

Remote Sensing and GIS

M L Sharma¹, Sunil Kumar², Ajay Kumar Garg³, Shaman Singh Multani⁴, Aryan Chauhan⁵, Mohit Kumar Jha⁶, Aneek Anand⁷, Harsh Pathak⁸

^{1,2}*Professor, Electronics and Communications Engineering Department, Maharaja Agrasen Institute of Technology, Delhi*

³*Associate Professor, Electronics and Communications Engineering Department, Maharaja Agrasen Institute of Technology, Delhi*

^{4,5,6,7,8}*Research Scholar, Electronics and Communication Engineering Department, Maharaja Agrasen Institute of Technology, Delhi*

Abstract- Natural resources are foundational to a nation's socio-economic development, serving as essential sources of employment, raw materials, food, and energy. However, escalating population growth and unsustainable exploitation have led to severe resource depletion, environmental degradation, and increased socio-economic pressures. To address these issues, Remote Sensing (RS) and Geographic Information Systems (GIS) have become indispensable tools for sustainable land resource management. Recent technological advancements—such as high-resolution multispectral and microwave satellite imagery, enhanced temporal coverage, and open-access data—have significantly expanded the capabilities of RS and GIS in monitoring and managing land use, environmental health, and resource planning. GIScience provides critical frameworks for spatial modeling and analysis, while remote sensing delivers precise Earth observation data, even under adverse weather conditions. Together, these technologies support informed decision-making, efficient land planning, and predictive modeling in environmental and natural resource sciences. This paper synthesizes current research to highlight the integrated role of RS and GIS in achieving long-term sustainability goals and addresses their future directions in the era of data-intensive environmental research.

Indexed Terms- Remote Sensing Satellites, Multispectral, Hyper Spectral, LiDAR, UAV Platforms

1. INTRODUCTION

Natural resources, encompassing both renewable types like solar energy, forests, and fisheries, and non-renewable ones such as coal, oil, and natural gas, are fundamental to sustaining human life and driving economic, social, and cultural development. Some resources are also recoverable and recyclable, such as elemental and metallic minerals. The availability and accessibility of these resources are governed by various factors, including physiography, climate,

biological conditions, and technological capabilities. Their spatial distribution varies significantly, with some originating from oceans and others from land, while their temporal availability is influenced by patterns of usage and regeneration rates. Despite their importance, current systems for inventorying and monitoring natural resources are inadequate. Data is often incomplete, outdated, or inaccessible due to difficult terrain, administrative boundaries, or inconsistent methodologies. Challenges such as poor documentation, lack of standard data formats, and limited inter-agency data sharing further hinder effective land resource planning and sustainable management. It is in this context that the modern tools of Remote Sensing (RS) and Geographic Information System (GIS), and Satellite based positioning systems (popularly called GPS) are appropriate for natural resources assessment and management. RS is the acquisition of information about an object, a phenomena or a process by noncontact method, usually from airplanes or satellites, using sensors operating in any portion of the electromagnetic spectrum. The GIS allows inputting, management, analysis and display of the data collected by RS and other means. GPS instruments are used to obtain precise measurement of an object's location in terms of longitude, latitude and altitude. At global scale these technologies provide a cost effective means to study the biosphere, geosphere and atmospheric interactions. At micro scale, space technology is providing valuable inputs for developing land and water resources. Monitoring of changes in the forest cover using RS and drafting developmental plans for afforestation using GIS are good examples of macro and micro-level applications.

1.1 REMOTE SENSING TECHNOLOGY

The Earth observation using satellite remote sensing technique has made it possible to obtain uniform data covering the whole globe in a relatively short time, and has also made it possible for these observations to be continued for a long time in the future (Figure 1). The two main components of the space-based sub-system of the EOS, PolarOrbiting and Geostationary, continue to improve with every new launch. Geostationary satellites orbit the earth with the earth's rotation so that they observe the same point on the Earth continuously, but from a much higher altitude approaching 36,000 km. Geostationary satellites are the primary meteorological observation platforms and provide continuous but somewhat coarser spatial data. Polar orbiting satellites generally fly in a low Earth orbit (hundreds of km) and provide relatively high resolution measurements with repeat times of days to tens of days. Typical polar orbiting satellites (Table 1) are the NOAA-AVHRR, the French SPOT and the US LANDSAT and TM series. The data received from polar-orbiting satellites is very useful in understanding and monitoring the natural hazards. Also, the effect of the space and time distribution of water accompanied by phase changes on the water and energy budget at the earth surface from the point of view of understanding and control of the mechanism of environmental changes can be better evaluated with satellite data. It is based on the use of image data acquired by sensors of different types such as aerial camera, scanner or radar. The satellite remote sensing is used to interpret the images or numerical values obtained from a distance in order to acquire meaningful information of particular features on earth. The instruments used for this purpose may employ any of a variety of physical energy distributions. Sonars, for example, work on the principle of acoustic wave distribution, optical instruments such as the photographic camera and multi-spectral scanner use electromagnetic energy distribution. Remote sensing covers all techniques related to the analysis and use of data from satellites, such as Metaset, National Oceanic and Atmospheric Administration (NOAA)-Advanced Very High Resolution Radiometer (AVHRR), Landsat, (French: Satellite Pour observation de la Terre) SPOT, Earth Resources Satellite (ERS) - Satellite Access Request (SAR) and from aerial photographs. The main objective of remote sensing is to map and monitor the earth's resources.

Dataset of Earth Observation Satellites

Satellite	Country	Repeat cycle	Sensor	Sensor	Frequency/Band (microns)	Resolution	Swath (km)
MODIS	USA	1-2 days	MODIS	MODIS	250-1000	250-1000m	2350
AVHRR	USA	12 hours	AVHRR	SAR	1100m	1100 m	2800
Sentinel-1	Europe	12 days	SAR	5.4 GHz(C-Band)	20m (fine)	20m (fine)	250
ETM+	USA	16 days	TM PAN	0.5 GHz 2.2 0.5	30m,15m	25m 18	180
OLCI	Europe	27 days	OLCI	0.4-1.0	300m	1270m	180
ARGOS	France	100 min.	Argos	401MHz	—	—	—
VIIRS	USA	12 hours	VIIRS	0.4-12	375-750m	3000m	3000
SLSTR	Europe	1 day	SLSTR	0.5-12	500-1000m	500-1000	1400

Legend:
 SAR Synthetic Aperture Radar TM Thematic Mapper
 PAN Thematic Mapper OLC Ocean and Land Colour Instrument
 VIIR Panchromatic VIIRS Visible Infrared Imaging Radiometer Suite

1.2 WORKING OF REMOTE SENSING:

Remote sensing data are acquired in predetermined spectral bands (wave lengths). Visible and near infrared spectral bands (which can be displayed as colors as shown in Figure 1) are chosen to amplify or separate specific earth features such as vegetation, rocks, urban 14 area, snow and water. This way one can separate a chosen land feature from other land features by choice of the wavelength.

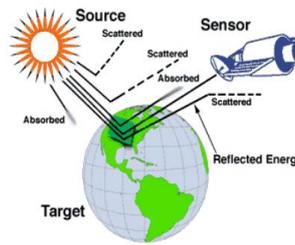


Figure 1: Concept of a satellite sensing the globe through its on-board sensors

In the following sections the focus will be on polar orbiting satellites, which are more relevant to natural hazards. Some of the prominent polar orbiting satellites are listed in Table 1. Few of the many agencies receiving/distributing the data from the above listed satellites are:

- i) RadarSat International (RSI), Canada;
- ii) Canada Center for Remote Sensing, Canada;
- iii) Center for Remote Imaging, Sensing and Processing (CRISP), Singapore;
- iv) EROS Data Center (EDC), USA;
- v) Space Imaging, USA;
- vi) SPOT Imaging, France; and
- vii) National Remote Sensing Agency (NRSA), India

1.3 Active and Passive Remote Sensing

Remote sensing uses devices known as sensors that can measure and record the electromagnetic energy. Active sensors such as radar and laser have their own

source of energy and can emit a controlled beam of energy to the surface and can measure the amount of reflected energy. These sensors are used to measure the time delay between the emission and return and can determine the location, height, speed and direction of an object under investigation. As active sensors can emit their own controlled signals, they can be operated both day and night, regardless of the energy available from external sources. Passive sensors, on the contrary, can only work using the natural sources of energy. As a result, most passive sensors use the sun as a source of energy and can only work during daytime. However, passive sensors that measure the longer wavelengths related to the earth's temperature does not depend on the external source of illumination and can be operated at any time.

1.4 Methods in Remote Sensing

i. Remote sensing image data: Data can be used from different satellites such as Land Remote-Sensing Satellite (LANDSAT) (spatial resolution 30m), LISS III (spatial resolution

23.5m) and Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data (spatial resolution 15m). These images provided suitable cloud-free spatial coverage with relatively high spatial and spectral resolutions.

ii. Geometric correction: Accurate registration of multi spectral remote sensing data is essential for analyzing land use and land cover conditions of a particular geographic location. The geometric correction of remote sensing data is done for the distortions and degradation caused by the errors due to variation in altitude, velocity of the sensor platform, variations in scan speed and in the sweep of the sensor's field of view, earth curvature and relief displacement. The images are geo referenced using the poly-conic projections with Root Mean Square Error (RMS) and LANDSAT-7 ETM+ data are re-projected to poly-conic projections.

iii. Ground reference data: In image analysis, ground reference data play important roles to determine information classes, interpret decisions, and assess the accuracies of the results.

Substantial reference data and a thorough knowledge of the geographic area are required at this stage.

iv. Classification scheme: Classification schemes provide frameworks for organizing and categorizing

information that can be extracted from image data. A proper classification scheme includes classes that are both important to the study and discernible from the data on hand. Image enhancement, contrast stretching and false colour composites are worked out and the interpretation of images are carried out using the various interpretation keys like the shape, size, pattern, tone, texture, shadows, location, association and resolution.

v. Image Classification Techniques: Image classification is the process of converting raw satellite imagery into meaningful land cover categories. There are two main types of classification techniques:

i. Unsupervised Classification: This technique groups pixels into clusters based on their reflectance values without prior knowledge. Algorithms like ISODATA or K-means automatically identify natural groupings in the data. The analyst then labels these clusters based on field data or visual inspection.

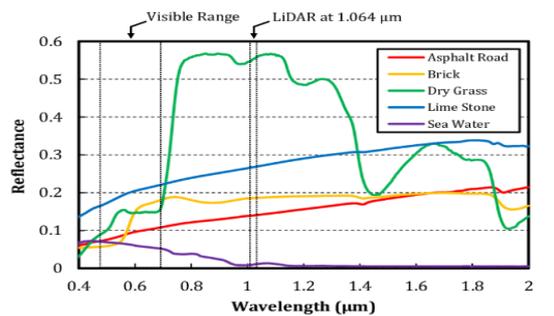
ii. Supervised Classification: This approach requires prior knowledge. The analyst selects training areas for known land cover types, and the algorithm (such as Maximum Likelihood or Support Vector Machines) uses this information to classify the entire image. Supervised classification tends to be more accurate when quality training data is available.

vi. Accuracy assessment: Accuracy assessment is a vital process in remote sensing used to evaluate the reliability of a classified image by comparing it with actual ground data. It helps determine how accurately the classification represents real-world land cover or features. The process involves collecting ground truth data—either through field surveys, GPS points, or reliable reference maps—and comparing it to the classified results using a tool called a confusion matrix. This matrix shows both correct and incorrect classifications, allowing analysts to calculate key accuracy metrics. These include overall accuracy, which measures the percentage of correctly classified pixels; producer's accuracy, which indicates how well real features are classified; and user's accuracy, which reflects how trustworthy the classification is from the user's perspective. This assessment is essential to ensure the data is dependable for practical applications like resource management, urban planning, and environmental monitoring.

vii. *Land Use Mapping and Distribution:* A supervised maximum likelihood classification may be implemented for the two images and the final classification products provide an overview of the major land use / land cover features of lands for two time intervals and classifications like Water Body, Forest Reserve, Built up Area Vegetation and Farmland etc. can be done.

2. CONCEPT OF SIGNATURE

Signature of any object and/or its condition comprises a set of observable characteristics, which directly or indirectly lead to the identification of an object and/or its condition (Figure 2). There are four principal characteristics of signatures to identify an object.



- Spectral variations: Changes in the reflectance or emittance as a function of wavelength.
- Spatial variations: Variations in the reflectance/emittance determined by the shape, size and texture of the target.
- Temporal variations: Diurnal and/or seasonal changes in reflectance or emittance.
- Polarization variations: Changes in the polarization of the radiation reflected or emitted by an object.

3. REMOTE SENSING SATELLITES

3.1) *Optical Remote Sensing:* Optical Remote Sensing:

uses multi-spectral sensors to observe the Earth's surface, with spatial resolutions ranging from coarse (500–1000m) to high (1–2m). High-resolution data across 5–15 spectral bands (in visible and infrared regions) enhances land assessment and monitoring, from regional to field levels. Panchromatic sensors offer even higher resolution (<1m) in a single visible band, making them ideal for detailed local planning and mapping, such as urban layouts and cadastral

(property-level) maps. These sensors also support the creation of high-resolution Digital Elevation Models (DEMs) through stereo imaging.

India's Resourcesat-2A and Cartosat-2E are prime examples, offering multispectral and panchromatic imagery. Other satellites like WorldView-3, SPOT-7, and Sentinel-2A/2B provide varying resolutions and revisit frequencies to suit different land monitoring needs. Freely available satellites like Landsat, ASTER, MODIS, and AVHRR supply open-source data for broader applications. China's Gaofen and Ziyuan-3, and US-based Digital Globe systems (like WorldView-3) also contribute high-quality imagery. These satellites collectively support precise identification of natural and man-made features and are crucial for land resource planning, monitoring, and development.

India launched state of art multispectral high resolution remote sensing satellite:

- Resourcesat-2A in 2016 and Cartosat-2E with very high resolution panchromatic sensor in 2019. The multispectral sensors offers spatial resolution ranges from 5.8 to 56m whereas panchromatic sensor provides data of <1m resolution.
- WorldView-3 satellite gives 31cm PAN, 1.24m MS and 3.7m SWIR resolution data every day. SPOT-7 provided 1.5m PAN and 6m multispectral data on daily revisit.
- Sentinel 2A and 2B provide 10 multispectral bands with spatial resolution of 10-20m and 5 days revisit for land applications.

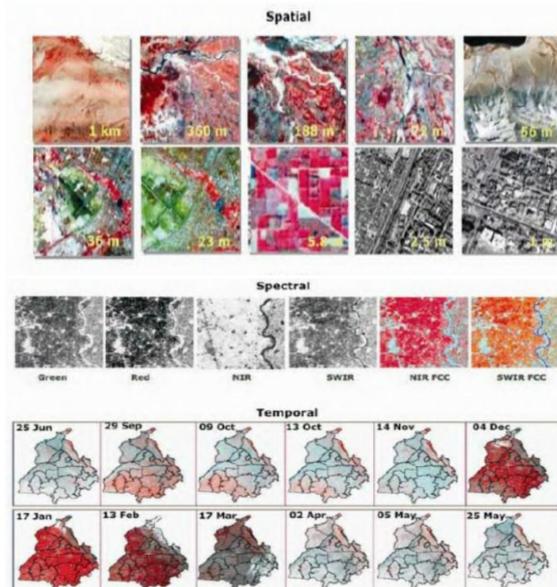


Table Remote Sensing Satellites with Panchromatic and Multispectral Sensors

Satellite	Country (Year)	Sensors	Spatial Resolution (m)	Revisit Time (days)	Remarks
Resourcesat-2	India (2011)	4 MS - LISS IV	5.8	5	-
		4 MS - LISS III	23.5		
		3 MS - AWiFS	56		
Resourcesat-2A	India (2017)	4 MS - LISS IV	5.8	5	-
		4 MS - LISS III	23.5		
		3 MS - AWiFS	56		
Resourcesat-3* series	India (2020–2021)	5 MS	10/20	5	
Cartosat-1	India (2005)	PAN	2.5	5	Stereo
Cartosat-2A	India (2008)	PAN	<1	4	-
Cartosat-2B	India (2010)	PAN	<1	4	
Cartosat-2 series	India (2017, 2018)	PAN	<1	4	
Cartosat-3A*	India (2020–21)	1 PAN	0.25	Daily	Continuous
		4 MS	0.50		
		MIR, VNIR & SWIR	5, 30, 50		
GISAT / GeoHR	India (2020–21)	6 VNIR	50	Daily / 30 min	
IKONOS	USA (2000)	PAN	0.8	3–5	Stereo
		MS (4)	4		
Landsat-8	USA (2013)	OLI (8)	30	16	
		TIRS (2)	100		
		PAN	15		
SPOT-7	France (2014)	PAN	2.5	1–5	Stereo

3.2) Microwave Remote Sensing:

Microwave Remote Sensing is a powerful Earth observation technique that uses microwave radiation (with wavelengths ranging from 1 mm to 1 m) to detect and analyze surface features. Unlike optical remote sensing, it can operate both day and night and penetrate through clouds, haze, and light rain, making it ideal for all-weather monitoring. This form of remote sensing is categorized into two types: active and passive. In active microwave sensing, the system transmits its own microwave signals toward the Earth's surface and measures the energy that is backscattered. Examples of active systems include RADAR (Radio Detection and Ranging) and SAR (Synthetic Aperture Radar), which are known for producing high-resolution images. On the other hand, passive microwave sensors like radiometers detect

naturally emitted microwave radiation from the Earth's surface.

Several types of sensors are used in microwave remote sensing. Synthetic Aperture Radar (SAR) is widely used for high-resolution imaging. Scatterometers are primarily used to measure wind speed and direction over oceans, while altimeters are used to measure surface height, such as sea level or ice sheet thickness. Radiometers play a crucial role in measuring parameters like soil moisture and atmospheric temperature.

Microwave remote sensing has broad applications. It is used for soil moisture estimation, flood monitoring, vegetation and forest mapping, snow and ice analysis, ocean wind and wave studies, and disaster management. Its capability to function under cloudy and dark conditions also makes it highly valuable for military surveillance and reconnaissance.

Table: Land Resource Mapping Using Microwave Remote Sensing Data

Mapping Scale	Thematic Mapping Scale	Standard Scale	Spatial Resolution	Microwave Sensors	User's Applications
Intensive (Very detailed)	1:5,000 to 1:10,000	1:5000	Very fine (<5 m)	TerraSAR-X, COSMO-SkyMed, RADARSAT-2	Urban infrastructure, cadastral mapping
Detailed	1:10,000 to 1:25,000	1:25,000	Fine (5–10 m)	Sentinel-1, RISAT-2B, ALOS PALSAR	Agricultural monitoring, land use
Semi-detailed	1:25,000 to 1:100,000	1:50,000	Medium (10–50 m)	RISAT-1, ENVISAT-ASAR	Forest cover, flood mapping
Reconnaissance	1:100,000 to 1:500,000	1:250,000	Coarse (50–100 m)	ERS-2, RADARSAT-1	Soil moisture, regional wetland mapping
Exploratory	1:1,000,000 and above	-	Very Coarse (>100 m)	SMAP, AMSR2, GRACE (passive microwave)	Climate studies, global hydrology

Here is the data from **Table 5: Microwave Remote Sensing Satellites** and there spatial resolution:

Microwave Remote Sensing Satellites

Satellite	Country (Year)	Sensors	Spatial Resolution (m)	Revisit Time (days)
RISAT-1	India (2012)	C-band SAR	1-50	-
RISAT-1A/1B*	India (2019-20)	C-band SAR	1-50	-
ALOS-2	Japan (2014)	L-band SAR	3	24
EnviSat	EU (2002)	C-band SAR	28/50/950	35
Sentinel-1A & 1B	EU (2014/2016)	C-band SAR	5/25	12
RADARSAT-2	Canada (2007)	C-band SAR	3/100	24
RADARSAT-3*	Canada (2019)	C-band SAR	3/100	24
Terra-SAR-2	Germany (2007)	X-band SAR	1/16	11
TenDEM-X	Germany (2010)	X-band SAR	1/3	11
HJ-1C	China (2006)	C-band SAR	5/20	4
KOMPSAT-5	South Korea (2013)	C-band SAR	1/20	28
NISAR*	India (2021)	L-band SAR, S-band SAR	3-10	12

LIDAR Satellites

Satellite	Country (Year)	Sensors	Spatial Resolution (m)	Revisit Time (days)
ICESat-2 (Lidar)	US (2003)	2 HSI	70	-
ICESat-1 (Lidar)	US (2018)	1 HIS	10	-

3.3 LiDAR

LiDAR [Light Detection and Ranging] is active remote imaging system and uses a very narrow band of electromagnetic spectrums. Satellite laser systems are primarily used to measure height of the target and land surface, ice sheet elevations, sea ice thickness, measurement of cloud and aerosol content

of the atmosphere or high biomass vegetation assessment . GLAS-LiDAR sensor was on the ICES Satellite (January, 2003) and its data is available for all, freely . CALIPSO is another space-borne LiDAR of ESA’s Aeolus Mission with the Atmospheric Doppler LiDAR (ALADIN) aboard in April 2006.

Table 6. Hyperspectral Remote Sensing Satellites

Satellite	Country (Year)	Spectral Bands	Spatial Resolution (m)	Revisit Time (days)	Data Access
HySI on IMS-1	India (2018)	64	550	-	Constrained access
GISAT / GeoHR*	India (2020-21)	60 VNIR, 150 SWIR, 6 LWIR	320, 192, 1500	-	Constrained access
Hyperion (EO-1)	US (2000)	220	30	16-30	Open access
HJ-1A/B	China (2008)	128	100	4	Constrained access
HyspIRI*	US (2020)	214	60	5-16	-
EnMAP-1	Germany (2017)	244	30	4	-
EnMAP-1*	Germany (2020)	244	30	4	-
PRISMA*	Italy (2019)	249	30	7-14	For Italy only
ALOS-3*	Japan (2019)	57 (SWIR), 128 (SWIR)	30	35	-
HISUI*	Japan (2019)	185	30	2-60	-
PROBA-1/2/V	Belgium (2001, 2009 & 2013)	15 (VIS), 4 (NIR)	100-300	1-2	-
HypXIM	France (2011)	210	8	3-5	-
TianGong-1	China	10 (VNIR), 20 (SWIR)	-	-	-
SHALOM	Italy-Israel (2017)	275	10	4	-

3.4) Hyperspectral Remote Sensing

Hyperspectral remote sensing involves capturing very narrow, contiguous spectral bands across the visible, near-infrared, mid-infrared, and thermal infrared portions of the electromagnetic spectrum.

This technique is based on beam splitting and line sensors, allowing it to collect reflectance data from each pixel in over 50 narrow bands. Such detailed spectral information makes hyperspectral sensing extremely useful for in-depth analysis of land surface

features. However, the data acquired requires extensive preprocessing, including corrections for atmospheric, radiometric, and spatial distortions, normalization, and quantitative analysis to ensure accurate interpretation.

Hyperspectral remote sensing has broad applications in agriculture, vegetation analysis, soil studies, geology, water resources, and environmental monitoring.

It enables detailed studies of biophysical and biochemical properties of crops and vegetation using specialized vegetation indices. It is also valuable for analyzing soil types, mineral compositions, and saline-affected regions, as demonstrated by the use of Hyperion data for sustainable land management.

Despite its potential, hyperspectral sensing faces challenges such as coarse spatial resolution (typically around 30 meters), high data volume, storage costs, and the need for skilled human resources for data handling. However, newer and upcoming satellites like SHALOM and HypXIM offer higher spatial resolutions (10–8 meters) and advanced panchromatic sensors, which significantly enhance data usability for complex environmental assessments. These improvements are expected to broaden the scope and applicability of hyperspectral remote sensing in the coming years.

3.5 Sensing from UAV Platforms:

Recent advancements in mini unmanned aerial vehicles (UAVs) have made them a promising tool for acquiring high-resolution remote sensing data for various land applications. Miniaturized electronics have enabled the development of lightweight sensors for UAVs, typically collecting data as images or videos. Payload capacities range from ~300g for 1 kg micro-UAVs to ~5 kg for 25–30 kg UAVs. UAV-mounted sensors cover visible, multispectral, thermal infrared, and microwave regions. Thermal cameras (8–12 μm) are especially useful for detecting land surface temperature variations. Hyperspectral sensors for UAVs are being developed for visible and near-infrared (0.3–1.0 μm) bands and are compact enough for small UAVs. Notable innovations include the lightweight micro-SAR sensor developed by Brigham Young University and the University of Colorado, and LiDAR systems such as the Velodyne VLP-16 and Riegl VUX-1. Hyperspectral sensors like the Rikola camera are also now UAV-compatible. UAVs are increasingly used for crop monitoring, disease assessment, mineral mapping, and disaster management due to their low cost, high

spatial-temporal resolution, and operational flexibility. However, challenges include limited flight capability, strict airspace regulations, and a lack of fast data processing methods and predictive models. While ideal for small-scale studies, UAV applications remain underexplored in diverse biophysical environments.

4. GIS

A Geographic Information System (GIS) is a computer-based tool designed to capture, store, manage, analyze, and display data that is linked to specific geographic locations on Earth. It combines spatial information (like maps) with descriptive data (such as population figures or land use types), allowing users to visualize patterns, relationships, and trends across space and time. GIS plays a crucial role in various fields by helping answer location-based questions such as "Where is this feature located?" or "What changes have occurred in this area over time?"

GIS systems consist of several components including hardware (computers, GPS units), software (like ArcGIS or QGIS), data (maps, satellite images, statistics), people (such as analysts and planners), and methodologies for processing and interpreting the data. These systems are widely used in urban planning for zoning and infrastructure development, in agriculture for crop monitoring and soil mapping, in disaster management for flood modeling and emergency response planning, and in environmental studies for tracking deforestation or pollution.

Additionally, GIS is employed in transportation for route optimization and traffic analysis, in public health for mapping disease outbreaks and healthcare accessibility, and in utilities for managing networks like water, electricity, and telecom services. Military and defense applications include terrain analysis and surveillance. A simple example of GIS in action is a digital map that not only shows physical features like roads and rivers but also overlays data such as flood risk zones, population density, and the proximity of hospitals—providing essential insights for decision-making and planning.

4.1) How GIS is Used

1. Data Collection and Integration:

GIS gathers data from various sources like satellite imagery, GPS, surveys, and sensors. This data can be maps, coordinates, or even photos and reports — all tied to specific locations.

2. Mapping

At its core, GIS creates layered maps that visually represent different data types — like land use, elevation, population density, or infrastructure. These maps help in better understanding patterns and relationships in a geographic context.

3. Spatial Analysis

GIS performs advanced analyses, such as:

- I. Buffering (e.g., find areas within 1km of a river).
- II. Overlay analysis (e.g., flood zones over urban maps)
- III. Hotspot analysis (e.g., disease outbreak zones)
- IV. Route optimization (e.g., shortest delivery routes).

4. Decision Support

By providing visual insights and data-driven analysis, GIS supports decision-making in urban planning, emergency response, agriculture, and many more fields. It answers the "where" and "why" questions.

5. Monitoring and Real-Time Applications

GIS is used with real-time data for applications like:

- a) Monitoring traffic flow
 - b) Tracking weather events or natural disasters
 - c) Managing utility networks (like water pipelines or power lines)
6. Integration with Other Systems

GIS often works with other systems like remote sensing, CAD, and database management systems to give a more comprehensive view of a situation.

5. APPLICATION OF GIS

Towards Sustainable Agriculture:

Agriculture uses the most land, water, and biological resources globally and provides a livelihood for over 70% of the country's population. However, modern agriculture faces two major challenges: increasing food production and minimizing environmental damage caused by intensive input use. Satellite-based Earth observation data plays a crucial role in achieving sustainable agriculture by helping to:

- i. Expand agriculture to suitable wastelands.
- ii. Boost crop intensity through improved practices like post-harvest cultivation.
- iii. Enhance productivity with better soil management and the use of high-yielding varieties.
- iv. Preserve biodiversity. support infrastructure planning, especially irrigation.

India developed the CAPE programme to estimate crop area and forecast production. It started from field-level studies and expanded to district and national levels using satellite data. CAPE used a 5x5

km grid with 10% sampling and focused on six major crops in 15 states. Key improvements included:

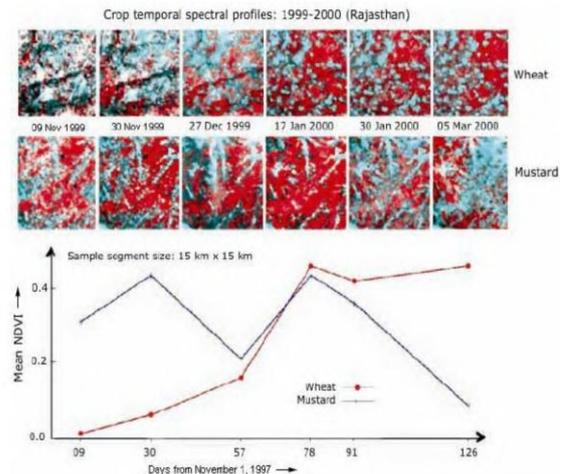


Figure 4. Multi temporal observations over agricultural region showing different growing pattern of wheat and mustard crops in India.

I. Sensor Use & Data Collection: Field studies helped identify the best IRS satellite bands. LISS-I and LISS-II sensors were first used for crop inventory.

II. Challenges in Phase-I: 22-day data gaps limited its use in areas with uniform crops. Adding the SWIR band improved crop identification, especially for wheat, gram, mustard, groundnut, and rice.

III. Sensor Upgrades: Better sensors like LISS-(23.5 m resolution) and WiFS (5-day revisit time) improved crop monitoring. These upgrades enabled national wheat production forecasting.

IV. Spatial Resolution Optimization: Studies found that under 70 m resolution was needed to identify 3 ha fields. Classification accuracy improved by 11% going from 188 m to 72 m resolution.

V. Advanced Sensors: AWiFS (56 m resolution, 5-day revisit, 10-bit radiometric resolution) was introduced for nationwide crop monitoring. ResourceSat-1 continued LISS-III use and added LISS-IV (5.8 m resolution) for better within-field variation tracking.

Water Security and Remote Sensing Applications :

Water security encompasses a broad range of data and management needs, from simple surface water inventories to complex processes like irrigation analysis, groundwater exploration, snowmelt run-off forecasting, and flood prediction. Remote sensing plays a pivotal role in addressing these issues, especially for providing safe drinking water across rural villages. Groundwater distribution varies across space and time due to differing rock formations, structural attributes, and surface features. Remote

sensing, when combined with accurate ground-truth data, aids in mapping geological and geomorphological conditions critical for understanding aquifer potential.

One significant application of remote sensing is in fishery management. Figure 9 illustrates the estimation of Chlorophyll-a using Ocean Colour Monitor (OCM) data and Sea Surface Temperature (SST) using AVHRR data. These datasets help in locating fishery zones by indicating biological productivity and thermal conditions of the sea surface, which are essential for sustainable fisheries management.

The Rajiv Gandhi National Drinking Water Mission (RGNDWM) has extensively utilized remote sensing for groundwater prospect mapping. Table 5.1 shows the success rate of wells drilled based on these maps across various Indian states. The success rates are remarkably high—reaching up to 100% in Gujarat—with other states like Andhra Pradesh, Chhattisgarh, and Kerala showing a 90% success rate or higher. This highlights the reliability of remote sensing and GIS in identifying suitable drilling locations for potable water.

Groundwater prospect maps are created using satellite data integrated with field data. These maps are vital in identifying high-yield zones, aquifer recharge locations, and appropriate sites for water harvesting structures. The information derived has proven effective, especially in water-scarce rural areas. Detailed hydro-geomorphic maps at national and regional levels (1:250,000 to 1:50,000 scales) have been produced to guide groundwater exploration.

Remote sensing also assists in identifying recharge areas with favorable lithological and

geomorphological traits, such as fractured rocks, floodplains, or regions with null slope. These areas often indicate better recharge potential. Moreover, satellite data is used to monitor surface water bodies, estimate water volumes, and schedule irrigation by tracking reservoir spread through seasons. Forecasts for snowmelt run-off—especially in the Himalayas—are developed using data from IRS-AWiFS and NOAA-AVHRR sensors, aiding in reservoir management and irrigation planning.

Monitoring glacier retreat in the Himalayas is another key area where remote sensing proves essential. It provides insights into glacial extent changes due to climate change, which impact river systems and power generation strategies. Satellite imagery helps in differentiating snow, ice, and rock based on their spectral properties, allowing scientists to estimate glacial depth either through radio-echo sounding or remote classification methods. Studies have shown significant deglaciation in regions like the Chenab, Parbati, and Baspa basins, with a 21% reduction in glacier area from 1962 to the present.

Hydrological modeling also benefits greatly from remote sensing. Models of sediment erosion, inter-basin water transfer, sub-surface groundwater flow, paleo-channel mapping in deserts, water budgeting, and climate change impacts on glaciers are increasingly relying on satellite-derived data for simulation and decision-making.

Success Rate of Remote Sensing-Based Groundwater Prospect Mapping

State	No. of Wells Drilled as per Groundwater Prospect Maps	Success Rate (%)
Andhra Pradesh	29,873	90.0
Chhattisgarh	19,503	90.0
Gujarat	34	100.0
Karnataka	5,213	93.0
Madhya Pradesh	7,730	92.0
Kerala	10,430	90.0

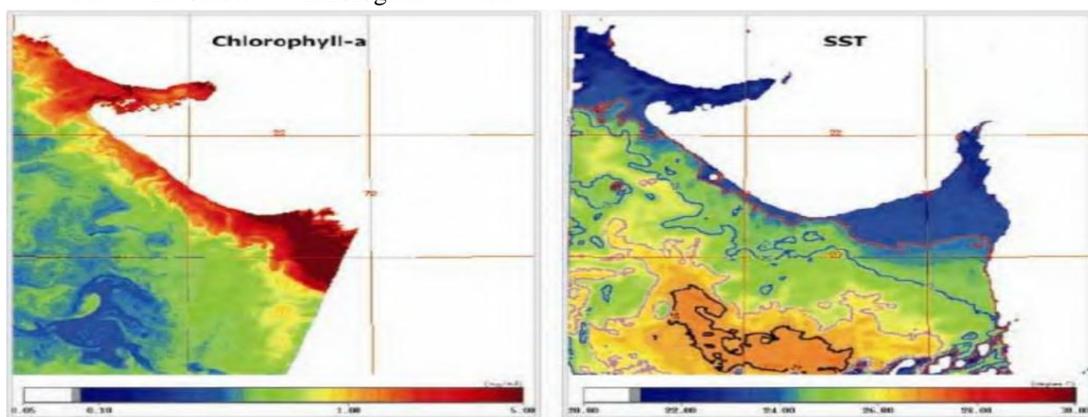


Figure 9. Estimation of Chlorophyll-a using OCM data and Sea Surface Temperature (SST) using AVHRR data for fishery management.

Environmental assessment and monitoring focus on understanding ecosystems to manage the impact of development and preserve ecosystem services. One major initiative was the national-level remote sensing-based forest cover mapping started in 1983 by the Forest Survey of India, which now conducts biennial surveys. The use of high-resolution satellites like IRS-P6 has improved forest type and density mapping.

Remote sensing and GIS also support biodiversity assessment, hydrology, climate modeling, and environmental impact studies. A collaborative effort has mapped biodiversity-rich and disturbed areas for conservation, especially in regions like the North East, Western Ghats, and coastal zones.

Mangrove forests are critical coastal habitats. Satellite data from 1986 to 1990–93 show changes in mangrove areas across states. For example, Gujarat saw an increase (767.0 km² to 1012.0 km²), while West Bengal and Andaman & Nicobar Islands saw decreases. These changes underline the importance of continuous monitoring using remote sensing tools.

Special Focus Areas:

- a. North East Region
- b. Western Ghats
- c. Andaman and Nicobar Islands
- d. Central India
- e. Eastern Ghats and East Coast

Region	Area (1986) (km ²)	Area (1990–93) (km ²)
Andaman & Nicobar	922.0	762.0
West Bengal	2067.0	1838.0
Orissa	203.0	187.0
Andhra Pradesh	322.0	380.0
Tamil Nadu	30.0	23.0
Karnataka	11.3	8.7
Goa	5.5	6.7
Maharashtra	124.0	222.0
Gujarat	767.0	1012.0
Total	4451.8	4439.4

CONCLUSION

India’s growing population and expanding development needs have made the sustainable management of land resources more critical than ever. To address challenges like food security, industrial growth, and employment generation, a strategic and data-driven approach is essential.

Remote sensing and GIS technologies play a vital role by offering accurate, timely, and spatially rich information for planning and decision-making. These tools support various sectors—agriculture, urban development, forestry, and environmental

protection—by enabling effective analysis and management of natural resources.

To further strengthen this effort, national initiatives like the Natural Resources Database (NRDB) and the National Spatial Data Infrastructure (NSDI) have been established. NRDB compiles standardized spatial data layers, while NSDI, led by the Department of Science and Technology, facilitates organized access to spatial data across 16 key agencies. Together, they provide a comprehensive framework for e-governance, empowering planners and policymakers from local to national levels.

The integration of geospatial technologies with institutional data infrastructures marks a significant step toward achieving sustainable, informed, and efficient land resource management in India.

FUTURE WORK

The integration of Remote Sensing and GIS with national platforms like the NRDB and NSDI has laid a strong foundation for informed decision-making and sustainable resource management. Future work can focus on enhancing spatial and temporal data resolution to enable more localized planning and near real-time monitoring. Incorporating advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML) could significantly improve the accuracy of land use classification, change detection, and predictive analysis.

Promoting interoperability among diverse spatial datasets and adopting open-data standards will be vital for expanding collaboration across institutions. Enhancing user-friendly platforms and mobile applications can also help bring these technologies closer to field-level users and local governance bodies.

Moreover, integrating community participation and field-validation methods will enrich data quality and ensure that the resource management strategies are both inclusive and grounded in reality. These future directions aim to strengthen the impact of geospatial technologies in addressing India’s evolving developmental and environmental challenges.

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