the elite. It is now the poor who determine a great part of the city's political character, economic base and social profile. To improve these environmental degradations in and around the cities, the technological development in related fields have to address to these problems caused by rapid urbanization, only then the fruits of development will percolate to the most deprived ones.

2. Urbanization as a Global Phenomenon

The world now lives in cities and towns. The twentieth and twenty-first centuries have witnessed rapid industrialization and urbanization of the world's population. The global proportion of urban population has increased from a mere 13% in 1900 to 29% in 1950 and has reached >55% (>4 billion) by 2020 as a result of higher population growth and migration due to globalization, occupying nearly 1% of the land area (Ritchie & Roser, 2018). About 3.5 billion people live in urban areas and as the world is projected to continue to urbanize, around 62% of the 8 billion global population, that is, about 5 billion is expected to live in cities by 2030. The striking differences in urban population change between developed and developing nations is that in 2005, around 74% of population of developed nations was urban as compared to 43% in developing nations, but by 2030 the developing nations would have 56% of their population in urban areas and around 81% in the developed nations (UN, 2001 and 2006). The developed nations also differ from developing nations with regard to number of megacities (with population 10 million and more). Such a demographic trend in the developing countries leads to greater stress on the natural resources and quality of life, both within and outside the urban areas. During the coming decades, the urban areas of developing countries are projected to absorb a major share of global population growth for various reasons. Thus, the speed and scale of urbanization would pose important challenges for urban planners and government in developing countries. Further, as the urban areas are considered as drivers of economic, social, political and cultural change, they are also viewed as a phenomenon with mainly negative consequences as far as quality of life is concerned. The developmental initiatives must address the enormous challenges and make the best of the opportunities brought by the growing urbanization scenarios to provide sustainable solutions to urban problems in the 21st century.

3. Urbanization Scenario in India

Urbanization phenomenon is no exception to India; in fact, Indian cities are one of the fastest growing in terms of population and in geographical area among most of the cities outside India. Though, the level of urbanization in India, in comparison to the world scenario, appears much lower. The migration of people from villages to towns and cities continues unabated. The rapid urban growth has resulted in increasing the share of India's urban population from 159 million (23%) in 1981 to 217 million (26%) in 1991, to 286 million (28%) in 2001 and 377 million (31.16%) in 2011. Thus, post-independence, while the population of India has grown three times, the urban population has grown five times. The total number of urban settlements have increased from 4029 (1981) to 4689 (1991), 5161 (2001) to 7935 (2011). The 7935 towns and cities house 377 million of the urban population (Table-1). The average population density/sq.km of the country is 370 persons/sq.km, whereas the urban population density is at 1260 persons/sq.km within an area of 26 million hectares or 0.6% of country's geographical area in 2006. The urban population in the country is expected to rise further around 600 million by 2030 (WUP, 2018). India's population is likely to reach around 1.50 billion by 2030, according to a UN projection (2001); it is also estimated that close to half the country's population would be living in cities by then. However, the number is projected to be around 590 million (40%) - UNFPA Report (2007). Thus, we are likely to face a scenario where a large number of people would have to live in smaller geographical areas. In 1991, India had 23 million plus cities and a decade later in 2001; this number has increased to 35 out of which 6 are megacities with 5 'million plus's population. In 2011, it is further increased to 53 million plus urban agglomerations with eight 5 'million plus's population Further, urban India contributes to over 65% of the National GDP.

Table-1: Growth in Number of Urban Settlements: 1901-2051

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: Census of India.

City development authorities in India are unable to keep pace with the increasingly growing demands of the basic amenities and services in urban areas. While the urban areas continue to contribute to country's economy and employment, they suffer from lack of open spaces, inadequacy in infrastructure, overcrowding and congestion, mushrooming of slums, lack of drinking water supply and sanitation, insufficient solid waste disposal sites, inadequate green cover and living environment that is highly unsustainable thus, leading to poor quality of life. Indian urban population of 377 million as per 2011 census is more than the total population of many European Nations put together. Nevertheless, living environment of our cities is far from satisfactory by any standard. In 1901, less than 11% of the population of India lived in urban areas. By 2011, this increased to 31.16% and by 2051 it is expected to rise to 47.50% of the total population. Apart from these common problems, some of the major urban centres are facing a variety of environmental problems like disasters and social problems for example shifting of industrial activity to outside city areas and so on. Thus, urban areas of today are posing major challenges which call for greater efforts for urban planning and management, especially when they are gearing for new investments and economic activities after liberalization of economic and investment policies in the country for over a decade since 1990. Therefore, for the proper planning and management of the urban areas and the process of urbanization, there is an urgent need to provide accurate and timely geospatial information that will assist the planners and decision makers in understanding, planning and managing the changing urban environment.

From the Table 1, it is clear that emerging canvas is towards an integrated urban-rural continuum as the key for a balanced urbanization. By 2051, it is expected that around 820 million persons would reside in about just 6500 urban agglomerations, whereas, over 906 million persons would be spread over nearly 570,000 rural settlements. Trend indicates that settlements and their outward spread would continue eating into lands required for agriculture, forest cover and even wetlands and by 2051, it is forecasted that a further 10 million hectares of good agricultural land would be eaten by such expansion and their linkages. By 2051, a decreasing amount of agricultural land would be available to cater to a near doubling of food production after protecting forest owned lands, water courses and wetlands. The Special Economic Zones (SEZs) are a typical example of this scenario. Also, it has to be underlined, that the number of urban settlements has not increased in proportion to increase in urban population. Therefore, most urban settlements would get larger both through vertical and guarded horizontal expansion. By 2051, India would be the most populous country in the world with over 1.70 billion people on fixed quantum of land. By then, the land: man ratio would drop to 0.19 hectares per capita (0.95 in China) against 1.28 in 1901 and 0.32 in 2001 (1.33 in China). Land is, therefore a scarce and diminishing resource.

This process of urbanization is not only the indicator of the shift of urban population from rural to urban areas, but also the indication of social and economic changes associated with that shift, such as changes in occupation, attitudes, values and life styles. As the process of urbanization is inevitable, and indeed it should not be stopped, but it can be regulated. Therefore, in developing countries the "Planned urbanization and regulated urban growth" is required. In achieving this goal of planned urbanization and regulated urban growth, modern technologies have a role to play. The planners engaged in this herculean task should, therefore, have access to the technological developments taking place in various fields, specially, with regard to physical inputs, where newly emerging techniques of remote sensing and GIS can play a vital role in monitoring/ updating and thematic information about land, soils, water, vegetation, etc.

4. Definition of Urban Settlements

As per Census of India, the definition of urban areas (http://censusindia.gov.in/2011-prov-results/paper2/data_files/India2/1.%20Data %20Highlight.pdf) are as follows -

a. **Statutory Towns**: These towns are notified under law by the concerned State/ Union Territory Government and have local bodies like Municipal Corporations, Municipalities, Municipal Committees, Cantonment Board or Notified Town Area Committee, etc. irrespective of their demographic characteristics.

b. **Census Towns:** These towns meet following criteria- i) population is more than 5,000, ii) 75% of its male main working population is engaged in non-agricultural activities and iii) Population density is more than 400 persons per hectare.

c. **Urban Agglomerations (UAs):** A continuous urban spread comprising one or more towns and their adjoining out growth(s). An urban agglomeration must consist of at least a statutory town and its total population (i.e. all the constituents put together) should not be less than 20,000 as per the 2001 Census.

d. **Out Growths (OGs):** It is the area around a core city or town, consisting of well recognized places, like, Railway colony, University campus, Port area, etc., normally lying beyond the town limits.

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. The classification of towns in India as per the above mentioned six fold classification, for the census years 2001 and 2011 is depicted in Table 2.

Table-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

5. Problems of Physical Planners

In such scenario of rapid urbanization, both in terms of population growth and areal expansion in most of the urban centers/ areas, the planners need of updated information of physical growth, and its trends is not only essential but is of critical importance. The physical planners need this information/ data for preparing to development plans. For such development plans to be really effective and meaningful, are to be naturally based on information and other physical data derived from maps which are updated. However, preparation of such maps on adequate scales and periodicity is a gigantic task. Moreover, problems of keeping these maps up-to-date are further compounded because of the fact that in most of the developing countries, urbanization is taking place at a very rapid pace.

In India, the problems of such rapid urbanization becomes more complex because of the "spontaneous developments" on account of huge immigration of people from rural areas to cities in search of jobs and livelihood. In such a situation of great influx, mapping requirements becomes more urgent. However, on the contrary, in our country, such mapping as is required by urban, rural and regional planners and revenue departments, both in urban and rural areas (cadastral maps) is neither organized at appropriate levels (State/District/Towns) nor geared to tackle such problems arising due to rapid urbanization and has remained almost aloof from the modern survey and mapping techniques. The modernization in survey and mapping techniques that have taken place in India has remained confined to the national mapping organization, and fruits of such modernization have not adequately passing on to the organization involved in mapping such as State Cadastral Survey Organization, State/District/City level planning departments and town and country planning organization. All these organizations, therefore, look forward to and depend on the national mapping organization for their survey and mapping requirements.

These are considerable areas in the country which have not been surveyed for cadastral mapping, and in some areas, the cadastral records still remain primitive, and unaffected by modernization. Lack of adequate urban land use data on regular basis which can form the bases for planning and execution of various development schemes is a big hindrance in urban development in a planned manner. Absence of large scale urban maps and their updating at regular interval is a big challenge.

6. Information Need and Mapping Program

An urban area is a complex ensemble of interrelated and tangled socio-economic, spatial and environmental processes. Irreversible demographic changes being witnessed in an urban set-up poses threat to the rapidly depleting resources. Therefore, the study of urban footprints and the services with associated infrastructure is a compelling subject for urban planners. Although, planning has more to say about cities, it is equally imperative to explore all perspectives of a holistic regional development keeping in view the social, economic, cultural, environmental and governance issues. Interestingly, with the advent of Smart city concept, the conceptualization of the six key enablers of the Mission viz. Smart Governance, Smart Living, Smart People, Smart Mobility, Smart Environment and Smart Economy, finds its complete implementation scope in spatial planning aided with Information and communication technology (ICT) solutions. From infrastructure to resource management, from Smart Energy to Smart Environment, all the pillars are achievable through smart planning of an urban setup with the help of geospatial technologies.

The need of the hour is to generate digital database of every sector of economy, demography and maps of natural as well as man-made resources at two levels – at national or state level for making policies and programs and at parcel level for implementation of policies and programs. Land use/land cover (LULC) maps, urban growth and land use changes are not only indicators to analysis the socio-economic changes in the society. Conversion of land records into a digital mode would help to enhance the revenue generation, transparency in the land-dealings and taxation.

Each government has a unique set of circumstances that result in different management responses to improve community services. An important factor in improving the delivery of customer service is through the investment in spatial information system known as Geographical Information System (GIS), spatial information is widely used for tax collection, management of infrastructure, town-planning scheme, etc. Out of the prerequisites for spatial information management in government, involves the establishment and maintenance of a database of relevant information in digital format. Access to reliable and up-to-date information reduces the uncertainty planning and management by helping identify, model and analyze situations and issues, spatially. The value of the information and the effectiveness of the decision-making and planning processes are closely related to the quality and completeness of the information or the challenges facing government is not whether to use spatial data but how best to use spatial data to enhance operational activities and community services for complete transparency.

Spatial information and information management systems allow users to manage, understand, question, interpret, and visualize data in new ways. One of the major strengths of a spatial information system is its ability to link numerous databases of information within a single system. Good data management through the implementation of sound policies and procedures, ensure that data is a valuable asset. The dynamics of urban areas require prompt responsiveness for their sustainable development. In such a scenario, understanding the facets of an urban purlieu is a challenging task that require methodical solutions and urgent commitments.

7. Potential of Remote Sensing and GIS in Urban and Regional Planning

Geospatial technology i.e. a system involving RS (remote sensing), GIS (geographic information System) and GNSS (global navigation satellite system); play a pivotal role in analysing the numerous facets of urban environment. It helps us in monitoring green spaces, understanding the climatological concepts within the region, pollution monitoring, identifying suitable sites for infrastructure, mapping and delineating infrastructure deficit, identifying potential zones for harnessing energy, hazardous site mapping, etc.

The modern technology of remote sensing which includes both aerial as well as satellite based systems, allow us to collect wide range of physical data rather easily, with speed and on repetitive basis, and together with GIS helps us to analyze the data spatially, offering possibilities of generating various options (modeling), thereby optimizing the whole planning process. These information systems also offer interpretation of physical (spatial) data with other socio-economic data, and thereby providing an important linkage in the total planning process and making it more effective and meaningful. Generally, these remote sensing data products have following applications: a) mapping, b) interpretation, and c) map substitutes. Therefore, it is essential to know more in detail about the characteristics and capabilities of these remote sensing data products available to the various users, especially to the urban and regional planners.

8. Requirement of Urban, Rural and Regional Planners

Apart from topographical mapping, the planners also look forward to the remote sensing and geospatial technology to provide them information on existing land use and their periodic updating and monitoring. In addition, with appropriate technique and methodology the same data products can be used to: a) Study urban growth/sprawl and trend of growth, b) Updating and monitoring using repetitive coverage, c) Study of urban morphology, population estimation and other physical aspects of urban environment, d) Space use in city centers like 3-D city model, e) Slum detection, monitoring and updating, f) Study of transportation system and important aspects both in static and dynamic mode, g) Site suitability and catchment area analysis, h) Study of open/vacant space, i) Cadastral mapping, j) Modeling Urban Growth, k) Facility and infrastructure mapping and l) Urban Hazard mapping and risk zonation, etc.

To enable the users/planners to extract appropriate/suitable information for their specific needs, as above, the details of various remote sensing data products are provided in the following paragraphs. The modern technique of remote sensing and GIS that includes, air borne as well satellite based system, scanned imagery as well as photographic products, are capable of providing data/information at various levels, on repetitive basis, with spatial resolution varying from 1 m and 2.5 m in Cartosat-2 and Cartosat-1, respectively to 1 m in IKONOS and 71 cm in Quick bird. Space-borne data products, both photographic as well as non-photographic include large format camera (LFC) product e.g., as obtained from Space Shuttle missions, have applications in various other fields and to obtain data/information at macro-level. For regional planning, IRS LISS-III and LISS-IV data products provide means to update maps at the scale of 1:50,000 and to the extent on 1:10,000 which also provide lot of information to planners, at various levels of planning.

9. Applications of Geospatial Technology for Urban and Regional Planning

9.1 Pattern of Human Settlements

Geospatial technologies play an important role in analysing the settlement pattern as remote sensing images provide an updated and synoptic view of settlements across landscape pattern. Geographic Information System (GIS) based approaches have been used to analyse spatial pattern of settlements such as nearest neighbour (Linard et al., 2012; Tian et al., 2012; Zhang et al., 2014), spatial autocorrelation, Ripley's K function (Uria–Diez et al., 2013), high/ low clustering method, etc. Nearest Neighbour (NN) distance technique is widely used due to its simplicity and ease of implementation (Kint et al., 2004; Yang and Lee, 2007). It investigates the arrangement and distance of the sample points by calculating the average NN distance, which is an index based on the average distance from each feature to its NN feature. This index depicts if the settlement points are spatially clustered or randomly located within the study area. If the average NN ratio is less than 1 then the pattern exhibits clustering. If the average NN ratio is greater than 1 then the trend is towards dispersion.

The urban settlement pattern in NWH was analyzed for the three constituent states, i.e., H.P., J&K and Uttarakhand based on NN analysis. The list of urban settlements based on 2001 census was downloaded from Census of India website and their location was identified with the help of high-resolution images. The generated vector data was then used as an input in GIS environment for calculating the NN ratio (Table 3). The analysis showed that HP state had a random pattern of urban settlements whereas J&K and UK states exhibited clustered pattern. Although all the three states have a hilly terrain where location of urban settlements is largely determined by the topography, accessibility to water sources and availability of agricultural land. However, H.P. differed from both other states in its settlement pattern, one of the reasons being the good level of infrastructure facilities across the state due to which the tendency of settlements to cluster was reduced.

Table 3: 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

9.2 Study of Urban Sprawl and Land Use/Land Cover

Since, satellite based remote sensing systems have unique capability to provide repetitive coverage for any area on the Earth's surface, this makes it most suitable for monitoring and updating especially for regional planning and analysis. Therefore, to study the feasibility of such data products for urban expansion and land use, the Dept. of Space (DOS) formulated 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). Out of those 12 cities, Delhi, Jaipur and Lucknow were allotted to then Human Settlement Analysis Division of IIRS, Dehradun. The mission project was taken up in 1986 and completed in 1988/89. Mainly 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 organizations 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 another study, Indian Remote Sensing (IRS, LISS-II, 36.5 m and LISS-III, 23.5 m) and Landsat TM (79 m) data approximately at an interval of five years (1987, 1992, 1998, 2003 and 2008) have been used to carry out the study for analyzing the urban growth in Dehradun. After the temporal data geo-referencing and co-registration, six land use/land cover (LULC) classes namely urban built-up, forest, agriculture, water body, scrub land and tea garden were identified as target classes using maximum likelihood classifier (MLC) (figure 1). The urban growth map was generated by extracting urban area for each time period and an 8-directional cardinal scheme (i.e., north, north-east, east, south-east, south, south-west, west and north-west) with 1 km

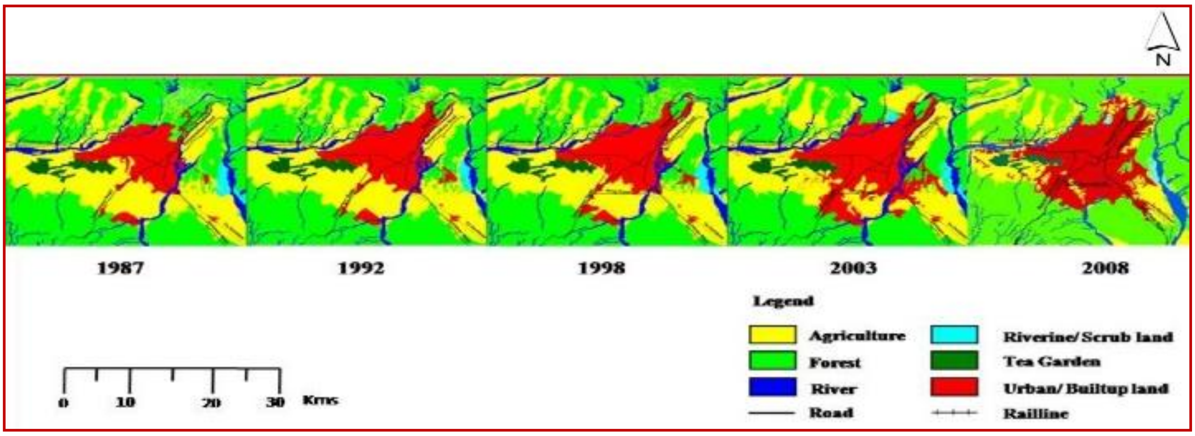


Figure 1. LULC maps of Dehradun Urban area over a period of two decades incremental buffer from growth centroid of Dehradun clock tower was analyzed. Dehradun experienced a very high growth rate, almost 32% and 49% in 1998-2003 and 2003-2008, respectively which is very high as compared to growth rates experienced in previous time periods.

9.3 Monitoring urban growth using night time data

Built-up areas can be assessed using nighttime light datasets provided by Defense Meteorological Satellite Program (DMSP) Operational Line-scan System (OLS). For a study on Indo-Gangetic Plains, a new approach to estimate the fraction of built-up area on per pixel basis, using two coarse spatial resolution remote sensing data namely DMSP-OLS and Terra Moderate Resolution Imaging Spectro-radiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data was used. The applicability of Human Settlement Index (HSI) for monitoring growth of built-up areas in the Indo-Gangetic plains for the 2001-2007 period was examined. OLS is an oscillating scan radiometer, on board the DMSP satellites and operates in two spectral bands, namely, the visible near infra-red band (VNIR) from 0.4-1.10 µm and the Thermal infra-red band (TIR) from 10.5-13.4 µm. The OLS has a spatial resolution of 2.7 km, radiometric resolution of 6 bits and a swath of 3000 km thus, it provides a complete coverage of earth each day. The correlation analysis between HSI, OLS and NDVI datasets were carried out.

In order to analyse the built-up area growth on state-wise, the total number of growth cells falling in each of the states and union territory were first determined and then these cells were classified into the three respective HSI growth classes. The states of Delhi and West Bengal had the maximum percentage of Class 1 growth cells, while Chandigarh had the least percentage of Class 1 growth cells. The maximum percentage of Class 3 growth cells were in Bihar followed by Uttar Pradesh. While the least percentage of Class 3 growth cells were in Punjab (Figure 2).

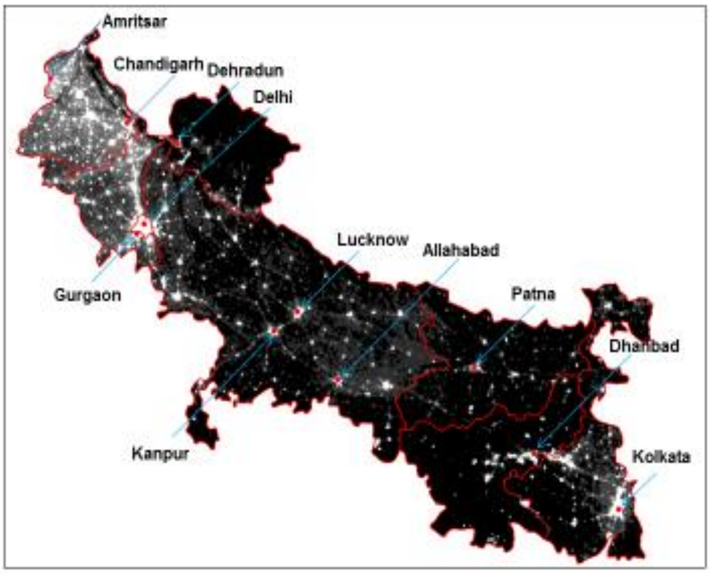


Figure 2. Night-time OLS stable lights yearly composite for year 2001

9.4 Urban Growth Modeling

In developing countries like India, the urban areas are expanding in an unplanned manner on their peripheries. This unplanned growth is leading to an irreversible transformation of contiguous agricultural and forest lands into built-up areas. Thus, monitoring the growth of built-up areas at regional and global scales has become an urgent task. The urban planners are now looking for tools and techniques to model and predict the urban growth pattern based on indicators or drivers of urban growth and also the policies.

In a study over Uttarakhand, the land cover change (LC) in the Uttarakhand state was analysed and the LC trajectory was extrapolated using a Cellular Automata (CA) based spatial predictive model. This study employed CA-MARKOV chain analysis, which is a combination of both CA and MARKOV chain analysis. Markov Chain is a stochastic process in which the future state of a system is modelled on the basis of the immediate proceeding state without much information about the past. The Markov Chain Analysis describes the probability of land cover changes by developing a transition probability matrix based on land cover maps of two different time periods. However, there is no knowledge of the spatial distribution of these land cover changes. In order to add the spatial character to the model, CA is integrated to the approach. Land cover maps of Uttarakhand state for the year 2006, 2010 and 2015 were downloaded from the Bhuvan site. These maps were reclassified into nine classes for analysis purpose, i.e., built-up, agriculture, forest, grassland, plantation, snow cover, wasteland and water bodies (figure 21.10). Map overlay analysis was done in a GIS environment for analysing the LC during the period 2006-2010 (T_1) and 2010-2015 (hereafter T_2). Markov transitional probability matrix was calculated based on the LC map of period T_1. The CA-Markov was calibrated for period T_1 by varying the neighbourhood size and model iterations. The model was then validated for period T_2 and subsequently the model was executed to simulate the land cover for year 2020 (Figure 3).

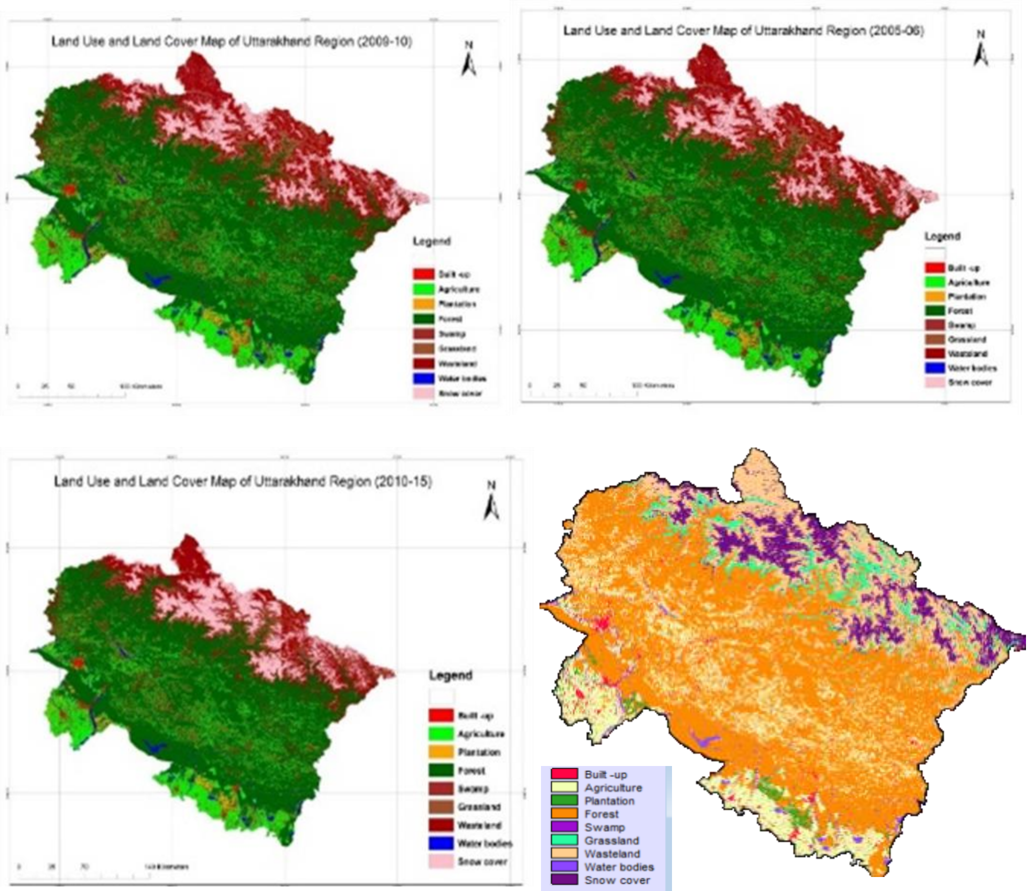


Figure 3. LULC map of Uttarakhand for the period 2005-06, 2009-10 and 2010-15 and simulated Land Cover map for 2020

9.5 Quantifying Urban Landscapes-Green Space Assessment

Urban areas are characterized by heterogeneous landscapes. The natural urban landscapes within the closed urban system in the form of parks and greenbelts are extremely helpful in counteracting the local climatic influences within an urban morphology. With increasing in-migration to the city and restricted permissible city expansion limits, the phenomenon of de-densification within cities inexorably damages the sustainability rate of urban set-up. The spatial metrics are measures to quantify the structure and pattern of landscapes. It can be used in conjunction with remote sensing data for improved understanding and representation of urban morphology.

The landscape pattern was explored using percentage of landscape (PLAND), mean patch size (MPS) and number of patches (NP) metrics (Jain et al., 2013) using IRS-1C/1D LISS-III and Landsat-TM images of Dehradun city. Five LULC classes viz. built-up, forest, green space, open space and river were classified using supervised classification technique. The amount of green spaces were quantified within seven buffer zones of one km each from city centre to find the pattern of changes in green spaces due to the influence of population. Statistics depicts high fragmentation in the year 1998. The compactness in pattern was observed during the years 1986 and 2011, in both the classes i.e. built-up as well as green spaces. The decrease in open spaces is also clear from PLAND and MPS values. Though, PLAND of forest has increased from 1986 to 2011, the low MPS and high NP during the period indicates fragmentation in forest cover. Consequently, seven buffers of 1 km each around the city centre (clock tower) were analysed to check the urban environmental quality (Figure 4). A drastic decrease in green spaces can be witnessed from 34.62% to 7.78% during 1986 - 1998 and then further reduced to 2.81% in 2011 within the 1 km zone. Up to 38% change was observed within 4 km buffer zone from the city centre. The percentage of green spaces increases with the distance from the city centre. The concentration of green spaces, more or less, follows the pattern of municipal boundary. Most of the green spaces are concentrated just outside the municipal boundary. It can also be observed that percentage of green spaces increases in buffer zones from 6 km onwards from the city centre.

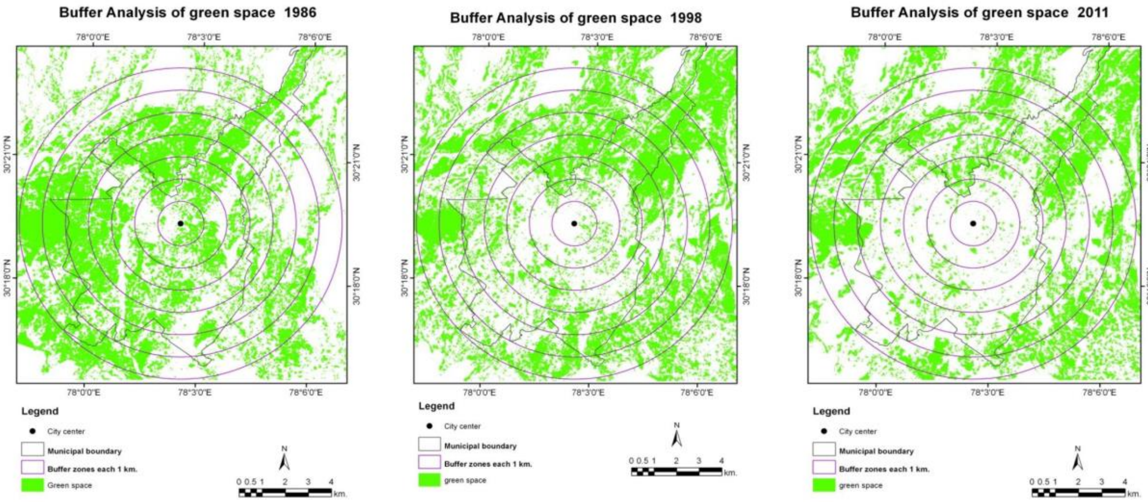


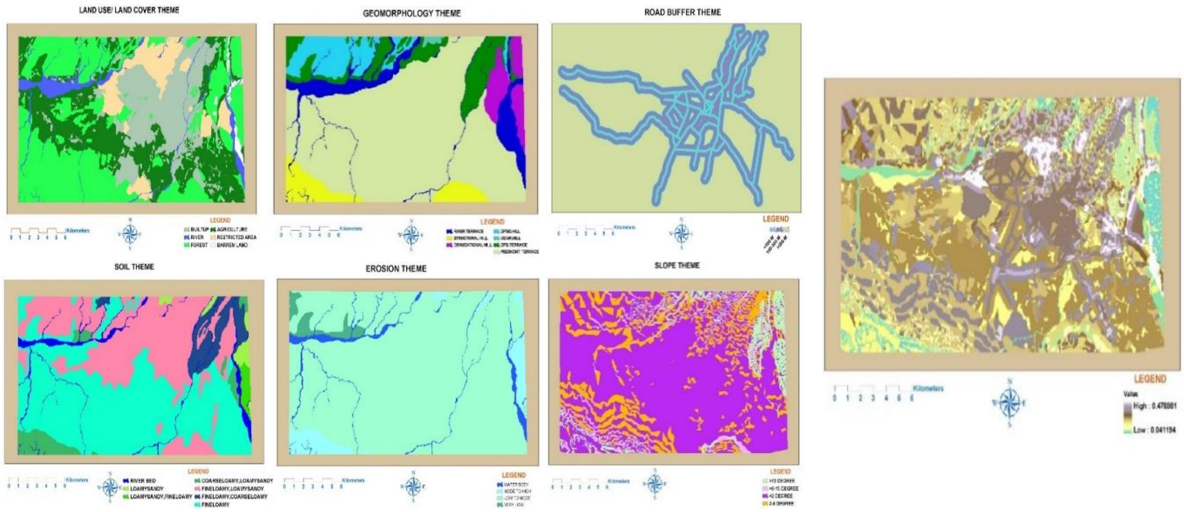
Figure 4. Distribution of Green Spaces within 7 Buffer Zones of 1 km from City Centre for the Year 1986, 1998 and 2011

(Source: http://technical.cloud-journals.com/index.php/IJARSG/article/download/Tech-162/pdf)

9.6 Land suitability for Solid Waste Management

Solid waste Management involves managing activities associated with generation, collection, transport and disposal of solid waste in an environmentally compatible manner, adopting principles of economy, aesthetics, energy and conservation. Most of the land within the urban premises are allocated to one or the other land use mentioned in Master Plans. Often, very less of these lands are allocated on the basis of any suitability analysis. Problem arises when the non-suitable sites convert themselves into hazard prone areas or show reflections of their misuse. These discrepancies can represent major issues for the future and the intensity may only be explained, rationally. A study has been carried out to- i) Identify landfill sites in Dehradun Urban Area (DUA) Using Analytical Hierarchy Process (AHP), ii) Demonstrate the utility and role of Remote Sensing and Geographical Information System (GIS) technology in creation, handling and analysis of database and iii) Study the utility of AHP in site suitability process modelling and demonstrate the pair-wise comparison procedure to capture relative and consistent judgments of two factors at one time (Figure 5).

Figure 5. Ranking of solid waste disposal sites based on AHP.



The model for data integration consists of four components: i) Defining criteria for building logic for analysis, ii) Assessment of relative weightage of each parameter, and iii) The criteria for analysis depends on objectives and also the available data sets. It is defined by relative contribution of each parameter towards the desired output. On the basis of relative importance of different parameters, a set of weights were decided by carrying out a suitable data analysis, and iv) The weights obtained from data analysis are assigned to different parameters, which aid in designing of decision rules.

9.7 Slum identification

Haphazard development of slums poses challenges on overall environs as well as quality of life, ranging from local to regional level. Its effect are manifested though the quality of ground and surface water. It has influence on the quality of surface and underground water. Major urban centres of the region face similar environmental challenges as about 80% of slum developments are on the river bed in these areas. Poor quality and dilapidated house structures dominate the slums, largely due to the meagre resources available to its residents and thus ruin the aesthetic appeal of the city. Most of the settlements are illegal on encroached public land and they also do not have the benefit of land tenure.

In Dehradun city, about 80% of the informal settlements are located along perennial drainage, namely Rispana and Bindal Rao as well as railway line. These are the high density developments in the marginal areas line hill slopes, along railway line and drainage network. The condition of houses near to the river is more dilapidated in comparison of the houses away from the river bed. These settlements are vulnerable to the flash floods due to the close proximity to river bed. Slum pockets are dynamic and observe major changes in the built environment over a period of time. With the increase in land prices of the surrounding areas, usually they sell the property and settle to other place. Also, pucca houses replace the kuccha houses, with the improvement in residents' economic conditions. Changes in the socio-economic conditions of its residents can be traced out through RCC structure and improved infrastructure. Most of these squatter settlements are near the existing high-and middle-income residential areas or small commercial areas where these people are employed in different activities.

Therefore, it is feasible to distinguish slums from satellite imageries. The increasing availability of high resolution satellite data along with airborne digital imagery has enabled precise extraction of ground objects, instead of regions of certain land cover classes only, and has become increasingly important for a variety of remote sensing and GIS applications.

9.8 Urban Heritage- Preserving the Built

The preservation of cultural heritage is not only important for a country's identity but its sustainable management is necessary to boost country's economic progress and development. However, it is equally important to understand and create a balance between new development and preservation of cultural and historical aspects of urban environment. It is necessary to have a comprehensive and integrated approach for urban revitalization and transformation for sustainable preservation of cultural heritage.

The advancements in geospatial technologies provide potential datasets and analysis platforms for analyzing the existing scenario, for detailed documentation and assessment of heritage structures, for prioritization of heritage for taking up conservation measures, etc. The advanced sensors such as Terrestrial Laser Scanner (TLS) provide ample opportunities for preparing the realistic 3D models of heritage areas, assessment of structural deformations and moreover keeping a permanent record of historic monuments. GIS helps in development of systematic database that facilitates data analysis. GIS also assist in scoring of the contributing factors that can have impact on the preservation of heritage buildings.

In this study, a GIS database for forty listed heritage buildings by Indian National Trust for Art and Cultural Heritage (INTACH) were generated with the help of high-resolution satellite data, GPS and extensive field survey. The data consist of location, age, physical condition, height, construction material, and ownership status as push factors; and distance from lake, connectivity from highways and accessibility to infrastructures as pull factors for each building. An index system in GIS was adopted for the evaluation of these factors and two indices namely, Redevelopment Potential Index (RI) and Urgency Index (UI) were used in the present study (Ko, 2008). Each push and pull factor was assigned different ranking for RI and UI e.g., good building condition was assigned highest ranking for redevelopment potential and lowest ranking for UI. AHP based evaluation of all parameters were carried out using Saaty's pairwise comparison method. For each group of parameters, different weights were computed for both the index. The final RI and UI maps are presented in Figure 6. The Urgency Index value of St. John Wilderness Church was highest, hence it was selected for further investigation using TLS. This church was established in year 1844 by Daniel Wilson and is a fine example of Catholic Church architecture.

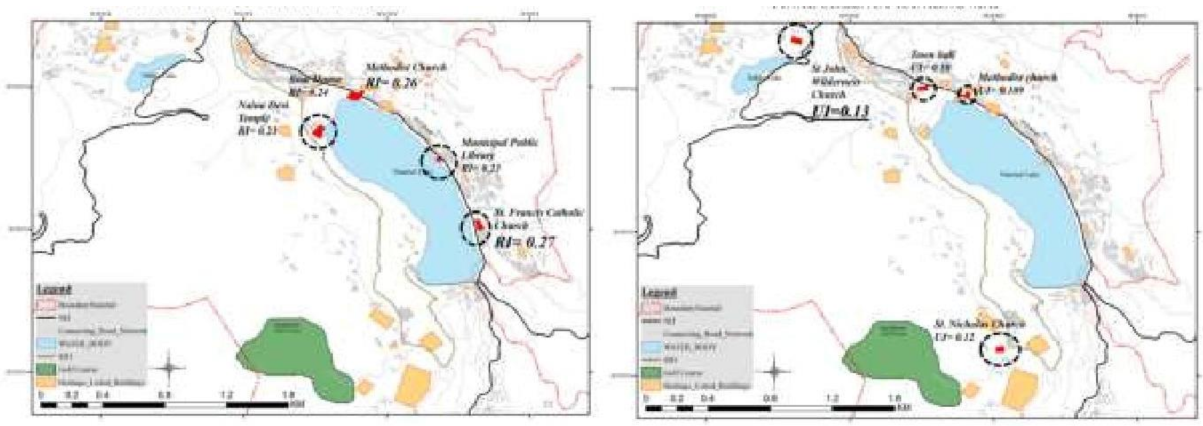


Figure 1: Redevelopment Potential Index Map and Urgency Index Map.

The whole building is constructed of stone and is situated near High Court in Mallital area of Nainital. The 3D laser scanning system RIEGL 3D laser imaging scanners of LMSZ series was used to capture exteriors of Church building. Overall 15 scans were obtained to ascertain the high density of point cloud and full coverage of the building.

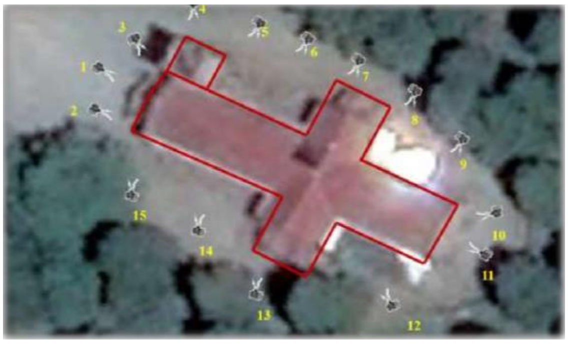


Figure 7: Locations for 3D laser scanning

Figure 8: Resultant Point cloud of church after geo-registration

Figure 7 shows the location of scans around the church building and Figure 8 shows the resultant point cloud of church after geo-registration. Some of the applications of resultant 3D model are structural assessment of building, deformation analysis, cross sectional measurements, measured drawings (documentation of building), identification of cracks in foundation & exterior cladding, jamming of doors or windows, rubbing or refusing to close, roof damage, deteriorated mortar, materials conservation, identification of remedial measures, etc. The TLS and GIS combination is a promising solution to generate a high-quality photorealistic model and useful for documentation/ preservation of complex heritage sites. It can provide an useful realistic 3D documentation which can be utilised by the for better planning and to boost tourism in cultural heritage area.

9.9 Seismic Hazard Assessment

Geospatial technology can be used to assess the seismic risk and vulnerability assessment. A study was conducted using seismic risk assessment methodology, Risk Assessment tools for Diagnosis of Urban areas against Seismic Disasters (RADIUS) developed by the United Nations (http://www.unisdr.org/files/2752_RADIUSRiskAssessment.pdf) in GIS environment. It is a very simple and easy tool that can be used by decision makers and urban planners to have an idea of the damage and human causalities in case an earthquake strikes a city.

The study area, Dehradun city as the interim capital of Uttarakhand State, besides being the district headquarters has emerged as the premier business as well as

service centre within the hilly region of Uttarakhand. A number of civil and defence institutions of national repute signify its importance in the country. The study aims at facilitating preliminary estimation of earthquake damages in developing countries by incorporating the role of urban planners and city administrators to raise awareness about earthquake risks in cities. The urban seismic hazard analysis requires scenario analysis. At the start, an earthquake scenario for the study area should be presumed. This involves deciding about various parameters of the earthquake scenario like its epicentre, magnitude and in some cases its location. The peak ground acceleration (PGA) values are generated from this scenario earthquake model. The hazard map prepared from the above analysis as represented by the various MMI values and is represented in the form of a direct relationship with the possible damage to various structures and lifeline facilities, in the RADIUS methodology. The scenario earthquake generated was same as that of the Chamoli earthquake that occurred on 29 March 1999. The parameters that were assumed for the scenario earthquake were: Richter Magnitude = 6.8, Depth of earthquake = 21 km, and Epicentral distance = 13 km. A soil amplification function of 0.7 was assumed for the entire study area.
The MMI values calculated were used to find the percentage damage for each building type using Primary Damage curve data based on Applied Technology Council (ATC) 25 document. It was observed that the old areas like Khurbura, Lakhi Bagh and Jhandawala were prone to high damage as most of the building stock in these areas were old, not complying with the latest code provisions. The slum areas along the Bindal and Rispana streams would be affected by maximum as most of the construction is informal or sub-standard construction. The newly developed areas of Rajpur road, Ballupur and Vijay park would be least affected as these areas have new construction following the engineering codes. Figure 9 shows the ward wise total buildings damaged (in percentage). The RADIUS tool has simplicity of implementation and ease with which it generates results about a possible earthquake hazard.

These results can be of great importance, as the planning agencies may better understand earthquake and the consequences related to it in case it strikes some urban settlements. The potential extent of damage and most susceptible points to destruction in their city are also clearly highlighted by these tools. With a wider part of India now being studied for seismic zonation and the cost effective tool like RADIUS is easily available, we have better chances of improving the condition of emergency management in our country.

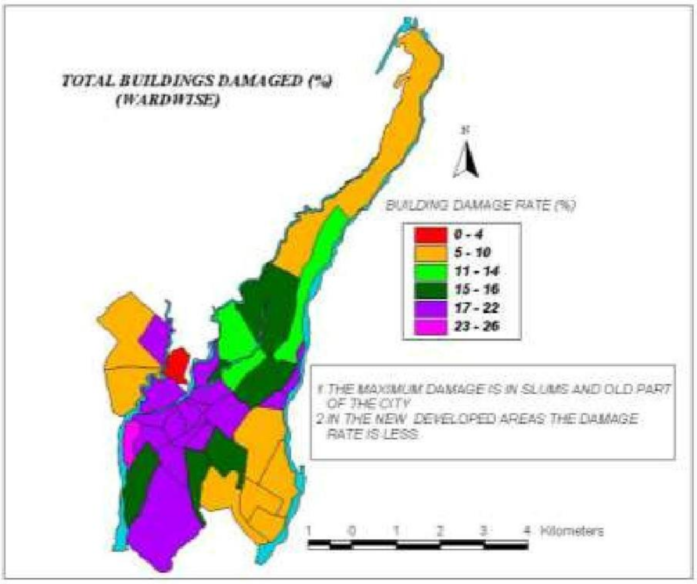


Figure 9: Total buildings damaged (in percentage) ward wise

9.10 Tourism Potential Estimation

Tourism plays an important role in maintaining social harmony, recreation and helps in enhancing excellence in community skills. Tourism can be domestic or international, and has importance towards country's balance of payments and economic growth. Today, tourism is considered as a major source of income for many countries, and it affects the economy of both the source and host countries, in some cases being of vital importance.

In a study on Nainital, remote sensing data along with ancillary information have been used to assess the tourism carrying capacity of Nainital town. Tourism carrying capacity is defined as the maximum number of people that may visit the tourist destination without causing destruction of the physical, economic and socio-cultural environment and an unacceptable decrease in the quality of visitors' satisfaction. The study area, Nainital is a popular tourist destination of Uttarakhand. It is also known as the Lake District of Uttarakhand. The tourist's influx during the peak season is nearly six to nine times of the local population. Nainital is now being inflicted by the growing traffic, anomalous growth and big turnout of tourists in the recent years and it is leading to inadequate accommodation and infrastructure facilities for tourists, which could be detrimental to the growth of tourism industry in the area. Since, Nainital's entire economy is dependent on the tourism industry with diminutive production in town, it can have far reaching effects on the city.

The tourism carrying capacity has been assessed based on a number of domestic and foreign tourists in peak season, residential population, Nainital municipal boundary area, and average number of days of tourists' stay in Nainital city, number of days in peak season, Urban Development Plans Formulation and Implementation (UDPFI) Density and Normalizing Density. The methodology proposed can be used by planners for the timely up gradation of infrastructure and facilities in tourist areas. The carrying capacity of Nainital city was calculated as available capacity which is equals to Carrying Capacity minus the existing load (Table 4). High resolution satellite imagery, Cartosat DEM of 30 m resolution, ward map, land use map, topographical map and Nainital Guide map have been used in the present study. Secondary data emphasizing on perception and opinion of tourists, persons engaged with tourism sector and experts were also considered. Network analysis was performed to make routing of tourist destinations such as Heritage sites, Lake Sites and also adventure tour path around Nainital town.

Table 4. Available carrying capacity in Nainital City

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

Geospatial techniques are useful for mapping, visualization and analysis of places of tourist importance. Major tourist destinations of Nainital include High court, Raj Bhawan, ARIES, Naini Lake etc. and the peak season for tourists is during the period of May – June. During peak season, tourist influx is beyond the carrying capacity and cause problems to tourist infrastructure/ facilities.

9.11 Solar Energy Potential Estimation

Large quantity of rainfall, abundant solar insolation and huge wind capturing locations offer opportunities to tap vast energy resources available in India. Being close to Tropic of Cancer and the Equator, it has huge solar potential. There is a need for countries to secure energy potential and production of their country along with developing the resources. The total irradiation that hits the ground surface and the energy generated due to this is not enough keeping in mind today's energy consumption requirement scenario. Taking advantage, radiation captured can also be utilized for meeting day to day needs (http://www.smartcities-infosystem.eu/renewable-energy-sources). Solar energy is one of the more promising sustainable energy sources due to its accessibility. India has a potential of about 750 GW of solar energy, according to the National Institute of Solar Energy (https://cleantechnica.com/2014/11/29/indias-solar-power-potential-estimated-750-gw/). Solar rooftop is an emerging renewable energy option for the cities to initiate smart city concept using smart energy.

Understanding the need for solar resource data, NCEI, Department of Energy's National Renewable Energy Laboratory (NREL), the National Aeronautics and Space Administration, the Northeast Regional Climate Center along with various universities and companies collaborated in creating the National Solar Radiation Database (NSRDB). It was updated in 2012 containing data from 1991 to 2010 for over 1500 stations in the United States. Similarly, in the Solar Energy Centre (SEC)-NREL collaborative project on "Solar Resource Assessment" under the Indo-US Energy Dialogue, solar maps were generated using satellite imagery based measurements. The maps are available for entire country at 10 km spatial resolution for entire India. Initially, the solar maps containing Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI) were prepared from January 2002 to December 2008. The maps are later updated extending the data up to 2014 using weather satellite METEOSAT measurements (NREL, 2016).

Solar Urban Planning may seem to be a new terminology but describes the increasing demand for energy conservation to a great extent. We are today in a 'new phase' of sustainable planning, with an aim to build smart cities: cities capable of survival, with an ability to perform efficiently. The world's energy problem and the huge scarcity of sources producing energy, drifts our attention towards renewable energy sources. This is a smart approach towards utilizing our resources which are in abundance. It is important to be able to accurately identify the key areas on the rooftops of buildings that receive maximum solar radiation, in order to prevent losses in solar gain due to obstructions from surrounding buildings and topographic features. Research has shown that net-zero energy buildings are achievable if site analysis and various climatological factors are taken into consideration while designing a building, house or a community further translating into a city. In order to respond to the growing urbanization process and subsequent energy demand, methodological approaches which implement alternative urban models are required to support the indispensable change towards more energy efficient cities. Smart energy is one of the important pillar to make city smart and smarter in the days to come.

a) **Air pollution in urban areas**

Air pollution is a grave problem and is exacerbated due to anthropogenic activities. Air pollution poses a grave health risk and is a matter of concern for researchers around the globe. Toxic pollutants like nitrogen dioxide (NO_2) is a result of industrial and transport sector emissions and need to be analysed at the current scenario. A study was conducted that focuses on analysing the gaseous pollution scenarios, before and during lockdown through satellite (Sentinel-5P datasets) and ground-based measurements (Central pollution Control Board's Air Quality Index) for eight five-million plus cities in India (Delhi, Ahmedabad, Kolkata, Mumbai, Hyderabad, Chennai, Bengaluru and Pune). The analysis was carried out for 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. The major reduction values as observed through Sentinel data can be seen in Delhi where the maximum and average values dropped by 70 per cent followed by Bengaluru (63 per cent), Mumbai (57 per cent), Ahmedabad (56 per cent), Hyderabad (49 per cent), Pune (37 per cent), Kolkata (34 per cent) and Chennai (33 per cent) in maximum NO_2 values.

The two-week mean value of NO_2 spatial analysis revealed a reduction in the values when compared with status in 2019 (first lockdown period) and when analysed w.r.t. pre-lockdown scenario (46% reduction in LD 1) which further rose nominally in the LD-2 period (5-10%) for the 8 five-million plus cities alone. AQI for the major cities also showed an improvement of 27% during LD-1 and 29% during LD-2 due to reduction in usage of motorised vehicles and non-operational thermal power plants. It was also observed that 53 per cent Corona positive cases and 61 per cent of fatality cases were observed in the eight major cities of the country alone, coinciding with locations having high long-term NO_2 exposure (Figure 10).

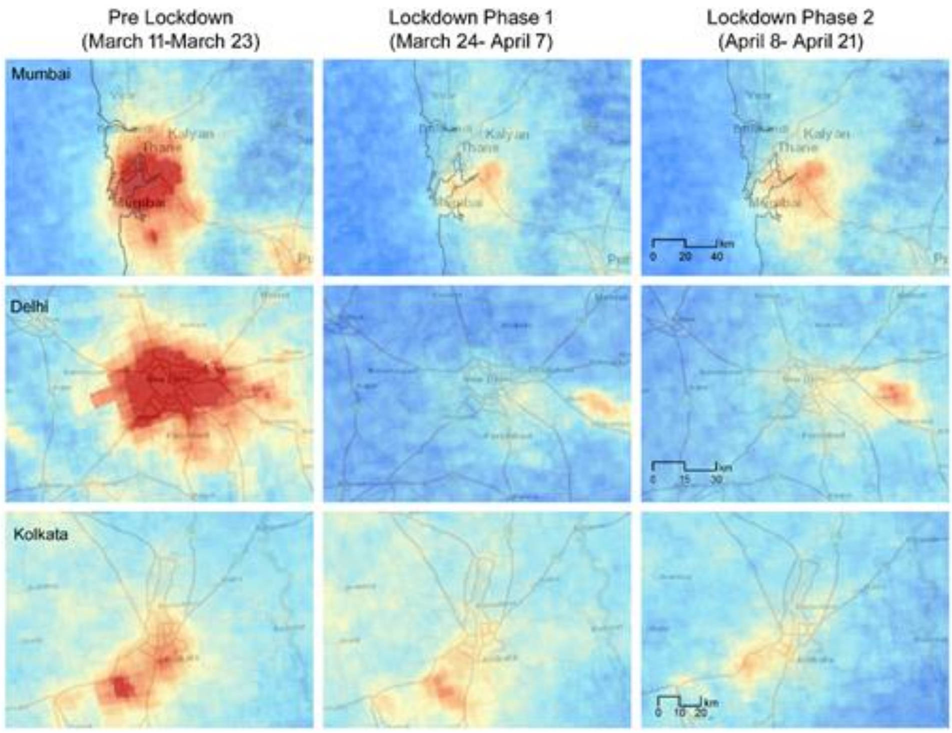


Figure 10. NO_2 levels in Indian cities during Pre-lockdown and during lockdown (1 and 2)

b) Characterization of Urban Materials using Hyperspectral Remote Sensing Data

Identification of materials in an urban scenario using hyperspectral remote sensing technique is a promising area of research today. The characterization of materials in an urban setup play a pivotal role in deciding the environmental regime in terms of urban heat islands (UHIs) and urban pollution islands (UPIs). The problem of heterogeneity within a pixel, resulting in mixed pixel, makes it inadvertent to use higher spatial resolution for multiple endmember extraction using appropriate wavelengths and identification of specific urban materials. Mixture Tuned Matched Filtering (MTMF) is one such partial linear spectral un-mixing approach that helps in identifying materials by suppressing background noise of a Minimum Noise Fraction (MNF) transformed image. The research aims at identifying the pure endmembers from the reflectance image of Airborne Visible InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG) over a part of Ahmedabad city acquired on February 11, 2016. The pure endmembers represent the various materials present in the scene. The endmembers are extracted on a spatially and spectrally reduced dimension of data to enhance the interactive extraction of materials present. An enhanced matched filtering (MF) approach called MTMF was employed on the data for the estimation of abundance images, signifying the presence of a specific chemical composition in a given pixel. The methodology adopted helped in extracting endmember abundance images while describing the presence of specific urban materials like asphalt, tin, china mosaic tiles, concrete, etc. (Figure 11).

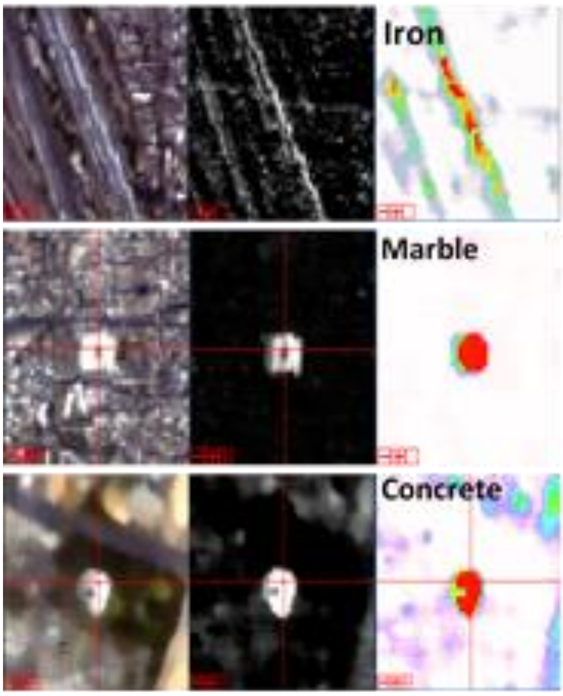


Figure 11. Identification of urban materials using MTMF technique for Ahmedabad

9.12 Urban Heat Island

Urban expansion involves land conversions from vegetated moisture-rich to impervious moisture deficient land surfaces. With growing urbanization, the local weather and climatic conditions of the area are varying considerably. Thermal remote sensing is a powerful tool to study the causes of changing land use pattern and the Urban Heat Island effect subsequently. The thermal infrared data is useful for studying UHI over urban areas and plan the open spaces accordingly.

The relationship between land cover dynamics and surface temperature was analyzed in Dehradun urban agglomeration using multi temporal Landsat satellite images of 19 February 2000, 29 January 2010 and 23 February 2019. The study revealed that in decade 2000-2010, suburban built-up registered a growth of 1624.95 ha and urban built-up increased by 1242.18 ha. While during 2010-2019 period, sub urban built-up and urban built-up increased by 3110.49 ha and 1211.94 ha respectively. LST was calculated using mono-widow algorithm and validated using the downscaled MODIS LST data of the three respective dates. It was found that the average LST increased by 14.8% in 2000-2010 and 11.8% during 2010-2019. There was no significant increase in standard deviation during 2000-2010 while it increased by 28.2 % during 2010-2019. Thus, it was found that there was an increase in LST values mainly due to urban densification, urban geometry (reduced sky view factor, urban canyons) and near ground source of anthropogenic heat (traffic, commercial activities and air conditioners). LST hot spots were found in dry river bodies, urban built up and some areas of cultivated and managed areas and bare soil near dry water bodies, whereas cold spots correspond to the regions of natural and semi natural vegetation. The percentage of urban built-up under hotspots increased from 6.8 % in year 2000 to 27.86% in year 2019, the percentage of suburban built-up as also increased from 1.36 % in year 2000 to 20.08 % in year 2019 while the proportion of all other land cover decreased (Figure 12). The proposed methodology can be used by urban bodies to design appropriate LST mitigation strategies.

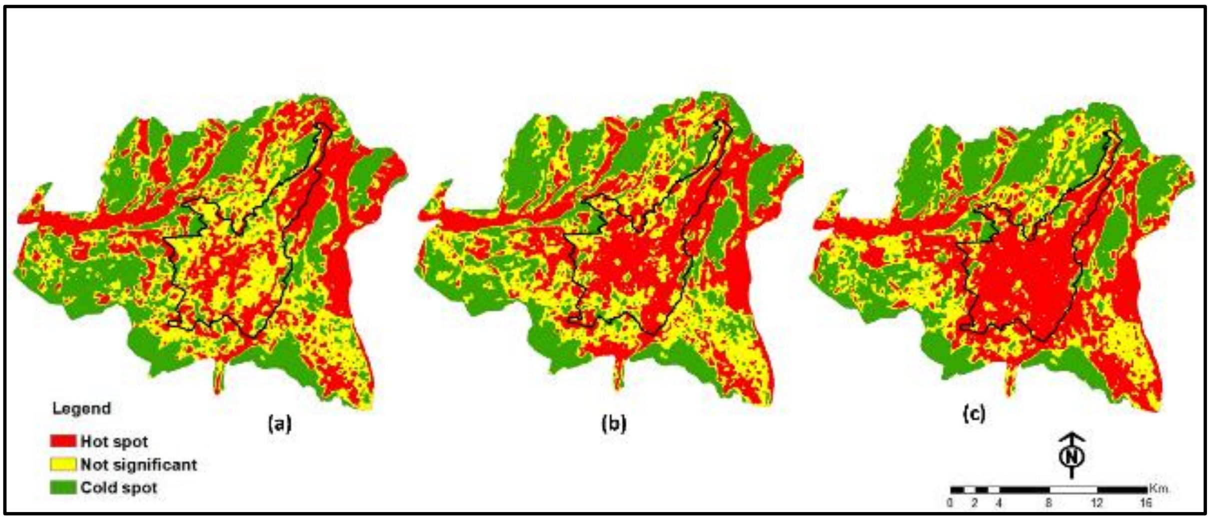


Figure 12. Spatial distribution of hot spots in Dehradun urban agglomeration on (a) 19 Feb, 2000, (b) 29 Jan, 2010, (c) 23 Feb, 2019

9.13 Urban feature extraction using UAV datasets

Imaging systems based on UAVs (Unmanned Aerial Vehicles) have been proven to be beneficial in a variety of remote sensing applications, including environmental, urban/land use, image classification, and agricultural studies. UAVs provide a number of benefits over traditional remote sensing platforms, including greater flexibility and reduced costs in data collection, as well as increased speed and safety. More importantly, UAVs may fly quite near to the target, resulting in images with extremely high resolution (cm to dm pixel size). UAV-based remote sensing data makes it easier to distinguish between impervious surfaces such as buildings, roads, parking lots, and urban land. The classification using pixel-based techniques is relatively restricted since it has significant issues coping with the rich information content of high-resolution data such as high-resolution satellite data and UAV images. Currently, the OBIA (Object Based Image Analysis) approach is particularly relevant in the context of image classifications for high spatial resolution and UAV images. OBIA techniques start with the segmentation of images followed by classification and feature extraction using contextual information and rule base comprising of spectral, textural, neighbourhood, and object-specific shape parameters. Segmentation is described as the division of a complete image into a number of segments or sets of pixels with the purpose of transforming the image's current pixels into more meaningful objects. The resolution and scale of the intended objects should be used to determine segmentation and topology creation. For high and extremely high resolutions, the OBIA approach outperforms the pixel-based technique.

In a study at Roorkee, Uttarakhand, UAV DJI Phantom-4 pro, which includes a non-metric camera with visible colour bands (red, green, and blue) was used to capture the UAV datasets. A set of 102 images recorded with a ground sampling distance of 1.79 cm from the flying height of 150 m. Collected UAV images were processed and the orthomosaic image with the DSM were generated. Figure 13 shows orthomosaic and DSM of the study area.

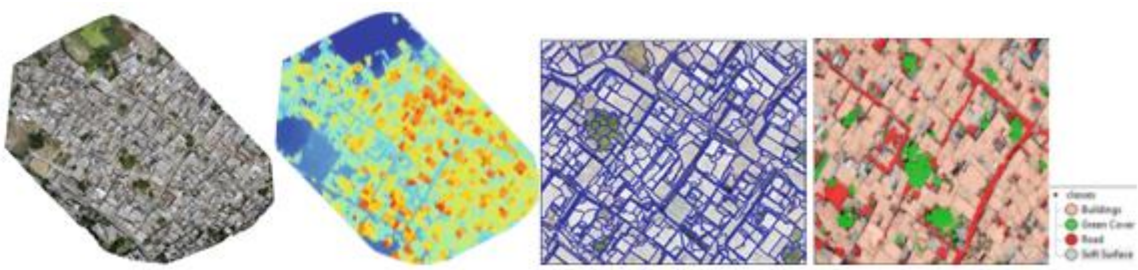


Figure 13. (a) Generated Orthomosaic of the study area, (b) Generated DSM, (c) Segmented image, and (d) Extracted objects

An integrated dataset comprising of orthomosaic image are then segmented using a Multi Resolution Segmentation (MRS) technique. MRS is a well-known technique to segment image objects into homogeneous patterns. Beyond merely spectral information, image objects include plenty of other characteristics that may be utilised for classification, including shape, texture, and relational/contextual data. MRS distinguishes contiguous areas in an image if they are highly contrasted, even if the areas themselves include a texture or noise. It's a bottom-up region merging approach that starts with a single pixel object and works its way up to multiple objects and pixels. Following the segmentation of the image with MRS, OBIA is used to classify the generated image objects. Object metrics were utilised to create rulesets prior to the classification of image objects. To quantify the parameters for object identification, object metrics are estimated. Hence after being segmented, area, length, breadth, compactness, density, asymmetry, roundness, elliptic fit, rectangular fit, main direction, border index, and shape index were deter-mined from the segmented objects. The spectral features included the mean of each layer, index features included the blue by green layer index and n-DSM was used for classification and estimation of impervious surface.

The goal of the research was to create an efficient method for extracting urban areas from UAV images with very high spatial resolution. OBIA analysis allows for the detection and extraction of numerous urban objects such as buildings, roads, and trees. The study efficiently demonstrates the potential of VHR orthoimage and DSM for urban classification using the OBIA techniques. The presented approach extracts features with great accuracy while requiring less human interaction. The improved segmentation parameters, such as scale, shape, and size, are discovered to be best for extracting urban regions. The combination of UAV with OBIA can provide a quick and effective method of updating maps, particularly in frequently changing urban areas. As a result, the study's findings provide new insight into the use of OBIA in information extraction from UAV data.

9.14 Geospatial Approach for Urban Flood Risk Modelling

Urban floods and water logging have occurred with frequent regularity especially over the last two decades while causing large scale damages and bringing the life to a standstill in many cities of the country. Rapid urbanisation causes the habitations to sprawl over natural areas/ flood plains and low-lying areas, often encroaching over drainage channels and it further accelerates the urban floods and water logging. Moreover, urbanisation leads to increase in impervious areas which, in turn, significantly increases the rate of runoff, resulting in overwhelming of designed capacity of the storm water drainage systems.

Studies have been conducted to understand the risk associated with water-logging conditions in urban areas with reference to the hydro-dynamic set up of the Bhubaneswar and Dehradun city and their level of urbanization. Storm Water Management Model (SWMM) was used to estimate the runoff depth, extent, peak flow and intensity of flooding, taking into consideration the elevation, slope, land use/ land cover (LULC), rainfall conditions and the designed storm water drainage infrastructure of the city. Very high resolution satellite data was used to extract the spatial information such as Digital Elevation Model (DEM) from Cartosat-1 stereo or the LiDAR DEM for micro-watershed delineation corresponding to various storm water drainage network as well as the catchment delineation.

The IRS LISS-IV (MS) and Cartosat-2 (PAN) merged product was used to generate a detailed LULC map for the study area. The design infrastructure for the storm water drainage (SWD) channels have been collected to evaluate the capacity of drainage system for various return periods of rainfall. It was assessed that a very heavy rainfall instance of 122 mm in 24 hours can cause average water accumulation of about 0.3 m - 0.6 m with some areas even reaching 1.5 m of depth in Bhubaneswar city.

The intensity of risk increases as against different return periods of heavy rainfall events due to rise in the level of water accumulation. 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.

9.15 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. In the present study, the spatial database of WDS for Dehradun city has been created in a Geographic Information System (GIS) environment while drawing data inputs from different sources such as 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.

Mapping of the existing 564 km distribution network revealed that more than three-fourth of the system had Polyvinyl Chloride (PVC) and Asbestos Cement (AC) pipes. An accuracy of 93% was obtained upon validation by Ground Penetrating Radar (GPR) and updation of pipe diameter in the database. The population figures 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. According to supply-demand gap analysis, Dehradun is a water surplus city yet it suffers from water scarcity mainly due to unsatisfactory condition of the existing WDS. Twenty-seven percent of the existing pipes are smaller than the least prescribed standards; there is an undesirable practice of direct pumping of water from tube wells into the network and storage tanks are required at least at 29 locations in the network. Extended period simulation over the network for 24 hours in EPANET 2.0 helped to identify the crisis localities where water supply experienced very low or negative pressures (Figure 14). 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.

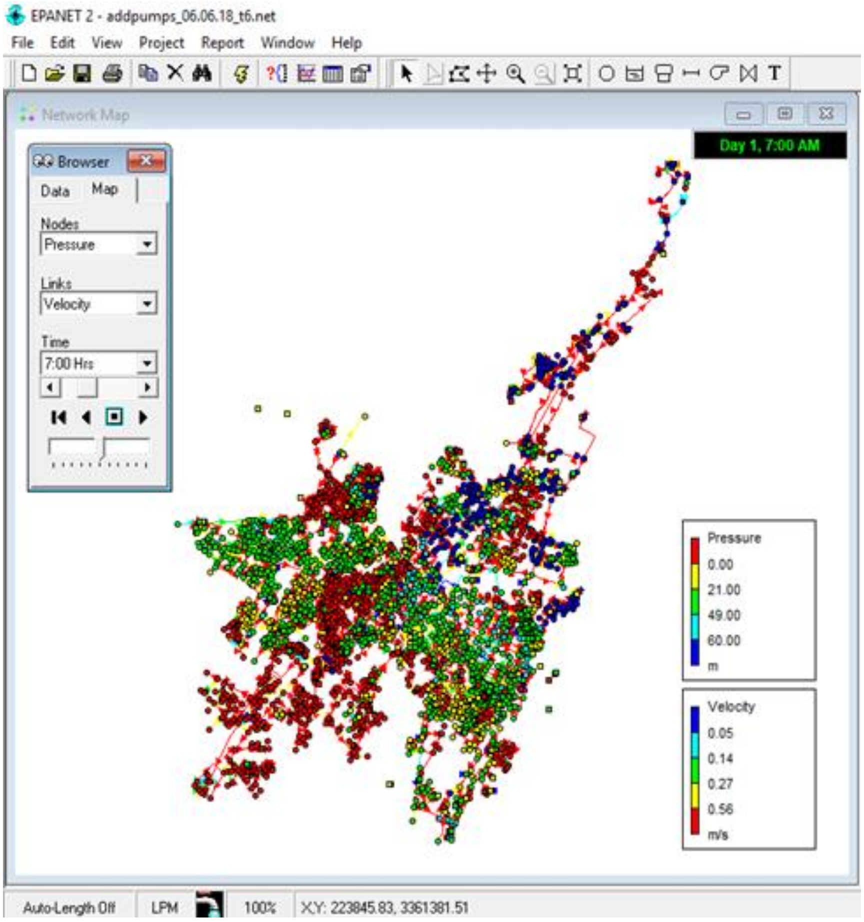


Figure 14. EPANET Simulation results

c) Urban canopy parameters computation using 3D databases in GIS

Urban Canopy Parameters (UCPs) significantly impact the UHI formation and natural ventilation in urban areas. Recently, a software have been developed at IIRS for the computation of key aerodynamic UCPs such as Frontal area index, Sky View Factor and Height-to-Width Ratio. Approaches for computation of many other 2D and 3D UCPs have also been developed and the same have been used to generate the urban ventilation path map of Delhi. The work is further extended in this project to include vegetation canopies and to extend this study to other urban areas in varied climatic zones. 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 figure 15. The class-wise error analysis of building heights reveals RMSE values of <1 m in all classes.

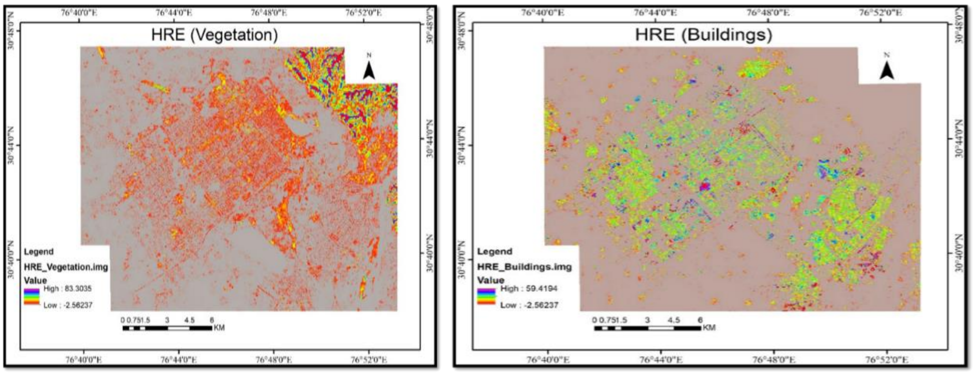


Figure 15. Vegetation and building canopy

9.16 Polarametric SAR data for Urban LULC

The urban land use/ land cover (LULC) information has very important role to play in land use planning, regulations and their optimal utilization. Generally, the spectral signature of urban classes have tendency to merge with several non-urban classes and prohibits their automated classification. Polarimetric SAR data minimizes the mixing of urban classes with nonurban classes. Built up and non-built up are separated automatically with speckle divergence of single Pol HH data. Polarization is an important characteristic of EM wave that influences the transmission characteristics of the SAR system. Polarization describes the orientation of the electric field plane with the plane orthogonal to its plane of propagation; it can be horizontal, vertical or at any angle; Polarimetry is to describe the polarization properties of the radar wave. The electric field and the magnetic field are always orthogonal to each other and perpendicular to the plane of propagation. Different decomposition methods are applied on quad pol data for different urban classes. Novel complementary information approach is proposed to improve urban LULC classification.

The complementary information extraction technique combines data in such a way that open lands are from classified images of Freeman Decomposition, sparse vegetation and vegetation are from Yamaguchi decomposition and built-up information are taken from the speckle divergence image. Local speckle characteristics can provide a texture layer that highlights built-up areas. Local deviation from the fully developed speckle -speckle divergence increases with a rising amount of true structures within the resolution cell.
The variation of structures leads to a local heterogeneity that gives urban areas a very specific and distinct appearance in SAR images. 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 (Figure 16).

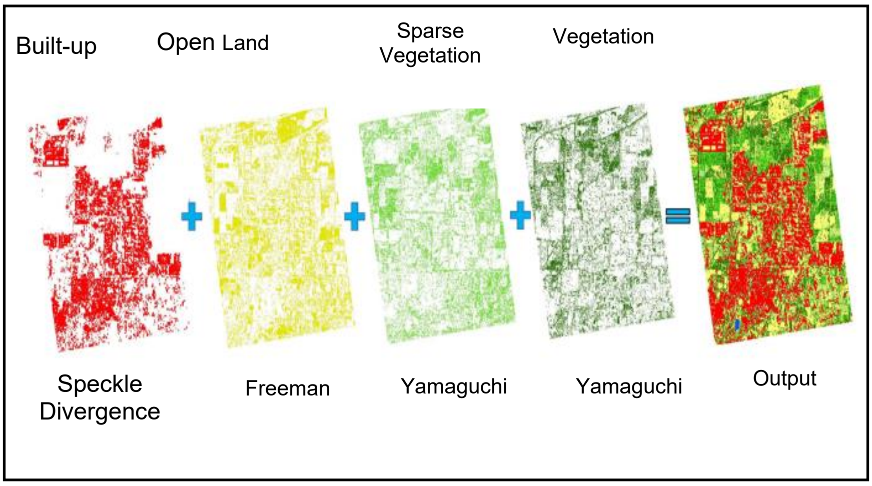


Figure 16. Urban LULC using Microwave data

10 Conclusions

Because of the distinct advantages in terms of the timeliness, repetivity, real time capability of data reception and transmission and computer compatibility, Remote Sensing and GIS are now indispensable tools for planners. Thereby, in the prevailing situation of rapid urbanization and spontaneous settlements, methods suggested above can provide solution to the urban, rural and the regional planners in fulfilling many of the mapping and other physical data requirements and with support from GIS, GPS systems data analysis can be carried out for urban and environmental planning.

Global phenomena of urbanization specially in the Indian context require that urban, rural and regional planners are at the earliest equipped with these modern tools and information system technologies for mapping and analysis, if they are to tackle these problems in an effective way. Further delay in adopting such systems/ methodology means more chaos, which we cannot afford. Therefore, in the prevailing situations of rapid urbanization and fast rural to urban immigration resulting in spontaneous settlements methods/ techniques mentioned above can provide immediate solutions to the urban/rural and the regional planners in meeting most of the mapping and other physical data needs and as such are indispensable and imperative.

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Chapter 12

Air quality monitoring, measurement and role of Earth Observation satellite

Chapter 12- Air Quality Monitoring, Measurement and Role of Earth Observation Satellites

1. Introduction

Clean air is one of the basic requirement for good human health and well being of the humanity. Clean air is essential to maintain the delicate balance of life on this planet — not just for humans, but wildlife, vegetation, water, and soil. Air pollution continues to be a well-known environmental problem worldwide. It can pose a serious threat to human health if it exceeds the permissible limit. Poor air quality occurs when pollutants reach high enough concentrations to endanger human health and the environment.

The quality of the air is the result of complex interaction of many factors that involve the chemistry and the meteorology of the atmosphere, as well as the emissions of variety of pollutants both from natural and anthropogenic sources. Many different primary air pollutants can impact health and environment - nitrogen oxide, carbon monoxide, ozone and sulphur dioxide, Aerosol Particulate Matter (PM 2.5 and PM10). PM2.5, i.e., aerosol particles smaller than 2.5 microns in diameter and 10 microns in diameter respectively. NO_2 is an air pollutant and an important precursor for the greenhouse gas ozone and aerosols, as the air pollutant SO_2 is also an important precursor for aerosols.

The major sources responsible for emitting these pollutants into the atmosphere are power generation plants, fossil fuels, vehicles, residential energy use, agriculture and industry. It is estimated that air pollution causes 36% of deaths from lung cancer, 34% of stroke while 27% are from heart diseases (WHO, 2016). These pollutants are responsible for formation of visibility, fog, smog fumes and act as cloud condensation nuclei towards formation of clouds, atmospheric chemistry and changes in air quality and climate forcing.

2. Health Impacts due to Air Pollutants

Adverse health consequences to air pollution can occur as a result of short/long-term exposure. Particulate Matter is capable of penetrating deep into lung passage ways and entering the bloodstream causing cardiovascular, cerebrovascular and respiratory impacts. The health effects of PM/Aerosols include eye irritation, depleted immune system, asthma, cardiovascular problems, chronic obstructive pulmonary disease (COPD) which includes chronic bronchitis and emphysema or lung cancer, diabeties, birth defects and premature deaths.

The WHO have identified fine particulate matter PM2.5, as the leading cause of death from air pollution. Outdoor and household air pollution worldwide causes 4.2 million and 3.8 million premature deaths every (WHO, 2018) of which 1.2 million premature death are only in India (GAHP, 2018). Exposure to PM2.5 is 5th highest risk factor for deaths worldwide whereas it is second highest risk factor in India. Regionally, South Asia, Southeast Asia, and the Western Asia are the hotspots of high particulate matter (PM2.5) pollution overall. Of the world's top 30 most polluted cities during 2019, 21 are located in India (few are-Ghaziabad, Delhi, Noida, Gurgaon, Bandhwari, Lucknow, Patna) (World Air Quality, 2019).

These pollutants are either deadly or have severe health risks even in small amounts. Exposure to surface ozone may cause chronic disease. Both healthy adults and asthmatics would be expected to experience significant malfunctioning of their lungs as well as airway inflammation that would cause symptoms and later performance. There are additional concerns about increased respiratory morbidity in children. Breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Both NO_2 and particulate matter aerosol have been linked to heart and lung disease and may lead to impact lung function. Sulfur dioxide irritates the skin and mucous membranes of the eyes, nose, throat, and lungs. High concentrations of SO_2 can cause inflammation and irritation of the respiratory system, especially during heavy physical activity. The resulting symptoms can include pain when taking a deep breath, coughing, throat irritation, and breathing difficulties. High concentrations of SO_2 can affect lung function, worsen asthma attacks, and worsen existing heart disease in sensitive groups. Increased levels of carbon monoxide reduce the amount of oxygen carried by haemoglobin around the body in red blood cells. Vital organs, such as the brain, nervous tissues and the heart, do not receive enough oxygen to work properly. For healthy people, the most likely impact of a small increase in the level of CO is that they will have trouble concentrating, becoming a bit clumsy as their coordination is affected, and they could get tired more easily. People with heart problems are likely to suffer from more frequent and longer angina attacks, and they would be at greater risk of heart attack.

Some of the other most common pollutants are mercury, lead, dioxins, and benzene. These are also most often emitted during gas or coal combustion, incinerating, or in the case of benzene, found in gasoline Benzene, can cause eye, skin, and lung irritation in the short term and blood disorders in the long term. Dioxins, more typically found in food but also present in small amounts in the air, can affect the liver in the short term and harm the immune, nervous, and endocrine systems, as well as reproductive functions. Lead (Pb) in large amounts can damage children's brains and kidneys, and even in small amounts it can affect children's IQ and ability to learn. Mercury affects the central nervous system.

Polycyclic aromatic hydrocarbons, or PAHs, are toxic components of traffic exhaust and wildfire smoke. In large amounts, they have been linked to eye and lung irritation, blood and liver issues, and even cancer. In recent study, the children of mothers who'd had higher PAH exposure during pregnancy had slower brain processing speeds and worse symptoms of ADHD.

It is estimated that around 3.3% of global GDP is attributed to air pollution from fossil fuels. These costs are the result of respiratory and non-communicable diseases made more likely by elevated polluted levels. China, USA and India bear the highest economic cost of soaring pollution, at an estimated cost of $ 900 billion, $ 600 billion and $150 billion (5.4% of India's GDP) per year respectively (Toxic air report, 2020). Pollution from PM2.5 costs 2.5% of the global GDP whereas pollution from O_3 and NO_2, each costs equivalent to 0.4% of global GDP (Toxic air report, 2020).

3. Ambient Air Quality Monitoring

Air quality monitoring program assists us in improving and developing air pollution control programs to reduce the effect of air pollution. Air quality monitoring helps us in better understanding the sources, levels of different air pollutants, effects of air pollution control policy, and exposure of various substances in the air we breathe.

The purpose of air monitoring is not merely to collect data, but also to provide the information necessary for engineers, scientists, policy makers, politicians and planners to make informed decisions on managing and improving the air environment. These air pollution indicators and information is also made widely public to citizens for awareness and at times to take meticulous decisions.

The Air Quality Index (AQI) is a scale designed to help one understand what the air quality around one means to ones health. AQI is a way of showing changes in the amount of pollution in the air. AQI helps in understanding the level at which air is polluted and the associated effects that might concern.

Air quality standards are set by individual countries to protect the public health of their citizens and as such are an important component of national risk management and environmental policies. Many national air quality standards are based on the WHO air quality guidelines. However, in some cases, the guidelines values are adjusted for the socioeconomics characteristics of each country, which result in specific air quality standards.

For purpose of setting Air Quality Standards, air pollutant concentrations should be measured at such monitoring sites that are representative of population exposures. National Air Quality standards varies according to the approach adopted for balancing health risks, technological feasibility, economic considerations and various other political and social factors, which in turn will depend on, among other things, the level of development and national capability in air quality management.

Due to the rapid development, migration of rural population towards urban metropolitan cities and industrialization, cities like Delhi, Gurgoan, Lucknow, Kanpur, Patna, Kolkata, and

Ahmedabad are on top of the Indian map in terms of pollution. The local emissions in the metropolitan cities also affect the ambient level of pollution in the neighbouring rural regions due to long and short range transport of pollutants. The Himalayan region is affected from episodic dust plumes generating from far west, regular forest fires particularly during pre-monsoon season in the Himalayan region, pollution from industrial and power plants refineries from Indo-genetic region and influence of fog and smog (Fig 1). Recent studies reported the air quality impacts on the Himalayan region through the summer monsoon and winter westerlies, which can transport pollution such as aerosol black carbon over long distances. The stubble burning during pre-monsoon and post-monsoon is also affecting the lower and higher Himalayan region. This is evident with uneven rainfall in pre and post monsoon seasons, extreme rain fall events, deterioration of air quality, and melting of snow/glaciers etc.

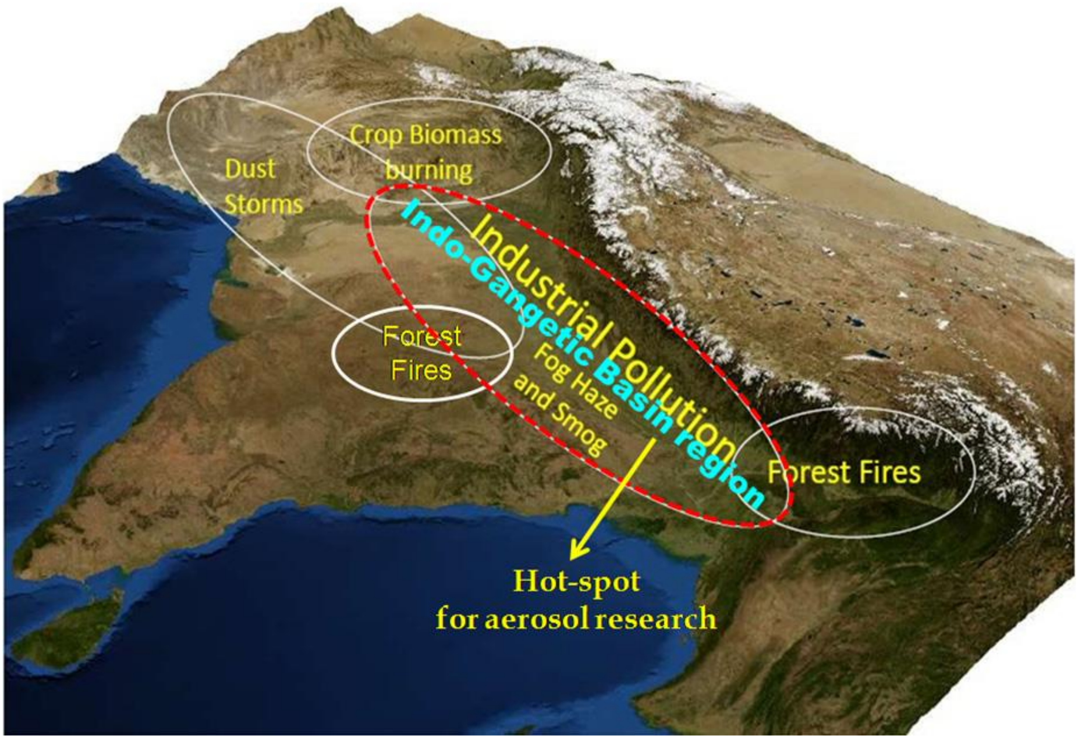

Figure 1: Influence different pollution sources to Himalayan region (Source: Srivastava et al., 2012)

4. Measurement of Air Quality

Instruments on ground and satellites orbiting Earth's orbit collect information on different pollutants that determines the air quality.

Understanding urban air pollution and the impact on environment and human health air pollution/air quality/aerosol data is needed by air regulators and managers to implement the National Ambient Air Quality Standards. To assess quality of air and to take steps for prevention, control and abatement of air pollution, Central Pollution Control Board (CPCB), Ministry of Environment and Forest (MOEF) is executing a nation-wide ambient air quality monitoring network through a National Air Quality Monitoring Programme (NAMP). CPCB measures the ambient air quality status through automatic monitoring stations to measure air quality parameters like, CO, O_3, SO_2, PM2.5, PM10, NO_2, NH_3, Pb operating around 780 monitoring stations across 340 cities in India. Continuous automatic ambient air quality monitoring analyzers alongwith manual monitoring comprising of Gravimetric and wet-chemical methods are used to measure the concentration of different air pollutants. National Ambient Air Quality Standard (NAAQS) estimates the AQI for 8 major air pollutants- ground level ozone, particulate matter (PM2.5, PM10), carbon monoxide, sulfur dioxide, and nitrogen dioxide, Ammonia and Lead (Source: CPCB).

Since 2014, Air Quality Index (AQI) is being generated and disseminated across 105 stations from 18 states to make public aware the status of the air quality in their locality and take immediate measures by local administration in case of severity (fig, 2). AQI value upto 50 $\mu g/m^3$ is good & safe values for health; value upto 100$\mu g/m^3$ is satisfactory & usually safe values for human health; upto 200 $\mu g/m^3$ is moderately polluted &unsafe values for human health; values upto 300 $\mu g/m^3$ is Poor standard & is an alarm value. AQI values upto 400 $\mu g/m^3$ is very poor status & is unsafe to be exposed and needs immediate action; and AQI values upto500 $\mu g/m^3$ is severe status& is hazardous to be exposed and needs urgently intervene by local authorities and actions.

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.6 –1.0
Moderate (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10.1-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17.1-34	801-1600	1201-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

Figure 2: AQI categories and breakpoint concentrations with averaging times (units: µg/m^3 unless mentioned otherwise)

Indian Space Research Organization (ISRO) through Geosphere Biosphere Programme (IGBP) established a regional network of aerosol and air quality observatories named as Aerosol Radiative Forcing over India network (ARFINET) across more than 35 cities/stations across length and breadth of India. The main objective of this network is to provide a comprehensive scenario of aerosol characteristics and its radiative forcing over Indian region including mainland and terrain regions. To achieve this, different kind of instrumentation pertaining to optical, physical, chemical characteristics of aerosol particulate matter and lidar based instruments are established as a part of Aerosol observatory.

Under the program, various automatic trace gas analyzers (CO, SO_2, NO_x, HC) are established under a network of various cities to get a continuous profile of the pollutant levels. Various land, ocean and aircraft campaigns are conducted to understand the aerosol and trace gases emission, transport and lifetime properties. Apart from the Indian networks, National Aeronautics and Space Administration (NASA), USA established a global network named as AERONET (AErosol RObotic NETwork) for regular measurements of aerosol and air quality parameters. The main purpose of the AERONET program is to maintain a long-term database of aerosol products and it utilised to validate the satellite remote sensing algorithms at different environments.

5. Earth observation satellites in air pollutants

Aerosols and trace gases (air pollutants) are generated at one place and are transported over long distances *via* winds, and produce consequent effects at locations far away from the source. Hence, study of air pollutants are important on regional and global scales. However, the observations of pollutants are geographically limited, and their regional impacts still remain uncertain (IPCC 2014). In this context, satellite remote sensing has the advantage of generating spatial and temporal distribution of aerosol optical properties. Various earth observation sensors have been measuring aerosols and trace gases for over 40 years over land and ocean. Earth observation satellites have the unique capability of capturing the spatial heterogeneity of aerosol parameters and different surface and at different atmospheric level trace gas concentration for each day. These data are being used to continuous monitor decadal/seasonal and yearly levels of these pollutants over different regions of the world.

Retrieval of aerosol properties from satellite-based observations started some 4 decades ago with Aerosol first operational aerosol product was generated from using AVHRR data (TIROS-N satellite) in 1978. The Nimbus-7, launched in 25th October 1978, carrying the Stratospheric Aerosol Measurement instrument (SAM) and the Total Ozone Mapping Spectrometer (TOMS). AVHRR and TOMS have provided a long term aerosol product over the ocean spanning regularly for a period of 40 years. A long term aerosol product over land, since 1995, is produced using ATSR-2 (Along Track Scanning Radiometer) and AATSR (Advanced Along Track Scanning Radiometer) measurements.

The capability of satellite instruments to measure the tropospheric pollution first became apparent by measurements of GOME on NO_2 (Leue et al., 2001) and MOPITT on CO (Edwards et al., 2004). These instruments enabled for the first time global measurements of pollutants in the troposphere in the form of maps of monthly or yearly averaged concentrations. Up to that point, only models provided such information, and independent data to validate these models was sparse. SCIAMACHY extended the measurements of the troposphere to greenhouse gases like methane (Frankenberg et al., 2008). The GOSAT satellite (Hamazaki et al., 2004) was launched in 2009 is dedicated to measure CH_4 and CO_2 with very high accuracy. Recent results suggest that GOSAT CO_2 retrievals are useful to constrain surface fluxes of CO_2 (Butz et al., 2011). In 2014 NASA's OCO satellite (Crisp et al., 2004) was launched to measure CO_2.

Because of its small pixels and daily global coverage, OMI provides much more measurements of the troposphere than previous instruments were able to.

These instruments clearly showed the unique capability of satellite measurements to obtain global coverage and consistent quality of the measurements. For instance, ground-based networks for most of the tropospheric trace gases are sparse and the quality of the data is sometimes station dependent.

The chemistry of the troposphere is complex and involves many trace gases and chemical reactions. Combining the observations of trace gases from satellite instruments is therefore a great advantage. The satellite observations are also used for data assimilation and integrating alongwith with other meteorological parameters in different models for forecasting of air quality over a region. Many of the data from these satellites are used in Numerical Weather Prediction studies. Hence, measurements of tropospheric trace gases are important for air quality monitoring and forecasting.

Especially, observations of longer-lived trace gases such as CO have proven useful in analyzing the impact of distant sources to local air pollution levels. Air quality prediction systems increasingly use satellite observations to improve their forecasting capability. Satellites provide top-down constraints on emission inventories, which traditionally rely on rapidly outdated bottom-up estimates, and generally go unchecked by measurements. As a result of the unique global character of satellite data and their consistency (one retrieval algorithm for all measurements), satellite measurements provide an exceptional tool for checking emission databases. Some of the Aerosol and trace gas retrieval satellite sensors are mentioned in table 1.

Table 1: Remote sensing sensors for observing Aerosols and Greenhouse gases

Satellite	Sensor	Properties
ENVISAT	Medium-Resolution Imaging Spectrometer (MERIS)	Aerosols, Clouds and precipitation
ENVISAT	Advanced Along- Track Scanning Radiometer (AATSR)	Cloud and aerosol properties, land and sea surface temperature

EarthProbe	Total Ozone Mapping Spectrometer (TOMS)	Ozone
ENVISAT	Global Ozone Monitoring Experiment (GOME-2)	O_3 , SO_2, NO_2, BrO, HCHO, H_2O, Aerosol distribution
ENVISAT	Global Ozone Monitoring by Occultation of Stars (GOMOS)	Vertical profiles of O_3, NO_2, NO_3, H_2O, O_2, and aerosols
ADEOS –I & II	Polarization and Directionality of the Earth Reflectance instrument (POLDER)	Aerosols, sea surface reflectance, Earth radiation budget
NOAA	Advanced Very High Resolution Radiometer (AVHRR)	Aerosol properties, cloud classification
Terra/Aqua	Moderate-Resolution Imaging Spectro-radiometer (MODIS)	Cloud and aerosol Properties, water vapour, surface and cloud temperature, fire data
Terra	Multiangle Imagining Spectroradiometer (MISR)	Cloud properties, Aerosol properties, Solar radiation flux, upper air winds, cloud cover
Terra	Measurement of Pollution In The Troposphere (MOPITT)	CO, CH_4
Aqua	Advanced Microwave Sounding Unit (AMSU)	Profiles of temperature and water vapor, cloud liquid water, rain rate
Aqua	Atmospheric Infrared Sounder (AIRS)	Temperature and humidity profiles, O_3, CO, CO_2, CH_4, sea and land surface temperature, outgoing longwave radiation (OLR), cloud properties
Aura	Ozone Monitoring Instrument (OMI)	Aerosols, O_3 , SO_2, NO_2, BrO, HCHO

Aura	High Resolution Dynamics Limb Sounder (HIRDLS)	Profiles of temperature, pressure, mixing ratios of H_2O, O_3, NO_2, CH_4, N_2O, HNO_3; aerosol
Aura	Microwave Limb Sounder (MLS)	Profiles of OH, HO_2, H_2O, O_3, HCl, ClO, BrO, HNO_3, N_2O, CO, volcanic SO_2, cloud ice, temperature, and geopotential height
Aura	Tropospheric Emission Spectrometer (TES)	O_3, CO
CALIOP	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	Backscatter profiles from clouds, Aerosol types, Aerosol extinction and vertical height
ENVISAT	Medium Resolution Imaging Spectrometer (MERIS)	Aerosols, clouds, precipitation, water vapor
Ocenasat-2	Ocean Color Monitor (OCM)	Ocean color, Aerosols
MetOp	Global Ozone Monitoring by Occultation of Stars (GOMOS)	NO_2, BrO,SO_2, H_2O, O_3, and aerosols
MetOp	Infrared Atmospheric Sounding Interferometer (IASI)	CO, O_3, CH_4, HNO_3, SO_2, N_2O, temperature and humidity profile
Meteosat Second Generation (MSG)	Spinning Enhanced Visible and Infra-Red Imager (SEVIRI)	Cloud properties, aerosol properties, water vapour, surface temperature, winds, albedo, infrared flux, O_3, CO_2
INSAT-3A, 3D, 3DR	Imager, Sounder	Cloud and Aerosol properties, temperature, humidity profiels, CO_2 Ozone, water vapor
Suomi-NPP	Visible/Infrared Imager/Radiometer Suite (VIIRS)	Aerosol & cloud properties, fire data

Suomi-NPP	Ozone Mapping and Profiler Suite (OMPS)	total columnar ozone
Sentinel-5P	TROPOspheric Monitoring Instrument (TROPOMI)	O_3, SO_2, NO_2, CO, HCHO, CH_4, Aerosol properties

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Chapter 13

Geospatial Applications in Water Security

1. Introduction

'There is a water crisis today. But the crisis is not having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people and the environment – suffer badly' (World Water Council, 2000)

A major concern in the Water Resources Management is the inadequate and timely available field data. Imaging from space provides near real time hydrologic information within few hours to few days with spatial resolution of 1 Meter to few km. and Synoptic coverage of 25 km to 2000 km. Remote Sensing (RS) has emerged as a powerful tool for providing information in spatial and temporal domain (digital form, high resolution) in contrast to traditional point measurements. Presently there are many satellites available in different orbits launched by USA, Europe, China, Japan, Russia and India. Geostationary satellites are used widely for telecommunication as well as utilized for monitoring weather phenomena.

Kalpan1 is one of the Indian Geostationary satellite which provides continuous information about cloud, cloud top temperature, water vapour etc. Polar orbiting satellites are used for mapping and monitoring of Natural resources viz. forest, agriculture, water, geology, marine and urban area. The resolution of images obtained from these satellites ranges from 40 cm to 1km. For water resources management it is necessary to monitor many parameters viz. Rainfall, Snow cover, Land use land cover, Evapo-transpiration. Space based imaging is extensively utilized in Flood mapping, monitoring and damage assessment, irrigation water management, drought monitoring and watershed management in India.

2. Rainfall

Recognizing the practical limitations of rain gauges for measuring spatially averaged rainfall over large areas and inaccessible areas, hydrologists have increasingly turned to remote sensing as a possible means for quantifying the precipitation input, especially in areas where there are few rain gauges. Direct measurement of rainfall from satellites for operational purposes has not been generally feasible because of the presence of clouds prevent observation of the precipitation directly with visible, near infrared and thermal infrared sensors. However, improved analysis of rainfall can be achieved by combining satellite and conventional gauge data. Useful data can be derived from satellites used primarily for meteorological purposes, including polar orbiters such as the National Oceanographic and Atmospheric Administration (NOAA) series and the Defense Meteorological Satellite Program (DMSP) and from geostationary satellites such as Global Operational Environmental Satellite (GOES), Geosynchronous Meteorological Satellite (GMS) and Meteosat, and Indian Satellite (INSAT) series which includes Kalpana 1. The visible and infrared bands are used to estimate rain indirectly by thresholding and index techniques. However microwave remote sensing have great potential for measuring precipitation directly.

The GOES Precipitation Index (Arkin, 1979), derived from thresholding the infrared brightness temperature of cloud tops has been used to study the distribution of tropical rainfall. Spencer et.al., (1988) have shown that the DMSP Special Sensor Microwave / Imager (SSM/I) data can identify rain areas and Adler et.al., (1992) has used a cloud based model with 85 and 37 GHz SSM/I data to estimate rain rates. Ground-based radar, which is a remote sensing technique, has advanced to an operational stage for locating regions of heavy rain, and for estimating rainfall rates also. The accurate measurement of the spatial and temporal variation of tropical rainfall around the globe remains one of the critical unsolved problems of meteorology. Tropical Rainfall Measuring Mission (TRMM) is a joint venture of US NASA and Japan Aerospace Exploration Agency (JAXA). TRMM consist of five sensors namely Precipitation RADAR (PR), TRMM Microwave Imager (TMI), Visible and Infrared Scanner (VIRS), Cloud and earth radiant energy sensor (CERES) and Lighting Imaging Sensor (LIS). Out of all precipitation radar is one of the most important sensor which provide 3-D rain structure.

3. Snow

Snow is one of the form of precipitation, however, in hydrology it is treated differently because of the lag between when it falls and when it produces runoff. Remote sensing is a valuable tool for obtaining snow data for predicting snowmelt runoff as well as climate studies. Rango (1992) presents a good review of the status of remote sensing in snow hydrology. Depending on the need, one may like to know the areal extent of the snow, snow water equivalent, grain size, snow density, albedo and emissivity.

Microwave remote sensing offers great promise for future applications to snow hydrology because it provides information on the snowpack properties such as snow cover area, snow water equivalent (or depth) and the presence of liquid water in the snowpack which signals the onset of melt (Kunzi et.al., 1982). Snow density and snow water equivalent are also determined using microwave data.

Early use of remote sensing for snow melt runoff forecasting focused on empirical relationships between snow cover area or percent snow cover and monthly or accumulated runoff (Rango et.al., 1977, Ramamoorthi, 1987). Optical remote sensing data is widely used to determine snow cover area, snow depletion curve as input to Snowmelt Runoff Model (SRM) (Martinec et.al., 1983). SRM has been extensively tested on basins of different sizes and regions of the world (Rango 1992, WMO 1992). Although SRM is a degree day model that uses only snow cover as remote sensing derived input, energy balance models (Leavesley and Stannard, 1990 and Marks and Dozier, 1992) are able to use additional remote sensing data such as albedo and other energy balance parameters.

4. Evapotranspiration

One of the most important developments in the field of remote sensing hydrology is the determination of distributed aerial AET from satellite data, based on energy balance approach. Many methods and models have been developed to accept remotely sensed data, which uses one-dimensional models to describe the radiation, conduction and turbulent transport mechanisms that influence surface temperature and energy balance. Remote sensing has been widely used with this type of framework to estimate the turbulent flux component of the surface energy balance. To do this, surface temperature obtained from remote sensed data is used [Gert A. Schultz, 2000]. Remote sensing provides the needed dynamic temporal view of vegetation, and complete spatial coverage of various parameters Viz. Land surface temperature, Leaf area index, Albedo etc. There are several ways of calculating the energy balance components. The latest in this direction is the Surface Energy BALance (SEBAL) (Bastiaanssen, 1998). The energy balance equation is given below

$$LE = R_n - G - H$$

Where

LE - Instantaneous Latent Heat Flux (W/m^2) ↑

R_n - Instantaneous Net Radiation (W/m^2) ↓

G - Instantaneous Soil Heat Flux (W/m^2) ↓

H - Instantaneous Sensible Heat Flux (W/m^2)↑

5. Hydrological Modelling

With the advent of fast processing computers and space based spatial input to hydrological models there is a more advance and accurate estimation of river flows as well as other hydrological parameters. Imaging from space provides watershed geometry by deriving digital elevation model from stereo pair images as well as input parameters like land use/ land cover, Leaf area Index, Albedo, Soil moisture, land surface temperature etc. As data received from space based sensors is spatial in nature hence, it can directly be used in physically based distributed hydrological models which are complex in nature and highly data driven. Many such models viz. Mike SHE, SWAT, VIC are used world wide to estimate various hydrological parameters. Hydrological modeling not only estimate the hydrological parameters but also help us to generate scenario for future climate change conditions.

6. Flood Management

India is one among the disaster prone geographical zone of the world and suffers losses worth more than $300 million as a result of flood and cyclone damage annually. It is also Worst flood affected country after Bangladesh (Agarwal and Narain, 1991) and accounts for 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 coast line is exposed to tropical cyclones arising from Bay of Bengal and Arabian Sea.

Space technology has made substantial contribution in every aspect of flood management such as preparedness, prevention and relief. Information acquired by remote sensing covers wide area, periodicity. It provide direct assessment of post flood damage using change detection technique. The utility of the satellite remote sensing has been operationally demonstrated for mapping the flood inundation areas, major floods and cyclones that occurred in the country were mapped in near real time and information was provided to the department concerned. Even partially cloud free data is acquired and analysed and interpreted and flood maps were prepared in near real time. IRS satellites namely IRS 1C, 1D, P6, Cartosat-1,2 along with Radarsat and ERS are used for flood inundation mapping , flood damage assessment and infrastructure loss. Following are some Indian satellite used for flood monitoring and damage assessment

Satellite	Sensor	Spatial Resolution (Meters)	Revisit time (days)
IRS 1 A/1 B	(LISS-I & LISS-II)	36.5 and 72.5	22
IRS 1 C/D	PAN	5.8	5

	LISS 3 WIFS	23.5 188	22 5
IRS P 4	OCM	360	2
IRS -P 6 (Resourcesat-1and 2)	LISS 4, LISS 3, AWIFS.	5.8 23.5 56.0	22 22 5
IRS – P 5 (Cartosat – 1)	Stereo pan	2.5	5
(Cartosat – 2)	Pan	80 cm	5

7. Watershed Management

Inappropriate land use practices in the upstream catchment leads to accelerated soil erosion and consequent silting up of reservoirs. Watershed management is an integral part of any water resources project. The prioritization of watershed i.e. which needs to be paid attention is based on sediment yield potential so that the treatment would result in minimizing sediment load into the reservoir. Satellite data have been extensively used in many watershed for deriving the parameters of USLE, MMF, SWAT models to provide quantitative silt load estimates in watersheds or catchments

Space borne multi-spectral data have been used to generate baseline information on various natural resources, namely soils, forest cover, surface water, ground water and land use/ land cover and subsequent integration of such information with slope and socio-economic data in a Geographic Information System (GIS) to generate locale-specific prescription for sustainable development of land and water resources development on a watershed basis. The study covering around 84 M.ha. and spread over 175 districts has been carried out by the Department of Space, Govt. of India under a national level project titled “Integrated Mission for Sustainable Development IMSD)”. Implementation of appropriate rain water harvesting structures in selected watersheds under this programme has demonstrated the significant benefits by way of increased ground water recharge and agricultural development of once barren areas. Multi-year satellite data is also used to monitor the impact of the implementation of watershed management programmes.

8. Irrigation Command Area Management

Irrigation development has been accepted as a major factor in increasing agricultural production. Development of irrigation is, therefore, the *sine-qua-non* for agricultural prosperity and general economic wellbeing of the population in the country. Irrigation forms the datum line for sustained successful agriculture

In most of the Irrigation Command Areas in India, the present status indicates that there is considerable scope for improving efficiency in the realm of water management. All the irrigation command areas suffer from the problems of inadequate and unreliable water supply, wide gaps between created and utilized irrigation potentials, temporal imbalances of water demands and supplies, excessive seepage losses, and rise of groundwater table leading to problems of water logging and salinity. The poor state of affairs in irrigated agriculture is the consequence of lack of scientific approach to planning and management of irrigation water.

The usefulness of remote sensing techniques in inventory of irrigated lands, identification of crop types, and their extent and condition and production estimation has been demonstrated in various investigation in India as well as in other countries. Periodic satellite monitoring of command areas has helped in evaluating increase in irrigation utilization and improvement in agricultural productivity through the years. Deviation from the recommended cropping pattern leading to ineffective water management have been detected. Problem soils viz. saline, alkaline and water logged soils resulting from injudicious water management have been mapped and monitored to aid reclamation activities. Remote sensing techniques are now increasingly applied in land use planning and in identifying areas suitable for sustained irrigated cropping through satellite derived irrigability maps. RS based vegetation indices and demand supply analysis is used to evaluate performance of irrigation command in many irrigation commands of India.

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Chapter 14

Geospatial Technology for Disaster Management

1. Introduction

Natural disasters are one of the most important causes of death and destruction of life and property and have a huge impact on the economies of the countries involved as well as the global economy. Infact some of the natural disasters has been observed to change the social and economic fabric of nations especially among the smaller nations. 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.

In this chapter you will be studying the various types and the recent trends and technological advances in natural disaster management. 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.

The economic loss to the global economy since 2000 is in the tune of $2.5 trillion and is still a very conservative estimate. This assessment is around 50% higher than the previous estimates. The recent major disasters in US and Japan like Hurricane Sandy in 2012, the 2011 floods in Thailand and the 2011 Japanese earthquake and tsunami has resulted in enormous loss to the private sectors which has still now looked at the short term gains and in general neglected the long term losses due to natural disaster. It has been estimated that Toyoya lost $1.2 billion due to 2011 earthquake as a result of loss in sales due to unavailability of parts in US plants. Apart from the economic losses, the loss of human lives due to disaster also puts a huge burden on the society. The recent natural disaster in Uttarakhand due to cloud-burst in the Kedarnath valley is a testimony to the fact. Even now there are many villages in the region where the working male population has been totally lost to the disaster. UN has estimated that over the past decade on an average around 70000 people have been killed and 200 million have been affected over the world due to various natural disasters.

Natural disasters can be categorized into eight categories. They are floods, landslides, cyclones, earthquakes, droughts and forest fires. The image below gives a clear picture of the different natural disasters and their impact on a particular year.

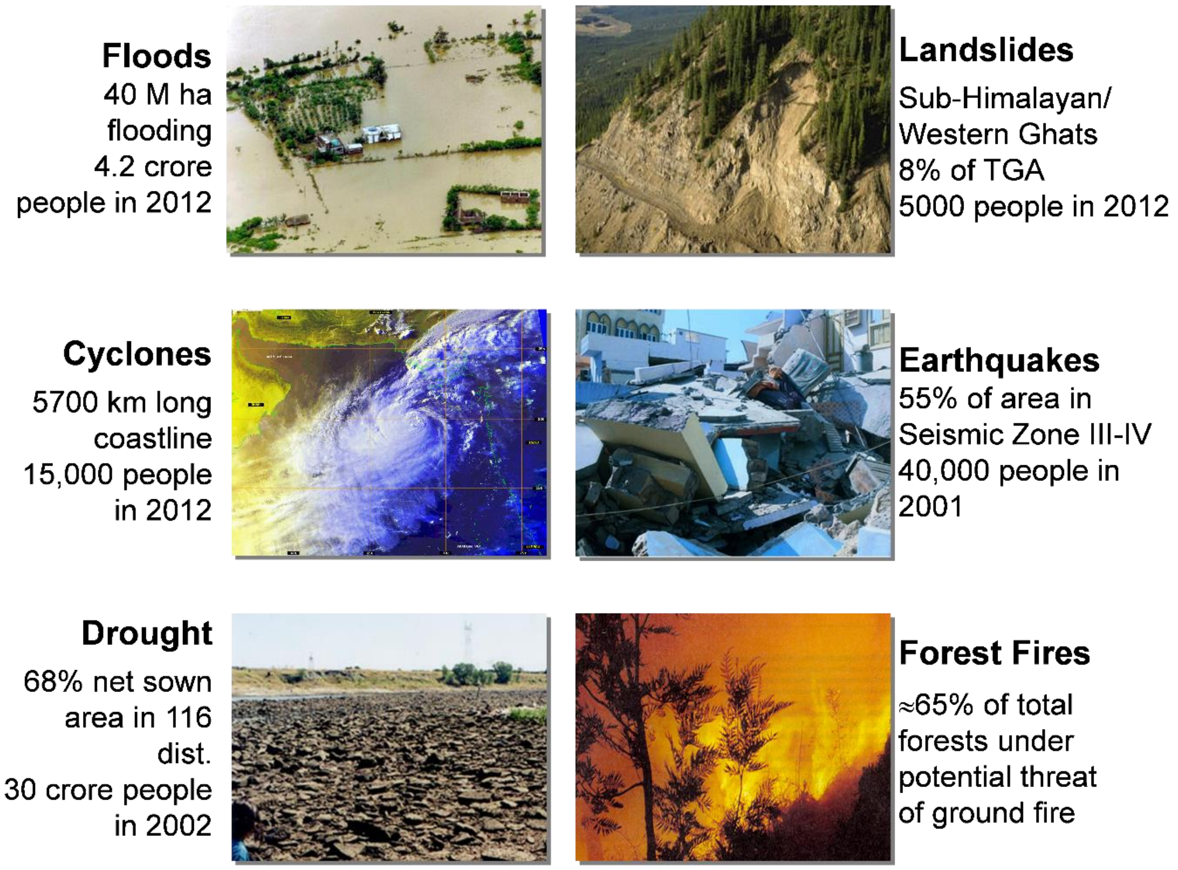

Fig 1. Major Natural Disasters in India

2. Types of Natural disasters

Forest fires: Indian forests fires are mostly due to the anthropogenic causes and are the most during the dry months of the year (January-June). The forest fire is in response to various climatic, soil conditions, topography, distance form habitation and the physiological conditions of the forest vegetation. Using a combination of satellite based, ground based and metrological data the probability of the fire occurrence can be predicted. The information can be uploaded on to the web in real-time to give sufficient time to the concerned authorities to take preventive steps.

Flood: Flood is a natural disaster which is overflow of water on land which is otherwise dry. It may occur in few days or the whole event may take place in few minutes (flash flood). Flood may be local affecting a community or it may impact a complete river basin. Floods may be of different types namely, Riverine Floods, Glacial Lake Outburst floods, Flash floods, Landslide Dam Burst Floods etc (UNDP, 2014).

Most of the flood affected areas lie in the Ganga basin, Brahmaputra basin (comprising of Barak, Tista, Torsa, Subansiri, Sankosh, Dihang and Luhit), the northwestern river basin (comprising Jhelum, Chenab, Ravi, Sutlej, Beas and the Ghagra), peninsular river basin (Tapti, Narmada, Mahanadi, Baitarani, Godavari, krishna, Pennar and the Kaveri) and the coastal regions of Andhra Pradesh, Tamilnadu, orissa and Kerela. Assam, Uttar Pradesh, Bihar and Orissa are some of the states who have been severely prone to floods. Our country receives an annual rainfall of 1200 mm, 85% of which is concentrated in 3-4 months i.e June to September. Warning is issued by the Central Water Commission (CWC), Irrigation & Flood Control Department, and Water Resources Department (R.S. Kaul, 2012).

Risk Reduction measures: Mapping of the flood prone areas, Land use control, Construction of engineered structures and Flood Control, Flood Management.

Increased siltation load of rivers and dams, erratic monsoon behavior and unplanned settlements in flood basin have increased the risks of flood hazards

The average area affected by floods annually is about 8 million hectares while the total area in India liable to floods is 40 million hectares in which Uttar Pradesh has 21.9 percent, Bihar (12.71 percent), Assam (9.4 percent), West Bengal (7.91 percent), Orissa (4.18 percent) and other states have 43.9 percent flood prone area (CBSE, 2006).

An analysis of data of different states for the period of 1953-2009 reveals that average annual damage to crops, houses and public utilities in the country was around Rs. 1649.77 crore and maximum reported 8864.54 crore was in the year of 2000. On an average, an area of about 7 million hectares (17.50 mha maximum in 1978) was flooded, of which, on average crop area affected was of the order of 3.302 million hectares (10.15 mha in 1988). The floods claimed on an average 1464 human life and 86288 heads of cattle dead every year (GoI, MHA, 2014).

Drought: Drought is negative balance between precipitation and water use in a geographic region. Drought can occur by improper distribution of rain in time and space, and not just by its amount. Droughts can be of two types: Meteorological drought (least severe form of drought), Hydrological drought and Agricultural drought (UW-DMS, 2014).

The following criteria have been set by the Indian Meteorological Division (IMD) for identifying the drought.

- Onset of drought: Deficiency of a particular year's rainfall exceeding 25 per cent of normal
- Moderate drought: Deficit of rainfall between 26-50 per cent of normal
- Severe drought: Deficit of rainfall more than 50 per cent of normal

Severe and rare droughts occur in arid and semi-arid zones once in almost every 8-9 years. Drought is a perennial feature in some states of India. 16 percent of the country's total area is drought prone and approximately 50 million people are annually affected by droughts

Landslides: 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.

Avalanche: This is another natural disaster which results in significant loss of life and property in the snow clad mountainous regions of the land.

Cyclone: The Indian Ocean is one of the six major cyclones–prone regions of the world. In India, cyclones from Indian Ocean usually occur between April and May, and also between October and December. The eastern coastline is more prone to cyclones than the western coast. About 80 percent of total cyclones generated in the region hit the eastern coast. Out of approximately six cyclones formed every year, two to three may be severe (NDMA, 2014).

Earthquakes: The tectonic movements of the earth's plates which forms the outer crust of the earth are the major causes of earthquakes. It is a result of sudden release of energy stored in the earth's crust due to tectonic movements. It has been estimated that since 1900 there have been around 1469 major earthquakes across the world (with magnitude greater than 5 on Richter scale). The loss of life and property due to earth quake is immense and sometimes it has been responsible for reducing an entire nation to economic and social downturn as seen in Haiti earthquake.

Volcanoes: They 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 months.

Impact of objects from space: We have mostly concentrated on the natural disasters due to the various earth processes. But there is a high probability of a natural disaster from the outer space in form of a meteor or an asteroid stike and in a worse form a collision between the earth and a comet. All these scenarios are quite frightening as the impact on the human civilization can be disasterous. A meteorite impact in the recorded history in 1908 in Krasnoyarsk Krai, Russia, has resulted in a explosion yielding energy equivalent to more than 1000 times the energy of the atom bomb dropped on Hiroshima during the world war II. An impact of similar proportion over any major metropolis can result in complete annihilation of millions of people apart from loss to the economic potential of the region. It has been speculated that a impact much greater than the 1908 event has lead to the extinction of the dinosaur population from the face of the earth.

3. 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 approach which are being implemented or in the process of being implemented. Some of the major disaster management aspects are (EM-DAT, 2014):

1. Reducing Social & Economic Vulnerability - through Risk Management Approach
2. *Increased investment in Long-term Mitigation Activities - Preparedness, Capacity Building, use of state-of-the-art Technology Tools [Space, IT, Modeling, …]*
3. Integration of DM with other development sectors
4. 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:

1. Inclusion of Disaster Management in the Concurrent list of VII Schedule of the Constitution
2. Enactment of the National/ State Acts for Calamity Management
3. Enforcement of Detailed Regulations/ Codes - through Law

4. 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 gives 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.

5. Technology for disaster management

The technological inputs disaster management is at four stages:

1. Early Warning Systems
2. Detection and Monitoring
3. Rescue and Relief
4. 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.

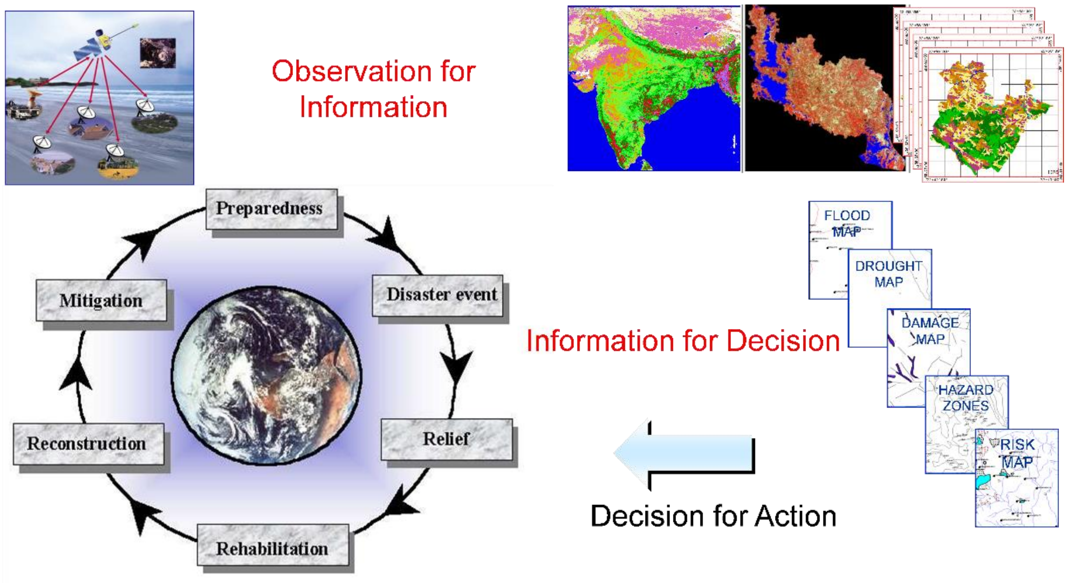

Fig 2. Technology for disaster management

6. 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.

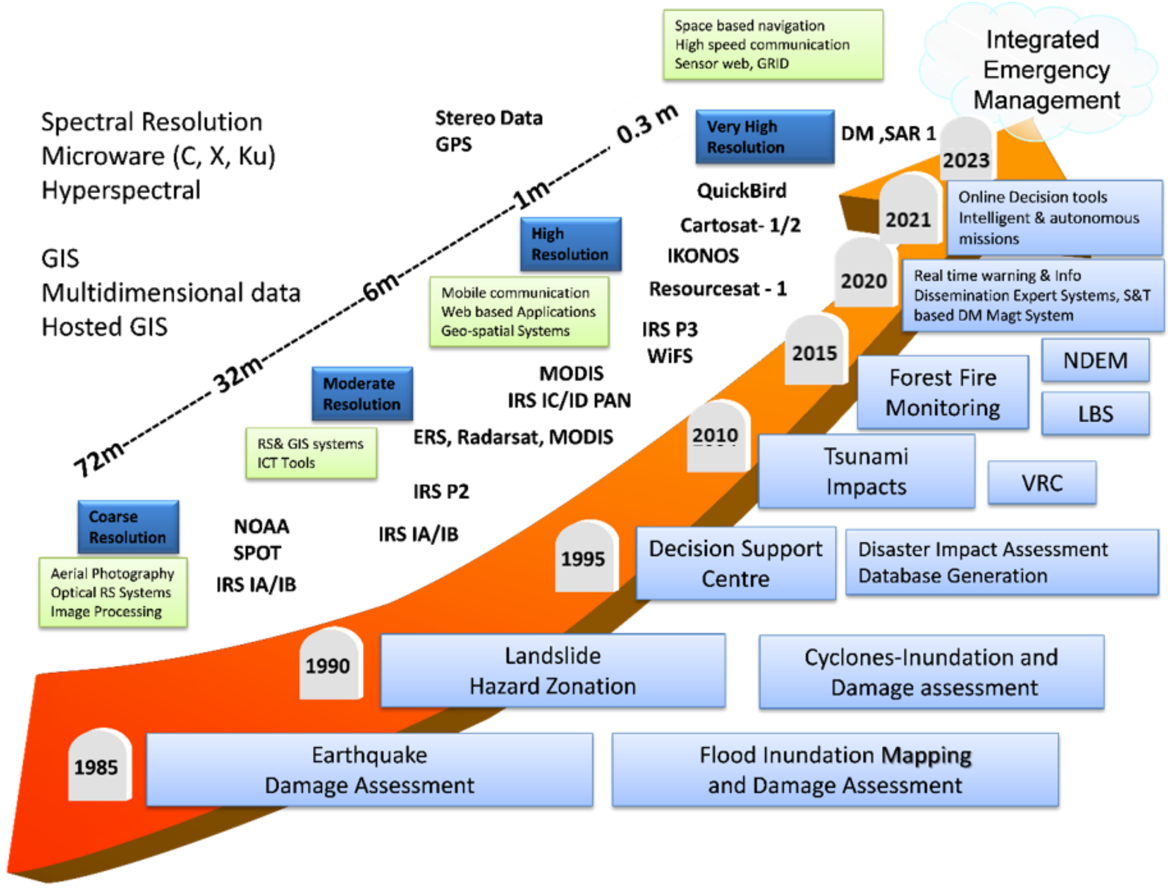

Fig 3: Growth of technology for Disaster Management

7. 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 it 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 location.

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 Neighborhood 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.

8. 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.

9. 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 is 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.

10. 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 a 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 regards proper training and handholding is required by the organizations.

11. Case Studies

Orissa Super Cyclone: The east coast of India has been affected by a minimum of four high-intensity cyclones every year for the past 100 years(Raghavan & Sharma, 2000). In October 1999, 12 coastal districts in Orissa suffered severe damage, 9885 persons died, 2142 people were injured and 12 lakh houses were damaged13. Similarly, more than 10,000 lives were lost around the Krishna delta in Andhra Pradesh in 1977 (Antonio Mascarenhas, 2004). Coastal hotels and resorts were inundated and habitations destroyed at Digha in August 1997. The number of displaced people is increasing as more land is eroded following violent storms. Most of the masses that occupy countless low-lying plains comprise farmers who live in mud houses; this section of society bears the recurring loss of humans, livestock and property.

Remote Sensing based information was one of the main inputs for relief and rescue operation carried out by the Indian government. The impact and extent of flooding as a result of the cyclone also helped in aid allocation and prioritization of the relief aid distribution in the affected areas (Fig 4).

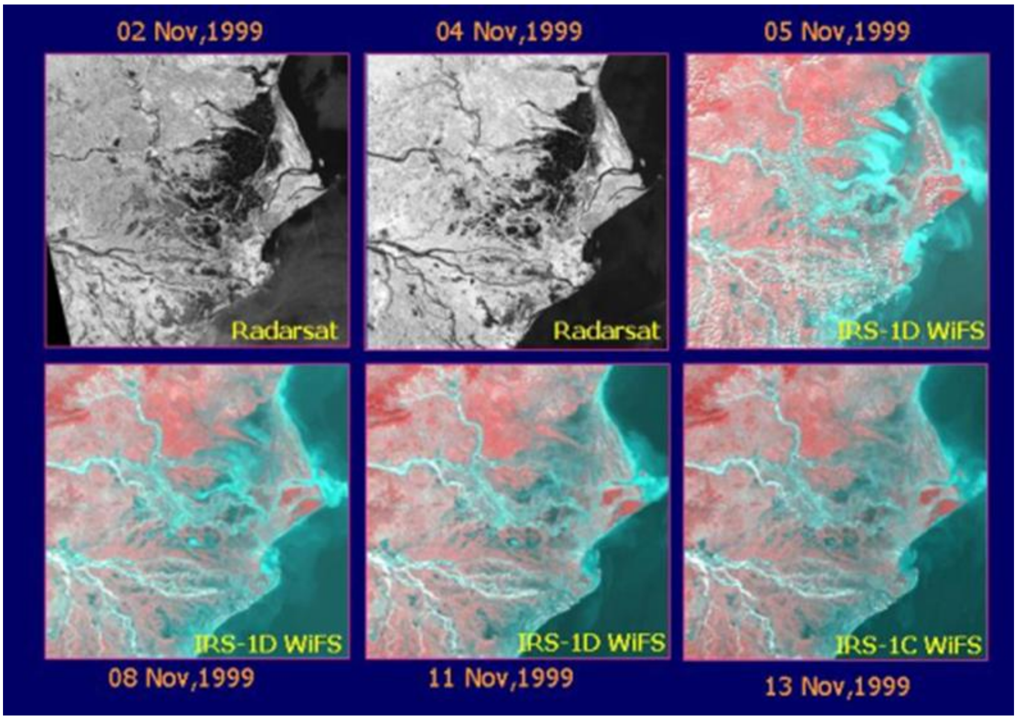

Fig 4. Extent of submergence in Paradeep Coast due to super cyclone of October 1999 (Source: NRSA)

Tsunami : The tsunamis of Sunday 26 December 2004 caught many people unprepared and unaware in Indian Ocean countries. This unexpected event struck without apparent warning on a clear day; many local people and tourists were on the beach and some walked over coral reef flats as the water receded to investigate a hidden realm. Within minutes, a series of massive waves returned to carry them away and invade the land. The tsunamis resulted in more than 250,000 people killed or missing and caused massive destruction to coastal resources and infrastructure.

Remote Sensing has helped in generating the spatial extent of the damage to the coastal regions of the Indian Ocean. National Disaster Management at NRSA has generated extensive areal database of the affected areas along the east coast of India and also Srilanka. The vivid spatial images on the extent and intensity of damage has helped in allocation and prioritization of rescue and aid to the affected people Fig 5.

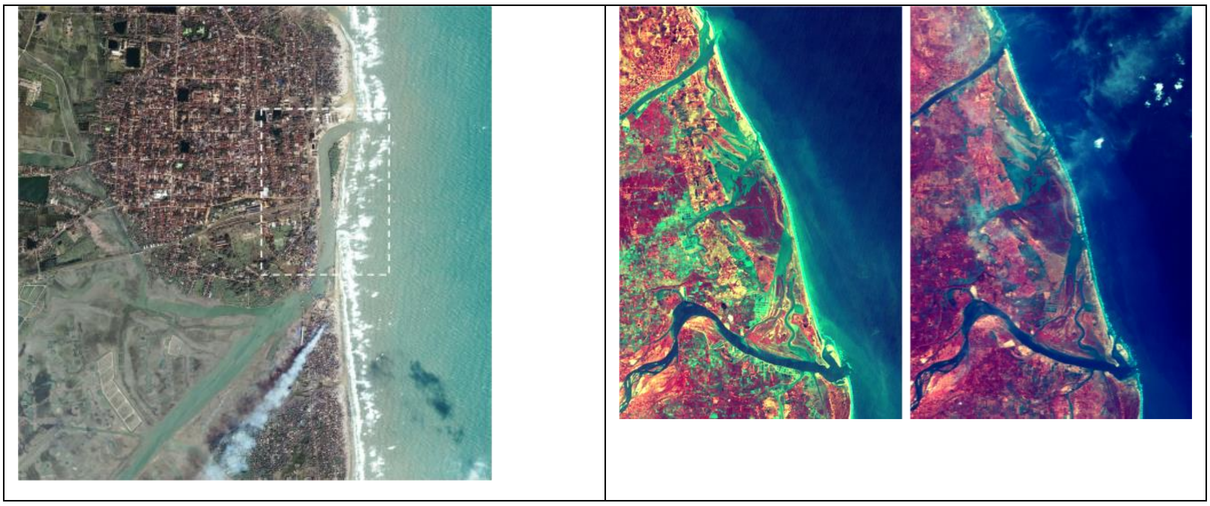

Fig 5 (a) Inlet channel cut by Tsunamiwaves at Nagapattinum (*left*) (b) Sand due erosion by tsunami wave in Vellar and Coleron estuaries , Tamilnadu (*top*) (Source: NRSA)

During Tsunami some of the coral reefs sustained damage, especially those in channels between islands and passes between coral reefs. Here the tsunami energy was concentrated by the island topography to create strong surges and currents. Many corals in these areas suffered considerable damage with large coral heads weighing several tonnes and many branching and table corals being either shattered or overturned, thereby absorbing some of the wave energy.

12. Summing up

With the global climate change the frequency of extreme events will increase and so will natural disasters. Effective management of the natural disasters in terms of early warning, evacuation, planning and rescue and relief can result in huge benefit for the nations and also economic effects of natural disasters. Advances in the technology has resulted in the improvements in the early warning systems, greater response time and much more informed rescue and relief efforts for mitigating the effects of the natural disaster. The technology is continuously improving and evolving to involve crowdsourcing to generate information for disaster mitigation and rehabilitation.

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