Monitoring of Natural Resources Using Remote Sensing and GIS Technology Under Changing Climate Scenario

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Abstract One of the major threats in the twenty-first century is the Earth's climate change, which bestows conspicuous effects on natural resources and human health. Remote sensing and Geographical Information System (GIS) create a profuse opportunity to monitor and manage the natural resources at multi-spectral, multi-spatial and multi-temporal resolution. Agricultural production systems are highly unfortified to alteration in environmental factors at different ecological regions in India. Under the changing climatic conditions, quick spatiotemporal assessment of extreme weather events and crop growth only possible with geospatial technology i.e. Remote sensing and GIS along with digital maps and simulation models. Water scarcity is one of the major problem that has been experienced at global and national level. Therefore, state of the art technologies like geospatial technologies and modelling will be necessary for judicious management of water resources under changing climate scenarios. Based on the area statistics, the total area under degraded and wastelands in the country stands at 114.01 m ha. Therefore, timely monitoring and maintaining of the land resources in larger scale would be possible with remote sensing satellite with high temporal resolution. Forests occupy about 19.4% of the total geographical area of the country against the ideal requirement of 33% therefore remote sensing and GIS technology provide a crucial part in monitoring and protecting the Forest resources under changing climate scenario. Therefore, the integrated use of remotely sensed data, GPS, and GIS will enable consultants, natural resource managers, researchers in government agencies, conservation organizations, and industry to develop management and protection plans for different natural resources to cope with the changing climate condition.

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1 Introduction

Global warming, caused by the greenhouse effect, has threatened natural resource sustainability in many parts of the world. In the recent past, significant increases in extreme weather events have been observed. Amphan cyclone of 2020, Tautae cyclone of 2021 and variable rainfall that have led to long dry spells in some places, and cloudbursts and flooding in other places are the recent examples which have long-term socio-economic consequences in India. Information on the nature, extent, availability, spatial distribution along with the condition of natural resources is a prerequisite to achieving sustainable resource development goals [25]. Spaceborne multispectral measurements possess the ability to provide a synoptic view of a relatively large area at regular intervals, hence, it holds great promise in generating reliable information on various natural resources, such as minerals, soils, surface and ground water, marine resources, forest cover in a timely and cost-effective manner. Geospatial technologies are very efficient in acquiring and managing massive spatio-temporal data sets by making use of various satellite information, maps and simulation models etc. This technology is extremely advantageous because of rapid and continuous availability of data, quick analysis and generation of valuable information for planners and decision-makers. Resources are biotic and abiotic based on their origin. Under changing climate scenario, there is more concern regarding the biotic resources.

2 Status of Natural Resources of India

Some of the very significant natural resources available in the country include: land resources, water resources, food resources, forest resources etc.

2.1 Land Resources

The rapid pace of economic development along with population growth, urbanisation and industrialisation exert tremendous pressure on the limited natural resource base of a country. Land, being one of the most basic natural resource, is under the constant threat of degradation [4]. In terms of area, the global ranking of India is seventh (329 million hectare), accounting for 2.42% of the total global area. Statistics on land use are available for approximately 92.9% of the total geographical area. The forest covers 21.02% of the country's total land area. Around 170.0 million hectares of the total land area of 304.2 million hectares is under cultivation. Fallow land accounts for nearly 5% of the total land. It includes arid, rocky or sandy deserts. First amongst various problems include, land fragmentation, according to the Agricultural Census, the area operated by large holdings (ten hectares or more) has decreased while the area operated by marginal holdings (less than one hectare) has increased [1]. Secondly, land degradation includes soil fertility loss, erosion, water shed and catchment area deterioration, and deforestation. Efforts are being made for vertical growth of cities and towns rather than horizontal and the researchers and the policy makers are also realizing the benefits of integrated land use planning.

2.2 Water Resources

Water is a vital natural resource affecting every sphere of life. It is involved in multiple purposes like drinking, power generation, agriculture, as a solvent in chemical industries, waste disposal, transportation etc. The total water statistics over the globe accounts to $140 * 10^{16}$ m^3. Rain water, surface and ground water and sea water constitute the chief sources of water. The oceans contain approximately 97% of the world's water supply, which is unfit for human consumption or other uses due to high salt content. Of the remaining 3%, 2.3% is trapped in the polar ice caps and thus inaccessible. The remaining 0.7% is available as fresh water. A very limited stock of usable water, which is 0.03% of the mass balance, is currently available. Further ground water constitutes 0.66% with recharge from infiltration, evapotranspiration and seepage. The annual rainfall received by the country accounts to $400 * 10^{10}$ m^2. The water resources are under constant threat due to continuous release of hazardous industrial and municipal waste water. It contains heavy metals, radionuclides and other harmful substances that not only deteriorate water bodies but also pose threat to aquatic life. With an estimated 251 km^3/year usage, India is the world's greatest groundwater user [34]. In India, GW accounts for 85% of rural water supply and 84% of net irrigated land [3] and 90% of fresh water usage is accounted by agriculture itself [9]. Water levels have depleted by nearly 8 m on an average since the 1980s [29] and the estimates of Ministry of Water Resources, predict the increase in irrigation demand by 56% by 2050 [22].

2.3 Food Resources

Wheat, rice, maize, barley, pulses, cereals, potato, sugarcane, sorghum, millet, oats, cassava, fruits, vegetables, milk, and sea food are the major food resources. Wheat and rice are staple foods for approximately 4 billion people in developing countries. Fish and seafood provide approximately 70 million metric tonnes of high-quality protein to the global diet. However, we have already exceeded sustainable fish harvests in most of the world's oceans. Food production is being affected by the catastrophic climate change. According to world estimates, on an average 71% yield losses in agricultural crops are caused by abiotic factors [15]. These comprise high temperature (40%), salinity (20%), drought (17%), low temperature (15%) and other forms of stresses [2]. To meet this demand, the global food production needs to increase by over 40% by 2030 and 70% by 2050 [13]. Future predictions suggest that there will be an increased demand for wheat by about 60% in 2050 to feed an estimated 9.7 billion populations in the world [35].

2.4 Forest Resources

India ranks tenth in the world in forested area, but only 120th in the percentage of land area covered by forest. The Forest Survey of India [10] estimates a total of 807,276 km^2 of forest and tree cover, accounting for 24.56% of the land area. It has commercial uses, ecological uses, regulates climate, reduces global warming, conserves soil, regulates hydrological cycle and, food products etc. Exploitation of forest is occurring at a very fast rate. Commercial demand for pines, teak, sal and conifers, use of timber, wooden crates for manufacturing railway sleepers and furniture, pulp for paper industries, plywood for packing in tea industries, fir tree for packing apples, all these activities have exploited forest resources to a great extent. Various projects (hydroelectric projects, railways, highways, power stations, roads, and dams) have resulted in vast deforestation, ultimately affecting the equilibrium of various flora and fauna. The Sunderbans tidal mangrove forests have been depleted, and the Southern Peninsula has become an acacia scrub semi-desert. Due to over-exploitation, the tropical deciduous forests of Mirzapur's Vindhyan range have been replaced by a savannah ecobiome and near barren wasteland. The country's per capita forest area is 0.08 ha, compared to the global average of 0.64 ha. Over the last two decades, India's forest cover has shown a depletion of 235 km^2 per year [19].

3 Relevance of Geo-spatial Technologies

The introduction of modern geospatial technologies such as Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) has proved very efficient in surveying, identifying, classifying, mapping, monitoring, characterization, and tracking changes in the composition, extent, and distribution of various types of earth resources, both renewable and non-renewable, living and non-living in nature. The first step towards accomplishing the sustainable resource development plan is assessing natural resource availability and condition. Four basic steps involved in assessing the natural resources are [14].

Mapping: by acquiring of thematic and quantitative baseline data (current or historical) in geographic format.

Measuring: by quantifying and documenting the properties of phenomena.

Modelling: by characterising a system under investigation through exact quantitative input–output relationships, and simulating its current, past, or future behaviour.

Monitoring: regular monitoring of the conditions through the recording of shifts or changes in natural events and human activities.

4 Geo-informatics as an Emerging Science

Geo-informatics refers to the use of information technology to manage and analyze earth resources. Geospatial technologies viz. Remote sensing technology, Geographic Information System (GIS), Global Positioning System, and simulation models are being efficiently used for their application in various disciplines of natural resource management. The combination of these technologies allows for the acquisition of high-resolution real-time data via remote sensing, data management and analysis via GIS, and geo-referencing of ground truth data via GPS, as well as the integration of all data into an information system and the use of the information for a specific purpose. The essential feature that distinguishes geo-informatics from other disciplines of information technology is that all input data is geo-coded, that is, it has a 3-D address and is linked to a specific location on the earth's surface. However, the amalgamation of such technologies in combination with various other analytical approaches is always desirable as it would produce better information which would enhance our understanding of natural resource management.

5 Remote Sensing Technology

Remote sensing is the process of identifying the physical characteristics of an area by measuring its reflected or emitted radiation without coming in contact with that area. Different objects reflect or emit different amount of energy in different wavelength bands of electro-magnetic spectrum based on their structural, chemical and physical properties and then the sensors measure the amount of energy reflected from that object. The process of remote sensing involves following steps (Fig. 1):

Source of illumination.
Radiation and the atmosphere.
Interaction with the target.
Energy recorded and converted by the sensor.
Reception and processing.
Interpretation and analysis.
Application.

Remote sensing delivers multi-spectral, multi-sensor, and multi-temporal data, allowing for the development of accurate, timely, and cost-effective natural resource

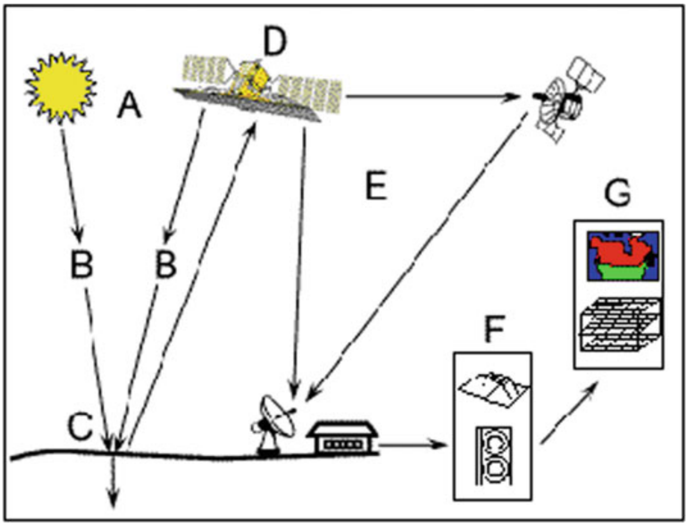

Fig. 1 The process involved in remote sensing

information. Based on source of energy remote sensing is classified in active remote sensing and passive remote sensing.

5.1 Active Remote Sensing

Active remote sensing involves active sensors and these sensors possess their own source of illumination. They illuminate the target with their own energy and then measure the reflected radiation from the target. Examples include LIDAR, RADAR.

5.2 Passive Remote Sensing

Passive remote sensing involves passive sensors and these sensors don't possess their own source of illumination. Here an external source of illumination (solar energy) is present which illuminates the target and after that the passive sensor measures the reflected radiation from the target.

Remote sensing sensors are further classified into optical, thermal, and microwave remote sensing based on the wavelength range the sensors are sensitive to.

5.3 Optical Remote Sensing

Optical remote sensing detects solar energy **reflected** from targets on the ground using visible, near-infrared, and short-wave infrared sensors (0.3–3 μ) to create images of the earth's surface.

5.4 Thermal Remote Sensing

Sensing radiation **emitted** by solids, liquids, and gases in the thermal infrared part of the spectrum (3–100 μ), where thermal emission dominates reflected sun energy, is used for thermal remote sensing.

5.5 Microwave Remote Sensing

The remote sensing using **microwave** spectrum (1 mm–1 m) is called microwave remote sensing. Optical remote sensing data available from IRS, Landsat, etc. faces limitations of data availability during intense cloud cover seasons. Microwave remote sensing through satellites like RADARSAT, SENTINEL-1, etc. have added advantage; has all weather capability, day and night observing capability and soil depth penetration capability to certain extent.

5.6 Aerial Photography

The original form of remote sensing is aerial photography and it remains the most widely used method. Aerial photographs are images captured by a camera mounted on an aeroplane flying over the terrain at a predetermined height, depending on the scale of aerial photography and the camera's focal length. The overlap between successive images is typically 50–65%, which is required for stereoscopic viewing and analysis of stereo-pairs (Fig. 2). With the help of stereoscope one can see the 3-D view of the aerial photograph. Aerial remote sensing is being widely used for natural resource management by various research institutes e.g. Survey of India.

5.7 Satellite Remote Sensing

The advent of satellite remote sensing can be marked form the launch of TIROS-1 i.e. Television and Infrared Observation Satellite which was operated by NOAA

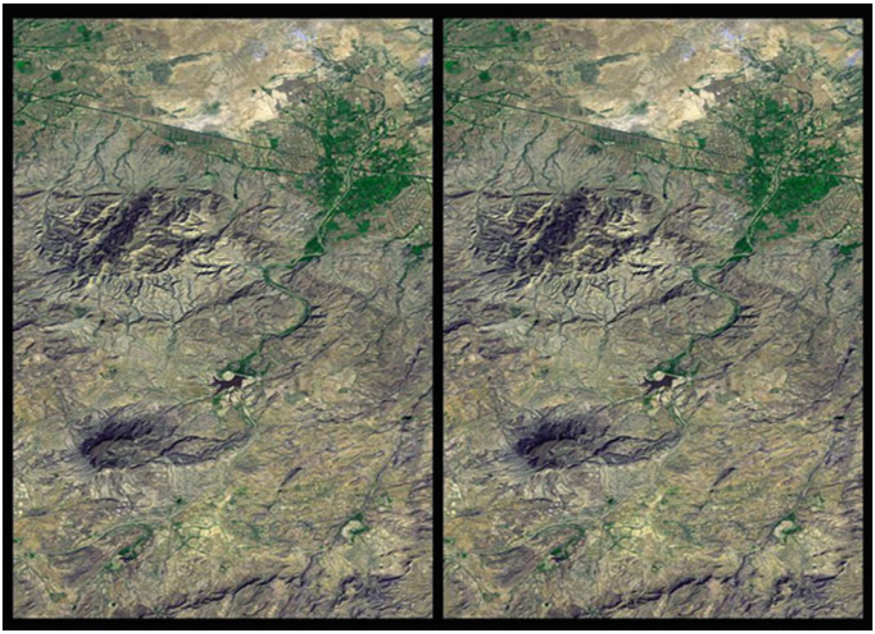

Fig. 2 STRM stereo pair of Northwest region of Bhuj (Image courtesy NASA/JPL/NIMA)

(National Oceanic and Atmospheric Administration) in 1960 which was carrying a single band TV camera. Since then the launching of numerous satellites (Landsat, SPOT, IRS) have increased the usefulness of satellite imagery for inventory and monitoring of Indian natural resources.

5.8 Geographic Information System (GIS)

A computer based information system that enables data acquisition, modeling, manipulation, analysis, presentation, and dissemination of spatially referenced data. Spatially referenced data can be in two forms; Spatial (x, y, or latitude, longitude of tube wells) as well as non-spatial (owner, status, wee id, meteorological parameters, socio-economic data). GIS can organize spatial data as type (point, line or polygon), feature (one particular point, line, area) and theme (collection of similar features of same type). Different components of GIS are hardware, software, data, people and procedure. Further its functionality involves: ***Data encoding, Data retrieval, Data Analysis, Data Storage, Data Display***. The GIS have been utilized to integrate spatial data on various resource themes and to construct an alternate development plan that includes site-specific primary production activities. Through the rule-based decision capabilities of the GIS package, the suitability of various combinations of land factors such as soil, groundwater quality, slope, landform, land use/land cover, and so on, can be linked to primary production activities.

5.9 Global Positioning System (GPS)

The Global Positioning System is a satellite-based navigation system made up of a network of 24 satellites placed into orbit at an altitude of 12,200 km by the U.S. Department of Defense which continuously transmit information to the receiver present at earth surface. Those satellites are positioned in such a way that at least four to five minimum satellites are visible and they all move in six orbits. The working of GPS is based on "distance". Each GPS satellite is equipped with an atomic clock and broadcasts data indicating its position and time. The operations of all GPS satellites are synchronised such that these repeating signals are broadcast at the same time. The GPS satellites' distance can be calculated by calculating the time it takes for their signals to reach the receiver. When the receiver calculates the distance between at least four GPS satellites, it can determine its three-dimensional position. It works on the principal of triangulation. Its various components include space segment (constellation of satellites), control segment (ground station) and user segment (users, GPS receivers). GPS is an all-weather, real time, continuously available, economic and very precise positioning technique that labels it perfectly suitable for monitoring natural resources.

5.9.1 National (Natural) Resources Information System (NRIS)

The Department of Space launched this programme to support National Natural Resources Management System (NNRMS) in decision making. Its goal is to provide decision-makers with information on natural resources such as land, water, forests, minerals, and soils and socioeconomic data such as demographics, amenities, and infrastructure. NRIS is being implemented nationally by Department of Space in collaboration with several institutions like ISRO, State Remote Sensing Centres and some private entrepreneurs are collaborating for that purpose.

5.9.2 Needs of RS and GIS for Natural Resource Management

Any nation's socio-economic, and cultural sustainability is largely determined by its land and water resources [11]. These natural resources are crucial to a nation's economy because they provide critical jobs, serve as a source of raw materials for numerous businesses, provide food and money, and provide medicine and energy. The aesthetic splendour of natural resources has always been viewed as a cultural expression of a nation.

However, understanding how to utilise these resources in a sustainable manner is critical for nations to ensure that their advantages are enjoyed by current and future generations. This is because if these resources are not used effectively and efficiently, they will be depleted. Because of the world's ever-increasing population, the world's resources are currently being overstretched [31]. As a consequence of this population explosion, forest cover has declined globally due to human encroachment. This has resulted in an increase in human-wildlife conflict and the development of desert-like conditions. Finally, the depletion of natural resources has resulted in an increase in the cost of living, changes in weather patterns, and a decrease in the economic, social, and cultural benefits accrued as a result of their utilisation.

Due to these restraints, it is critical to ensure that all these resources are managed appropriately. To attain this goal, a variety of management strategies in the field of natural resource management have been developed. Some have proven successful, while others have failed to produce the expected results. However, with the current trend in information technology advancement, natural resource management teams are emphasizing the use of remote sensing and GIS technologies in natural resource management. Remote sensing technology has become increasingly popular over the years for use in a variety of natural resource management disciplines. Remote sensing has become the ideal data source for large-scale applications and studies due to the availability of remotely sensed data from multiple sensors on various platforms with a wide variety of spatial, temporal, radiometric, and multispectral resolutions. Remote sensing data is currently used as input data for a variety of environmental process modelling applications [20]. The combined use of GIS, remotely sensed data, and GPS will empower researchers, planner, and natural resource managers of conservation organizations, government agencies, and industry to develop eco-friendly and novel management plans for the variety of natural resources management and its' applications [17, 23]. It has the potential to monitor changes in land cover, forest density, coastal morphology, reef status, and biodiversity on islands, even if they are located in remote locations.

6 Monitoring of Natural Resource Management by RS and GIS

6.1 Monitoring of Agriculture

The proliferative potential of using remote sensing platforms to gather real-time assessments of the agricultural landscape has received more attention. Precision agriculture is a farming method that encourages different management approaches within a field depending on the conditions. This method is based on new tools and information sources made available by modern technology. Seelan et al. [28] listed the remote sensing, geographic information systems (GIS), global positioning system (GPS), yield monitoring devices, soil, plant, and insect sensors, and variable rate technologies for input applicators as examples. Satellite remote sensing has been widely used and regarded as a potent and effective method for identifying land use and land cover change when combined with geographic information systems (GIS). It offers reasonable multi-spectral and multi-temporal data and transforms it into meaningful information for analysing and monitoring agricultural growth pattern. Change detection and database creation require a flexible environment for storing, analysing, and displaying digital data, which GIS technology delivers. Satellite imaging has been used to track distinct land cover categories using spectral classification and to estimate land surface biophysical parameters using linear connections with spectral reflectance or indices.

6.2 Monitoring of Soil

Standard soil examination and interpretation methods are time-consuming and costly, hence kriging and its variants have become generally acknowledged as an important spatial interpolation tool in land resource surveys [12]. Predictive soil mapping techniques have been developed in this frame of reference as geographic information system (GIS) and remote sensing technology have advanced. In situ point assessments of soil quality can be used in a regression analysis with extensive and comprehensive satellite-derived indices, and the correlation can be upscaled to larger spatial areas.

6.3 Monitoring of Crop-Irrigation Demand and Crop Modelling

Agriculture is the world's largest water consumer, consuming more than 70% of all fresh water. As a result, irrigation water plays a crucial role in enhancing land production. Land surface evapotranspiration (ET) is among the key components of the water balance that causes water loss [21], and it is important for environmental applications such as irrigation water use optimization, irrigation system performance, crop water deficit, and so on. In many arid and semi-arid growing regions, inadequate irrigation timing and water application are universal problems hindering agriculture production. In light of these issues, remote sensing technology has evolved as a useful tool for monitoring irrigated areas across a wide range of climatic conditions and locales over the previous few decades. By monitoring plant water status, measuring evapotranspiration rates, and estimating crop coefficients, it aids in determining when and how much to irrigate. Irrigation water policymakers have been very interested in the effective use of surface water and the monitoring of consumptive use of water using remote sensing techniques.

It is possible to combine crop models and remote sensing in order to evaluate yield variables using remote sensed data for each time step in model simulations, allowing us to fill in the missing model parameters during field scale recalibration. Furthermore, obtaining data from crop models at the field scale enables for the transfer of results from the field to the regional scale [24]. Wiegand et al. [33] and Delécolle et al. [8], for example, have proposed a number of methods for combining remote sensing data with crop models. A method is to use remote sensing to estimate LAI (leaf area index) data to calibrate crop models. The other option is to estimate the eventual yield early in the growing season; however, this strategy requires a lot of remote sensing data to employ in crop models. Baret et al. [5] used assimilation methodologies to combine remote sensing data with crop models to provide stress assessment. Crop and soil models combined with GIS can be used to identify methane emissions from fields [16], and GIS and crop models can be used to estimate world food production and the effects of global warming. With remote sensing, there are numerous strategies to reduce crop model uncertainty. One option is to use remote sensing photographs to classify agricultural fields and crop types, and then select crop models to use with this classification based on soil input data. Crop growth indicators that can be linked with crop models can also be estimated via remote sensing.

6.4 Monitoring of Water Resource Management

Water is a resource that is necessary for human survival. The availability of fresh water for human consumption has decreased over time, while the demand from a growing population has increased. In this environment, there is a pressing need to monitor and better understand its use, as this will give data that will aid in the creation of effective water management plans and infrastructure. This is especially important in areas where the amount of available water is restricted. For sustainable water resource management, understanding the complex water system necessitates a holistic approach that integrates concepts and ideas from other disciplines. Field research provides the first steps toward fully understanding the water cycle's many activities. However, political decisions are taken at the regional to national level, thus it is critical to upscale field scale studies to the regional or national level in a reasonable manner. Hydrological models are commonly employed for this, although they frequently face data scarcity or a lack of high-quality input data. Remote sensing technologies would then be a viable tool to combine with models in order to obtain continuous input data in data-scarce areas. Several Earth Observation (EO) based sensors launched from sophisticated satellites give continuous global observations on diverse hydrological components, which are critical input data for hydrological modelling. Satellite capture has filled in data gaps caused by a lack of on-the-ground monitoring of water resources around the world. Satellite products and advanced computational techniques for water management can thus play a key role in water resources' current and future management. The satellite remote sensing for hydrological applications includes, but not limited to rainfall (Global Precipitation Measurements (GPM) and Tropical Rainfall Measuring Mission (TRMM); Soil moisture (Soil

Moisture Active Passive (SMAP) and Soil Moisture Ocean Salinity (SMOS); Actual Evapotranspiration (Surface Energy Balance System); Mapping Evapotranspiration with Internalized Calibration (METRIC) and Surface Energy Balance Algorithm for Land (SEBAL); Groundwater level monitoring by Gravity Recovery and Climate Experiment (GRACE) [18, 30]. Water bodies such as rivers, lakes, dams, and reservoirs can be mapped in 3D using satellite data and GIS. It is possible to generate spatial maps of water availability. The relevant authorities can use the information to identify the sites or regions that require effective protection and management, and decisions can be made regarding the sustainable management of natural resources in the identified regions.

6.5 Monitoring of Water Quality

Water quality must be monitored on a regular basis in order to manage and improve the quality for human consumption. Water quality is currently assessed using in-situ measurements and laboratory analysis of water samples. Although these measurements are accurate for a specific point in time and space, they do not provide the spatial or temporal perspective of water quality required for accurate assessment or management of water bodies [7]. Furthermore, they are time-consuming and expensive, and they cannot meet the needs of regional or national monitoring. Water quality parameters (such as suspended sediments (turbidity), chlorophyll, and temperature) can be monitored using remote sensing techniques. Optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information required to monitor changes in water quality parameters in order to develop management practises to improve water quality. Remote sensing was also used to estimate chlorophyll concentrations in temporal and spatial using empirical relationships with radiance or reflectance [27]. To predict the water quality for several years, empirical relationships (algorithms) between the concentration of suspended sediments and radiance or reflectance for a specific date and site were developed [26].

6.6 Monitoring of Forest Management and Wildlife Habitat

Forests are an essential part of our ecosystem; they have an impact on human lives in a variety of ways. However, despite their importance, the world forest has been diminishing at an alarming rate. Forest cover can be renewed through sustainable management because it is a renewable resource. A forest manager can generate information about forest cover, types of forest present within an area of interest, human encroachment extent into forest land/protected areas, encroachment of desert-like conditions, and so on, utilising remote sensing data and GIS tools. This information is essential for the formulation of forest management plans and in the decision-making process to guarantee that appropriate policies are in place to control and govern how forest resources are used. Remote sensing data can also be used to assess the appropriateness and state of sites/forest areas for a certain type of wildlife using multi criteria analysis.

6.7 *Monitoring of Natural Disaster*

Natural calamities such as flooding, earthquakes, volcanic eruptions, and landslides necessitate large amounts of multi-temporal spatial data. Satellite remote sensing is an effective tool in this context because it provides information over huge areas and at short time intervals that can be used in multiple phases of disaster management, such as prevention, readiness, relief, reconstruction, early warning, and monitoring. GIS techniques and remote sensing are necessary to handle large geographic data sets and have thus gained prominence in disaster management [32].

7 Conclusions

The availability and conservation of natural resources such as land and water determine a country's social, cultural, and economic stability and growth. These resources are important in measuring specific criteria because they play a significant role in creating employment, in the growth of a country, in the provision of food and other critical raw materials, as well as medicine and energy. It is critical for countries to recognise that the management and sustainable development of natural resources is critical for the survival of life on the planet. As the rate of integration of nature and technology increases, Information Technology (IT) is becoming a hotspot for monitoring of natural resources across the globe. IT is being utilised extensively to monitor, investigate, and understand our natural resources, particularly those that are finite. A lot of emphasis is being laid on various geospatial technologies, which the scientists, researchers and policymakers can retrieve, generate, store, analyze, disseminate useful information and can make sound decisions for natural resource management and sustainable development. These essential techniques serve as a foundation for making sound judgments about long-term growth. Combining these essential techniques and data simplifies mapping the spatial and temporal extent of natural resources, which aids in developing scientific and site-specific management plans to ensure the long-term viability of these precious resources.

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