



A Review on remote sensing application in river ecosystem evaluation

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Abstract

A river is a huge natural freshwater stream that plays a significant role in hydrological dynamics, water resource management, and global activities. Understanding the dynamics of the river ecosystem, such as water quality, morphological traits, and so on, is crucial to determining its health. This article provides a broad review on Geographic Information System (GIS) and Remote Sensing (RS) applications for achieving geographical advantages, particularly in the river ecology. In recent years, the accessibility, accuracy, and popularity of RS technology have all increased dramatically. Land use and cover mapping, land cover changes, deforestation vegetation dynamics, and water quality dynamics at many scales utilising efficient methods are all covered using remote sensing data. RS may now be utilised for a variety of engineering-related applications at the same time. The importance of Landsat data and multispectral sensors in mapping and monitoring many environmental parameters of river ecosystems is highlighted. According to a recent research study, these technologies will aid in the establishment of safety measures prior to disasters. Additionally, river cleaning can be done in conjunction with the creation of an appropriate drainage system to protect the river from becoming contaminated. Future research is expected to build on developing technology, enhance present methodologies, and include innovative analytical approaches.

Keywords Review · River ecology · Remote sensing · Landsat

1 Introduction

A hierarchical network of fluvial channels, which begin as small headwater streams and eventually grow to reach estuaries that contact the sea, drains the land through river ecosystems. Regarding ecosystem aspects like the processing of energy and materials, habitat, biodiversity, and resilience in the face of disturbance, several conceptual models offer unifying principles about the linkages of rivers with the landscape. Estimating hydrometeorological states (like land surface temperature, near-surface soil moisture, snow cover, water quality, surface roughness, and land use cover),

fluxes like evapotranspiration, and physiographic variables that can affect hydrologic processes are a major focus of remote sensing applications in hydrology [1, 2].

Field data may become entirely or partially obsolete as a result of periodic changes in water and land management. As a result, satellite remote sensing is becoming an unavoidable option because it can provide objective information in a variety of circumstances, such as agricultural and hydrological, from the field to the basin size. Water management abilities can be improved as a result of this, allowing for better investigation and design of an efficient irrigation system [3]. The essential data is gathered through analysing the interactions of electromagnetic radiation with the earth's surface, as well as stored data in the form of photographs. The GIS is used to assist in the interpretation of these photographs or image which retrieved from remote sensing techniques [4].

In ecological studies which include riparian zone of river ecosystem, the lack of trustworthy data and sound assessment methodologies can have devastating effects for biodiversity conservation and the discovery of indicator species that can forecast changes in a given ecosystem [5]. Both

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ground-based and remote sensing approaches could be used to collect data for these goals like field observations, in-situ data and measurements, and land surveying activities are examples of ground-based data acquisition methods, whereas remote sensing technology is based on the use of data in the form of images obtained by sensors of various types. [6]. Because vegetation generally exhibits considerable absorption in the red band range and increased reflectance in the near-infrared bandwidth, remote sensing of vegetation was derived from the very nature of vegetation's spectral features. The study of temporal and regional fluctuations in vegetation structure and density is assisted by the use of vegetation indices. These studies have several uses, including river morphology analysis, watershed/river basin management, irrigation planning and management, water conservation, flood monitoring, groundwater research, and water quality assessments [7, 8].

The approach of detecting and monitoring any area's physical features by analysing its emitted and reflected radiations at a distance without making any direct contact is known as remote sensing technology (usually from an aircraft or satellite). Researchers acquire remotely sensed photos with unique cameras that allow them to detect changes in the earth's environment. Advanced technologies are currently required in a variety of sectors, including ecosystem management, biodiversity inventories and assessments, environmental monitoring, and species-habitat appropriateness analyses. These technologies should be based on the ecosystem's physical parameters as well as the community's socioeconomic position [7, 9]. As a result, remote sensing is used to assess the ecosystem's overall health by tracking the dynamics of the earth's surface. One of the most effective ways to monitor riverine environments, including lakes, channels, reservoirs, floodplains, and wetlands, is to use RS and GIS. Because of this, the utilization of RS and GIS in the study of large rivers has recently increased significantly [9–11].

2 Method

During the paper writing process, we follow a few phases as a methodology: initially, we identify the subject and sub-themes, then we do an initial database search using key terms. There were almost 500 publications listed. Refined database search in SCI, Scopus, and Google Scholar indexed publications in the following stage. After then, abstracts are screened and a shortlist of around 150 articles is prepared, with the papers chosen based on predetermined criteria. Finally, sort the more than 50 papers into six groups, as follows:

2.1 Remote sensing: sensors and data

Aside from basic remote sensing systems, the earliest people used a variety of strategies to identify objects or regions of concern at a distance. Because they lacked reliable weapons, one of their defensive and protective techniques against violent animals was to detect danger from afar and prepare for a swift escape [10]. Otherwise, they stand atop a high cliff or tree to survey the surrounding environment and investigate the surroundings directly. This suggests that some sort of remote sensing has existed before the dawn of time. Scientific remote sensing operations were mostly based on the use of aerial photography prior to the deployment of satellites. The modern use of digital satellite technology has prompted the collection of a vast amount of airborne and space-borne data equally in time and space across large parts of the globe. The first earth observation with a balloon, which took place in the 1860s, is considered a watershed moment in the history of remote sensing. The most major milestone in satellite-based remote sensing occurred in 1972, when NASA launched Landsat-1, the first civilian remote sensing satellite. Data acquired by Landsat-1 gave developing countries new hope in monitoring and managing their natural resources [11].

The Airborne Remote Sensing developed during World Wars I and II, when remote sensing was primarily utilised for surveying, reconnaissance, mapping, and military surveillance. The primitive space-borne satellite remote sensing period began with the launch of rudimentary satellites such as Sputnik 1 from Russia and Explorer 1 from the United States towards the end of the 1950s as a "proof of concept." The first meteorological satellite, known as Television and Infrared Observational Satellite-1 (TIROS-1), was launched by the United States shortly after. During the Cold War, spy satellites like as Corona were regularly employed. Its objective was nearly entirely to acquire data for military purposes.

The Meteorological Satellite Sensor Remote Sensing time, geostationary Geostationary Operational Environmental Satellite (GOES) and polar orbiting National Oceanic and Atmospheric Administration (NOAA) and Advanced Very High-Resolution Radiometer (AVHRR) meteorological satellite sensors were introduced. This was a time when data was created in digital format and evaluated using proprietary software [12].

The Landsat in 1972 launched the Landsat-1 (then known as the Earth Resources Technology Satellite), which carried a multi-spectral scanner (MSS) sensor. Other path-finding Landsat satellites 2 and 3, which carried MSS, and Landsat 4 and Landsat 5, which contained Sensors 2007, 7 3211 Thematic Mapper (TM), were launched after it. The Enhanced Thematic Mapper (ETM+) sensor is carried by the

Landsat 7. Unfortunately, the launch of the Landsat 6 failed. The Operational Land Imager (OLI)-equipped Landsat-8 is scheduled to launch in 2011. The Indian Remote Sensing Satellite (IRS) and France's Systeme Pour l'Observation de la Terre (SPOT) are both excellent sun-synchronous Land satellites from the Landsat era. These satellites have a high resolution (2.5 to 80 m) and cover the entire world. This is by far the most important phase in the history of environmental remote sensing data application, both locally and globally [13]. Table 1 lists the details of a variety of satellite data, including their launch period and aquatic uses.

2.2 Hydrological mapping

One of the simplest and straightforward applications of remote sensing in water resources studies has been the identification and mapping of surface water borders. The difference in spectral reflectance of land and water is used in optical remote sensing of water resources. In different wavelengths, the reflectance curves of water, plant, and dry soil. In the NIR and MIR wavelengths, water absorbs the majority of the energy, whereas vegetation and soil have a higher reflectance. Water shows in a deeper tone in the IR bands in a multi-spectral image, making it easy to distinguish from land and plants. The use of remote sensing techniques to map surface water bodies has applications in flood monitoring, water resource monitoring, watershed management studies and other domains [46].

Water shows in a darker tone in the IR bands of a multi-spectral image, and may be easily distinguished from land and vegetation in different Landsat bands. The contrast between water and other features is not very strong in the VIS bands (bands 1, 2, and 3). Due to the weak reflectance of water in the IR area of the EMR spectrum, the IR bands (bands 4 and 5) show a dramatic difference between them, as seen in Fig. 1.

2.3 Remote sensing in Landuse/Landcover in riverine ecosystem

Satellite remote sensing may be used to assess the diversity, type, and extent of land cover throughout a research area, which is a prerequisite for many ecological applications. Land cover data specify the terrain features of the surface environment, which can range from barren rock to tropical forest (Fig. 2), and are frequently generated using statistical clustering methods using multispectral remote sensing data [47]. Despite the complexity of the link between land cover and land use, remote sensing can aid in the compilation of land use data that depicts human interactions with the physical environment.

Using GIS technologies, the use of image processing mapping for tracking changes in land cover or land use in the desert fringes between Assiut and Sohag between 1984 and 2013 was investigated (satellite) [48]. The authors came to the conclusion that as a result of recovery and other operations, the low desert zone west of the Assiut-Sohag governorates has seen severe alterations. Recalcination is achievable in certain regions in the future, while it is required in others for future planning.

In today's world, a range of approaches for detecting LULC changes are widely employed, including post-supervised categorization of remote sensing photos and the use of NDVI and GIS tools. The variations in LULC were studied using multi-temporal remote sensing in Egypt's Qena-Luxor Governorates. Agricultural land growth expanded from 1984 to 2018, according to the findings, with overall accuracy of supervised classification of Landsat satellite data ranging from 87 to 92.5% and kappa values ranging from 0.83 to 90. Change detection is now faster, cheaper, and more precise thanks to these new technologies. The accuracy evaluation technique was applied to all of the selected remote sensed images [24].

Multiple dates of Landsat TM digital data, as well as SOI topographical maps, were used to investigate the shift in land use. To calculate the change, a GIS was employed. Agriculture/forest land has decreased by 55% while built-up land has increased by 300% in the previous seventy years. During the monsoon season, flooding has occurred due to damage to the city's natural drainage systems. The stream and length area of the ten drainage basins that drain the region were computed using this map overlay, which was based on the 1994 land use maps and drainage network map. The findings in this example point to the extent of damage to drainage networks in these two adjacent cities [17].

Since a nearby pond, Nandani Jhor, conveyed ashes to it, whose effects were seen even 50 km downstream, high-resolution optical data IRS-ID (PAN) and IRS-ID LISS III from the 6th of January, 2001, were immediately used to analyse and estimate the breadth of the afflicted regions. The information gathered was utilised to create a layer map of the settlements in order to pinpoint the regions that had been destroyed. The completed map was immediately submitted to NALCO officials so that rescue attempts could begin. They created pre- and post-breaching land cover/land usage maps, as well as the spatial extent of each type of land cover/land usage class in each village, using data from the IRS-ID LISS III data sets between December 12th, 2000 and January 6th, 2001. According to the findings, agricultural land, fields with or without scrubs, and fallow areas were found to be fully submerged in ash-mixed water [21, 49].

The land usage in the Udumbanchola Taluk was shifting according to the RS approach. The historic land use map

Table 1 Details of some satellite products with its application in Hydrology

S. No.	Applications	Satellite/Data	Resolution	Band	Launch Date/ Product Start & Extent	References
1.	Drainage Network	SRTM	90 m, 30 m	C-band,	2000	[14]
		ASTER	15 m	X-band, VNIR, SWIR, TIR	2009	[15]
2.	Landuse/ Landcover	AVHRR, LANDSAT	1 km	VIS, NIR	1978	[16]
		MODIS	30 m	VNIR, SWIR	1972-present	[17]
		SPOT ATSR/ERS2	500 m, 250 m, 1 km	VIS, NIR	1999	[18]
		IRS	20 m	G, R, NIR	1986	[19]
			30 m	IIR	1991/1995	[20]
3.	Vegetation Monitoring		35 m, 72 m	VNIR, SWIR	1988	[21]
		NOAA16	1.1 km	Microwave	2000	[22]
		MODIS	250 m, 1 km	VIS, NIR	2000	[18, 23]
		LANDSAT	30 m	VNIR, SWIR	2013 (Landsat-8), 2022 (Landsat-9)	[24]
		Sentinal-2	10–60 m	VNIR, SWIR	2015/2017	[25]
		SPOT/PROVA-V	1 km	Red, NIR	1990–2017	[12]
		AVHRR/GIMMS	1 km	VIS, NIR	1979–2015	[16]
4.	Water Quality	VIRRS	375 m, 500 m	VIS, NIR	2012	[26]
		(Land-sat + MODIS + VIIRS + Sentinel)	1 km	VIS, NIR	2002-present	[27]
		VIIRS-NOAA-20	750 m	VIS, NIR	2018-present	[28] [29]
5.	Water Temperature	MODIS-Aqua	1 km	VIS, NIR	2002-present	[18]
6.	River Depth	Lidar	10 cm	NIR	1961	[30]
7.	Oil Pollution	Sentinal-2	10 m, 20 m, 60 m	VNIR	2015	[31]
9.	Agriculture runoff	IRS	35 m, 72 m	VNIR, SWIR	1988	[32]
		Landsat	30 m	VNIR, SWIR	1972	[32]
10.	Soil Moisture	SMAP	36 km 9 km	L-band	2015	[19]
		SMOS	15, 25, 50 km	S, X-band	2010	[19]
		JERS-1 RADARSAT	18 m	L-band	1992	[33]
		Sentinel-1	3 m, 8 m	C-band	1995–2013	[34]
		AMSR-E	< 1 km ²	C-band	2014	[35]
		25 km	Passive microwave	2002–2011	[36]	
11.	Land Surface Temperature	AVHRR	1 km	VIS, NIR	NOAA_19 launched 2009 and	[37]
		ASTR/ERS2	90 m	IIR	MetOp-B launched 2012	[38]
		LANDSAT	30(multispectral)	VNIR, SWIR	2000	[39]
		MODIS,	-100 m (thermal),	VIS, NIR	2013 (Landsat-8), 2022 (Landsat-9)	[40]
		Sentinel-3	1 km/6 km	VIS, NIR	2000	[40]
		GOES	1 km	VIS, NIR	2015/2017	[41]
12.	Snow Cover		1 km		1975	
		AVHRR LANDSAT	1 km	VIS, NIR	1978	[42]
		SPOT	30 m	VNIR, SWIR	1972-present	[43]
		ATSR/ERS2	20 m	G, R, NIR	1986	[43]
		MODIS	30 m	IIR	1991/1995	[44]
		VIIRS	500 m	VIS, NIR	2000 to present	[42, 43]
		375 m, 500 m	VIS, NIR	2012 to present	[45]	

Note. VIIRS=Visible Infrared Imaging Radiometer Suite; AVHRR=Advanced Very High-Resolution Radiometer; MODIS=Moderate Resolution Imaging Spectroradiometer; SMAP=Soil Moisture Active Passive; SMOS=Soil Moisture and Ocean Salinity; VNIR=Visible near-infrared, Lidar=Light Detection and Ranging, SRTM=Shuttle Radar Topographic Mission, ASTER=Advanced Spaceborne Thermal Emission and Reflection radiometer, SPOT=Satellite pour l' Observation de la Terra, ATSR=Along Track Scanning Radiometer, ERS=European Remote Sensing satellite, NOAA=National Oceanic and Atmospheric Administration, GOES=Geostationary Operational Environmental Satellite Network, JERS=Japanese Earth Resources Satellite, IRS=Indian Remote Sensing Satellite

was created from topographic maps collected in 1910 and published by the Survey of India between 1912 and 1914. According to the 1997 land use map, visual interpretation of IRS-I C LISS III photographs had significantly altered

the original land use system. Ecodevelopment might help prevent previous missteps in which people's well-being was viewed as secondary to environmental protection efforts [50].

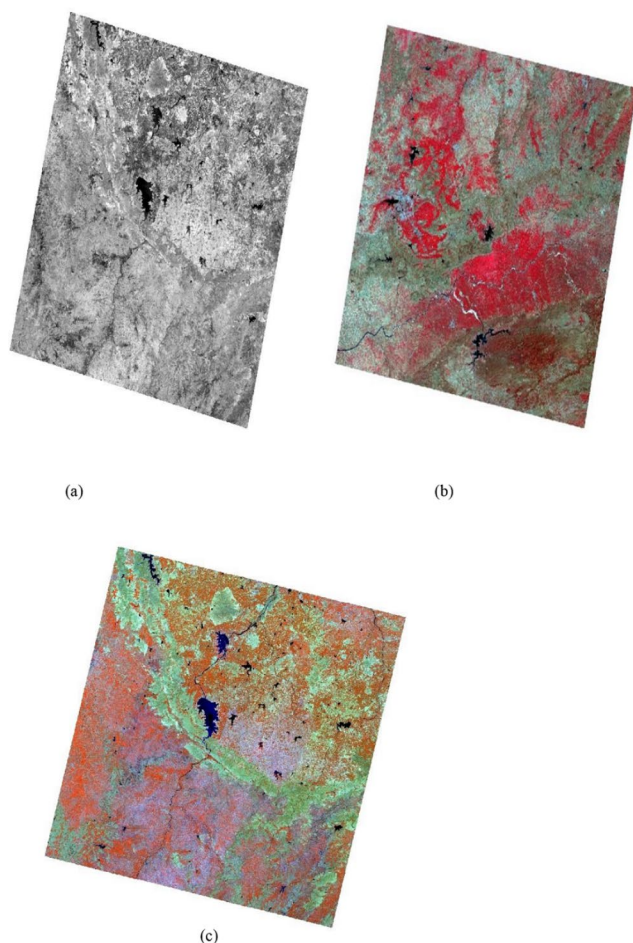


Fig. 1 Landsat 8 images of a part of M.P. Waterbody in different spectral bands. (a) Composite map of Band 1,2,3,4,5,6,7; (b) False Colour Composite map with B:5,4,3; (c) Composite map for Waterbody with B:5,6,4. (Source: USGS Earth Explorer)

Combining openly accessible SAR datasets with medium to high resolution optical data is one of the best ways for high-precision LULC mapping. A fusion strategy combining Sentinel-1 SAR data and Sentinel-2 optical data works for high-accuracy LULC mapping to estimate the area occupied by negative landforms like ravines. A VH-polarization fused image with Sentinel-2 optical data yields 85% accuracy, followed by 84% for a VV-polarization fused image with the same datasets, whereas Sentinel-1 and Sentinel-2 give 60 and 80% accuracy, respectively. For restoration and conservation of the degraded/Badlands, accurate land use/land cover (LULC) mapping of the Yamuna Chambal ravines is necessary. On the other hand, the asymptotic performance of fusion of SAR and optical data is rather good [51].

GIS are increasingly being used in place of traditional ground-based techniques due to the limitations of satellite data. Using GIS and RS techniques, land use indicators were utilised to build a raster map of the agroecosystem of West Bengal's South 24 Paragana area. The GIS and RS

techniques related to the agroecological study were successfully used in this work to create diverse data in the geographical and temporal domains, which is not possible with traditional approaches [52].

The watershed of the Garur Ganga's land cover classes as well as land use change were studied using Survey of India (SOI) Topographical Sheets and visual interpretation of LANDSAT 5 TM picture bands 2, 3 and 4. This water storage facility is located in Bageshwar, Uttaranchal, India. The information was gathered between 1963 and 1996, as well as between 1986 and 1996. This information was gathered using a Geographic Information System (GIS). According to a comprehensive investigation, farming and habitation accounted for 34.98 to 42.34% of the area, while barren lands and forest are on the decline. Agricultural land and built-up areas increase the greatest in the 200–1600 m elevation range, with a 7–140 slope class. 5.07% of vegetation cover was lost between 1963 and 1996, while 0.81% was lost between 1986 and 1996 [53].

The LULC fluctuations in the Abu Dhabi coastal zones between 1972 and 2000 were evaluated and quantified using data from “multi-temporal LANDSAT” satellites and digital change algorithms for detection. Because of the supervised classification and professional visual interpretation methodologies used by LULC, the photos categorised with an accuracy of 88%. Changes in the data were detected using ENVI's post-classification comparison tools. Wetlands and woody vegetation (*Avicennia marina*), an important coastal land use type, have been substantially reduced as a result of reclamation [54].

Because of its synoptic, multi-temporal, and multi-spectral character, remote sensing data has several advantages for this application. IRS LISS III sensor data was used to measure differences in land use and land cover in Gujarat's Hazira region. Because to the significant industrial activity, it's a high-risk location that requires continual monitoring. This study employed land cover data from a survey conducted over Indian topographical maps from 1970 to 1972, as well as satellite data from 1989 to 1999 to 2002, and visual analysis to estimate land cover/land use changes. Deposition and erosion have been noticed near the freshly constructed jetty. While the quantity of forest and agricultural land has decreased, the amount of built-up area has increased [55].

Used RS data, GIS-based multi-criteria overlay analysis, and field surveys to characterise biophysical land units in the Kanholi bara river basin” of the “sub-humid tropical environment.” To create a geospatial database including hydrogeological parameters, land cover, land use, soil erosion, slope, soil depth, landforms, and elevation, the soil survey data was combined with satellite data from IRS-ID LISS-III. Biophysical land units are established in a GIS by

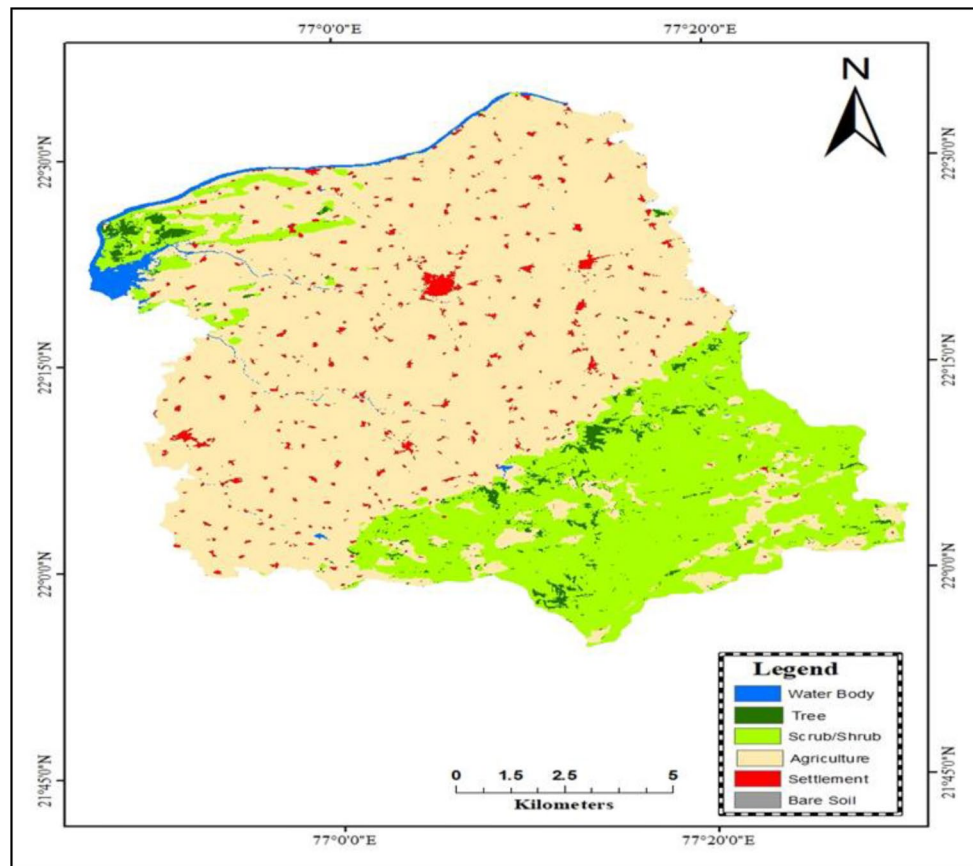


Fig. 2 Example of Landuse/Landcover map, Harda region, M.P. using Landsat data

assigning scores and weights to various layers depending on their characteristics and the degree of effect they have on the intended outcome. 17 types of different biophysical land units (20.0–68.5) were discovered in the river basin using a GIS-based multi-criteria overlay, ranging from minimal (20.5) to very less (20.5 to 29.5) and severe (50.5–59.5) to extremely severe (> 59.5) [56].

2.4 Remote sensing in Geomorphological Assessment

RS and GIS were used to investigate the morphometrics of two sub-watersheds in Gurdaspur district, Punjab. The most recent and produced “IRS-1D PAN sharpened LISS-III analogue data” was utilised to update the drainage system map, which was created using SOI toposheets and aerial images. In the delineation and updating of drainage systems, GIS and RS methods have proven to be a successful combination. These revised drainages were used to perform morphometric analysis on the two sub-water sheds [57].

The eight mini-watersheds of the Mohr watershed, which are located within the Kapadwanj taluka and Bayad taluka from the Kheda and Sabarkantha districts of Gujrat, respectively, are morphometrically analysed and prioritised using

RS and GIS methodologies. The morphometric metrics employed in the study included texture ratio, elongation ratio, bifurcation ratios, circularity ratios, texture ratios, stream lengths, stream frequency, drainage density, and compactness ratios. There was a dendritic drainage pattern in the Mohr Watershed. The greatest bifurcation ratio of all the mini-watersheds was 9.5, indicating that the drainage was under significant structural control. For the mini-watershed, the highest circularity ratio was 0.1197 [58].

Detailed field surveys and remotely sensed data (IRS-ID, LISS-III) are extremely helpful in landscape ecological planning and terrain analysis at the watershed level (IRS-ID). Geomorphologists have recognised narrow valleys, plateau side drainage floors, narrow slopes, plateau spurs, isolated mounds, table and the main valley floor. By analysing and reclassifying landscape ecological units, it was discovered that the research area’s landscape ecological stress zones have been delineated. The use of GIS to analyse RS and other data can substantially benefit in determining stress zones and ecological units in the landscape. Landscape ecological planning with preventative actions to maintain the watershed undamaged has been advocated in these watershed stress zones for better utilisation of natural resources [59].

Between 1989 and 2015, RS and Geographic Information Systems analytic techniques were employed to analyse the Chittagong Metropolitan City for spatiotemporal variation in Urban Water Bodies (UWBs). Additionally, Landsat TM and/or OLI satellite photos were obtained for ground truthing purposes in 1989, 2001, 2010, and 2015 [60].

From an Arc view GIS in the Agniar-Ambular-Southvellar river basins, a GIS was utilised to determine probable zones for artificial recharge. The research area spans 4566 square kilometres. To create 1:250,000 scale maps of physiography, water capacity, drainage intensity, effective soil depth, permeability, soil texture, and geology, traditional methods were used. They were scanned and registered to a base map before being generated as individual coverages or layers in the Arc view. The GIS was used to merge different maps in order to locate potential places for artificial recharge. For consideration, each issue was allocated a weighting depending on its impact on groundwater recharge. The importance of map units in groundwater storage and transit was ranked from one to four on a scale of one to four. The final map has been completed, and it depicts four unique sorts of regions where artificial recharging may be feasible [61].

Researchers were able to detect places at danger of landslides, degraded forest zones, and other hazards that demand special attention during development efforts using GIS approaches. In recent years, remote sensing and geographic information systems (GIS) have evolved into important tools for monitoring and managing natural resources. Traditional approaches, which are expensive, incorrect, and only cover a narrow region, make it difficult to identify changes in natural resources. Using a mix of traditional and RS methods, it is feasible to monitor and conserve the terrain's natural resources, such as hill regions [62, 63].

The researchers explained its geomorphic evolutions based on the identified geomorphic items employing remote sensed data, GIS, and flood eras. The findings clearly suggest that the rivers under study are undergoing unique morphological changes [64]. Historical maps, aerial pictures, and satellite images may reveal long-term morphological changes that are related to hydrological conditions. The most important feature of these resources is the ability to capture spatial-temporal changes and monitor the destruction of pre-existing landforms, the deposition of new landforms, as well as vegetation and land cover/land use fluctuations in riparian zones [65].

Many depositional and denudational landforms were explored throughout the geomorphology examination, as well as mapping of the research region. In isolated mounds, the soil depth is fairly modest, while in the Pedi plains, it is exceedingly deep [66]. Using conventional False Colour Composite (FCC) imaging of IRS-1D LISS-III data as well

as image features, soil depth, morphometry, plant cover, and slope gradient, four distinct groups of eroded land were detected and mapped. According to the deteriorating ground layers and geomorphology, considerable land degradation affects 6.05% of the total area in the Pedi lowlands, rolling plains, and subdued plateau regions. The most deteriorated terrain is found on solitary mounds, escarpments, dissected ridges, and plateau spurs, according to a geomorphic sub-unit research. RS data and GIS data-based comprehensive analysis for reclamation, geo-environmental based planning, and management provide a better understanding of landform-eroded land connections and distribution [67].

Data from satellite sensors collected over several decades can help us understand the natural processes of planform change, meandering, and braid bar formation. The research focused on the Ganga River's planform dynamics from Sahibganj in Jharkhand to Jalangi in West Bengal, India. The sequential river planform maps served as the research's foundation. The maps were constructed at 5-year intervals using Landsat 1, Landsat 3, Landsat 4, Landsat 5, and Landsat 7 data from 1975 to 2015. To analyse and categorise the river, the sinuosity index, braiding index, and map spatial analysis were used. The results demonstrated changes in channel migration over time and space. The results demonstrated changes in channel migration over time and space. The analysis indicated that the factors causing the Ganga River to shift in some areas are both natural and man-made. Landsat images were found to be beneficial in determining a river's meandering index, braiding index, and planform modification [68].

Due to limited resource allocations, the availability of data for hydrological and water management analysis is a cause of worry, particularly in developing nations. Remote sensing is effectively employed as an alternative that delivers geographically and temporally consistent information essential for optimal water resource management. This chapter attempted to emphasise remote sensing (RS) and geographic information systems (GIS) and their application in data-scarce locations for water resource analysis and management. The use of RS for crop categorization, rainfall and snowfall estimation, soil moisture analysis, surface and groundwater usage, and water resource planning and management in conjunction with GIS has been demonstrated [19].

2.5 Remote sensing in Biodiversity Assessment

Biodiversity refers to the variety and variability of living organisms at all levels of organisation, from genetic to species level, and from lower taxonomic levels to higher taxonomic levels, as well as the processes that occur within those habitats and ecosystems [69]. The information required for

biodiversity monitoring is extremely diverse. It should also be based on geography and used to predict the presence of new populations of endangered species. Researchers and conservation policymakers have found remote sensing to be quite useful in this field.

Invasive species are classified into four categories using RS and GIS to map their potential and actual distribution, based on whether or not they appear and dominate the ecosystem canopy. The authors believe that the capacity to employ RS to map intruders varies for each of the groups. Despite this conclusion, ecological databases demonstrate that the great majority of invasive species do not occupy the canopy. The terrain of these invading armies has received little consideration during the mapping procedure. This study discusses several approaches for mapping non-canopy invasion species. The study also goes through how to map the danger of invasion in places that haven't yet been invaded [70].

Given the importance of biomass, the author attempted to estimate Tripura State, India's AGB through time using MODIS, NDVI, LAI, and field inventory data. A model was built to determine the relationship between NDVI, LAI, and Biomass at the specified study location. It was also an objective of the project to enhance "inventory-based biomass stock estimating methodologies." The results of the study reveal a correlation of 0.87 between the NDVI and the LAI in 2011 and 0.53 in 2014 [23].

Using a set of indicators derived from RS data, an evaluation of the city of Dehradun's riparian zones' vulnerability as a result of urbanisation was made. These differences in landscape patterns were investigated by analysing Landsat-8 and Sentinel-2 data with "Google Earth Engine, ArcGIS, and ERDAS IMAGINE 2014" software. The researchers were able to determine the components that cause riparian area fluctuations using high-resolution photographs, reconnaissance surveys, and existing base maps. Human activities such as the development of new houses, roads, farms, and enterprises have enhanced the vulnerability of riparian zones (such as industrial facilities) [25].

This research seeks to combine remote sensing analysis of surface characteristics with the ground investigation technique of Electrical Resistivity Tomography (ERT) data in Sungai Batu, Bujang Valley, Kedah, to detect ancient remnants. To give visual interpretation and an elevation profile to extract archaeological features, the Normalized Difference Vegetation Index (NDVI) and Digital Elevation Model (DEM) were developed. The researchers recommended using NDWI (Normalized Difference Water Index) instead of NDVI when determining which approach to use [16]. Finally, the results of this research might be used to map out a possible archaeological interest region and help organise future fieldwork studies.

Using remote sensing-derived PSI values and field measurements aimed to assess the riparian conditions of China's fifth-longest river, the Songhua. The PSI values in each measurement section were analyzed using spatial statistics in order to determine the variation in riparian condition. Results from 13 measurement sections showed that human activities had disrupted the riparian zone in over 60% of the cases examined in this study. Riparian zone conditions were found to be significantly impacted by changes in land use patterns in both cold and hot spots. Use of PSI values to identify the vulnerability of the riparian zone is possible by employing low-low clustering [71].

Using remote sensing (RS) data, wheat yield maps were created on farmer farms in the Alipur Block of Delhi State during the rabi season of 1998–1999. "RS-derived leaf area index (LAI)" and "wheat simulation model WTGROWS" were linked using a "Modified Corrective Approach." The LAI was calculated using IRS LISS-III data from a single collection. The integration of RS data and a crop simulation model gives an option for mapping and forecasting crop output in India's highly variable cropping environment, which is required for Precision Crop Management (PCM) to be implemented [26].

The study's goal was to pinpoint environmentally vulnerable areas in Soon Valley. To achieve this purpose, GIS and RS technologies were employed to combine ecological knowledge. An ecological assessment research employed ecological indicators and their synthesis to identify ecologically significant and favoured places in the study region. The spatial extents of each of the eight ecological indicators developed for this purpose were mapped using GIS. When calculating the buffer zones and weighting variables for the study, the relevance of each attribute was taken into account. Ecologically vulnerable places were divided into four categories: low (34%), moderate (39%), high (20%), and extremely high (6%) [72].

The Nagarjunasagar Left Canal Command (NSLC) in Andhra Pradesh was benchmarked using WUI (Water Utilisation Index) and adequacy indicators. Based on satellite data (IRS IC/1D LISS 111 for tile year 1998-99 and IRS 1A/I B LISS 11 and Landsat TM for the year 1990-91), irrigated agricultural acres were calculated using a hierarchical categorization technique. Paddy is the main crop farmed in the study region, but other crops are also planted. The comparable wet area was calculated using the operationally employed project-specific conversion parameters (paddy crop area). WUI was calculated at the distributary, irrigation block, and irrigation zone" levels using canal discharge data. WUI was measured at the project level during the 1990-91 and 1998-99 rabi seasons, and was found to be 65 and 92 ha/MCM, respectively. WUI may be used to

benchmark the performance of irrigation command regions as a spatial performance indicator [27].

The researchers used terrain analysis to generate the regions physically related with the river channels for determining the floodplain ecosystems inside the Naryan river catchment area along the mainstream. This is accomplished using a multispectral remote sensing approach, the SRTM-1 elevation model for the stream network, and Landsat 8 data to differentiate between non-vegetated and vegetated regions. Using this approach, 2369.84 km² of the Naryan River catchment area was determined as being linked to the main streams. This region was covered by vegetation 65.74% of the time, water 18.18% of the time, and bare soil 16.08% of the time. More field calibration will be performed to assess and enhance the dependability of the results [32].

8 sites along the San Miguel River are studied for (a) riparian distribution, structure, and vegetation using RS technology and a UAV field sampling method; (b) production using vegetation data collected from satellite images; and (c) inconsistency exhibited by vegetation adjacent and riparian vegetation to riparian habitats. Landsat 8 data was received as a land surface reflectance (LASRC) from the OLI (Operational Land Imager)/TIRS (Thermal Infrared Sensors) Pre-Collection L1T data type. Landsat 8 data contains 11 bands, of which 7 (1–7) were selected and processed to form the final stack. They identified considerable changes in vegetation topologies depending on whether “obligate-riparian species” were present or not [14].

2.6 Remote sensing in Water Quality Assessment

Drinkable water, transportation power, industrial production, and horticulture are all dependent on a city’s water resource. As a result, most well-known towns were constructed beside rivers. Nowadays, population and business numbers are rapidly growing in lockstep with urban exploitation and expansion, resulting in serious water pollution. The study of acquiring data about the earth’s surface from afar using satellites is known as remote sensing (RS). Adopting RS techniques to water quality evaluation has offered enormous advantages compared to traditional data monitoring. RS approaches have been widely used in agricultural research, dynamic changes in deserts, and many other study fields [73].

Rivers in cities play a vital part in urban development and contribute significantly to urban environment. The majority of urban rivers serve as drinking water supplies; hence water quality is vitally important. The existing evaluation technique in China’s national standard has a number of drawbacks; as a result, this study offers a more advanced assessment, namely the Canadian Water Quality Index (CWQI). This approach can assist in providing a thorough

and impartial assessment of water quality in urban waterways. From 2014 to 2017, water monitoring data was collected in 24 parameters (pH, dissolved oxygen (DO), chemical oxygen demand (COD), ammonia nitrogen (NH₃ N), total phosphorus (T P), and other metal ions). To generate models of CWQI scores from satellite data (Landsat 7 and 8) a remote sensing approach is used [74].

The researchers intended to locate regions in Kerala’s “Ithikkara River Basin” with a lot of groundwater potential. The researchers used RS to build a number of themed maps as well as maps for potential groundwater. Ground truth surveys employing the Survey of India (SOI) topographic map and Landsat data (Landsat ETM+) were used to construct and evaluate many themes such as lithology, geomorphology, land use/land cover, drainage, and soil. The researchers utilised a technique called weighted overlay analysis to determine the prospective zones for ground water. GIS and RS might be utilised to analyse groundwater resources and establish a viable exploration strategy, according to the findings. The groundwater potential map shows that the gentle slope had larger groundwater potential [75].

For preparing and describing land suitability for cotton cultivation, irrigable land, land productivity, researchers employed a GIS and “high-resolution IRS-IC PAN integrated LISS III data.” Using ILWIS 3.1 (Integrated Land and Water Information System) software, thematic maps of land use/land cover, physiography, slope, and soils were scanned and processed in a GIS context. Because of the limits provided by shallow solum, moderate surface stoniness, and steep slopes, soils on undulating plateaus, escarpments, and moderately sloping pediments were found to be inappropriate for cotton. Because of shallow depth and moderate to severe erosion, soils on a very gently sloping plateau and pediment are only marginally suited. Furthermore, an action plan for taking appropriate management and soil conservation measures in order to maximise the use of the land is required [76].

Remote sensing has become popular in water quality monitoring in recent years. Satellite remote sensing remains a difficulty for inland water quality monitoring due to poor signal-to-noise ratio (SNR) and sensor resolution limitations. Hyperspectral remote sensing from the ground offers a high temporal-spatial resolution and can be easily fixed on the water’s edge to enable real-time continuous detection. The current study inverts water quality metrics using a mix of hyperspectral remote sensing devices and BP neural networks. Eight water quality parameters (chlorophyll-a (Chl-a), phycocyanin (PC), total suspended sediments (TSS), total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH₄-N), nitrate-nitrogen (NO₃-N), and pH) were modelled and confirmed using observed values and remote sensing reflectance [77]. It is a realistic way to determine

water quality in the river using hyperspectral remote sensing technology. The model embedded into hyperspectral remote sensing technology can assist decision-makers in comprehending real-time changes in water quality metrics.

Remote sensing has gained popularity in recent years, and its resources are particularly beneficial in the management of water resources. The water quality of the Kizil Irmak River was assessed utilising remote sensing technologies and satellite pictures using sensors operating in the 350 to 1050 nm wavelength region (e.g., CHRIS Proba). Samples are gathered in order to make ground-based spectroradiometer measurements. These samples were taken when the CHRIS Proba satellite was collecting imagery. Spectral fingerprints gathered from ground measurements are used as reference data to categorise CHRIS Proba satellite's hyperspectral images across the research zone. Satellite images are classified based on chemical oxygen demand (COD), turbidity, and electrical conductivity (EC). As a result, interpretations of classified CHRIS Proba satellite hyperspectral data are available for utilization [78].

The use of RS data with GIS technologies to determine the groundwater potential of any location has shown to be incredibly beneficial. IRS IA and LISS II data were used to identify probable ground water zones using 1:50,000-scale thematic maps and IRS IA and LISS II data. In the study, seven probable ground water zones were identified. When these variables are considered, groundwater potential zones may be determined more precisely [79].

To build the water quality map, this study will employ Kriging (spherical, exponential, and Gaussian models) and Inverse distance weighted (IDW) approaches. In addition, in the Iranian region of Fars, the link between water quality and distance to fault is studied. Groundwater quality is also predicted using the adaptive neural fuzzy inference system approach. The groundwater quality is determined using the observed sodium adsorption ratio and electrical conductivity data gathered from 384 wells between 2005 and 2014. The Kriging approach (spherical model) has a greater accuracy and a lower RMSE value than the IDW method, according to the results. This model is then utilised to create the interpolation maps [80].

In the measurement of watershed's hazardous non-point source pollution, GIS, RS, and a distributed parameter model called Agricultural Non-Point Source Pollution Model (AGNPS) were used. The input data for the modelling process came from the ARC-INFO GIS and remote sensing, whereas AGNPS projected the movement of contaminants such sediments, fertilisers, and pesticides (N and P). An integrated method is utilised to analyse sediment contamination in the Karso watershed. The expected runoff and sediment outputs matched the actual findings quite well. It's vital to remember that this research isn't intended to be

exhaustive. The Hydrology/Water Quality (H/WQ) modelling framework based on RS and GIS is meant to show the possible benefits of this method [81].

3 Result and discussion

The potential of remote sensing data in river ecosystem management is demonstrated by an overview of the remote sensing applications in many sectors of river ecological evaluation. After examining the aforementioned research, we found that it is the only method for measuring habitat characteristics across vast areas and identifying environmental changes brought on by anthropogenic or natural processes for a variety of applications. For the geomorphological study of rivers, thematic maps of lithology, landforms, lineaments, and surface water were produced using remote sensing data from satellites such as ASTER and SRTM. These maps were then combined with other data such as drainage density, slope, and soil types to perform the geomorphological assessment. Land cover classification was carried out to determine the hydrologic characteristics that are important in distributed hydrologic modelling using Landsat and IRS LISS data. Direct estimates of habitat loss are provided by MODIS, NDVI, LAI, and PROVA-V data assessments of broad-scale trends in vegetation. This increases the ability of applied ecological studies to identify changes in species distributions or simulate extinction rates. Monitoring droughts, managing irrigation, and monitoring floods have all been proven to benefit greatly from remote sensing's ability to collect data in close to real-time i.e., AVHRR, GOES, Sentinel, SMAP, etc. The higher geographical and temporal coverage that can be easily achieved to depict the dynamic character of the hydrological and meteorological condition variables is one of the key benefits of the remote sensing application and essential for hydrological and biological conservation applications which will become increasingly vital in the future.

After analysis of above papers, we found that Optical remote sensing systems, while providing very fine spatial resolution, have a limited ability to penetrate clouds, limiting its use in bad weather. This is a particularly serious issue in tropical areas, which are typified by regular cloud cover. This also limits the use of optical remote sensing in flood monitoring, as floods are typically linked with adverse weather. Another significant drawback of optical remote sensing is its inability to map water resources under dense vegetation. To a considerable extent, the use of an active microwave sensor helps to overcome these constraints. Clouds and plants can be penetrated by radar radiation (depending upon the wavelength of the signal and the structure of the vegetation). The difference in energy received

back at the radar sensor is utilised to distinguish and indicate the water bodies' boundaries. Surface water bodies and flooded regions under dense forest have been marked using radar remote sensing.

The need for a stronger link between remote sensing scientists and end users to better define the data/information requirements for an application like river monitoring, as well as to improve users' knowledge and capacity to use the tool, is critical for the successful integration of satellite observation products into aquatic monitoring. Despite the fact that each technique has its own set of advantages, there is still no consensus on the optimal set of processes to use for validation. However, there is no satellite data that provides direct water quality products, which is a key drawback of remote sensing. Many underdeveloped countries lack the financial and organisational means to take advantage of the existing remote sensing technology. Because of their high initial costs, a lack of high-level skills (required to process and utilise them), and a lack of staff training capacities, many developing countries do not have access to new remote sensing technology.

4 Conclusions

A holistic approach is required in order to recognize the complex water system for integrating the ideas as well as concepts to attain such management for water resources that are highly sustainable. Water cycle processes can be studied at a more detailed level by conducting a field study. As a result, it is imperative that field-based research be reasonably upscaled at the regional or national level, where political decisions are made. These models are commonly brought in use; however, they face difficulties due to a lack of such data which are of high quality and accuracy. The technologies associated with RS can become a useful tool for obtaining "continuous input data" in data-poor regions. Satellite acquisition has filled in the data gaps caused by the insufficiency of "on-the-ground monitoring of water resources" globally. For the management of water resources, satellite products and advanced computational techniques can play a significant role in both present as well as future of water resources. However, satellite remote sensing for hydrology does not only cover rainfall as well as Tropical Rainfall Measuring Mission (TRMM), but also moisture content in the earth's soil (SMAP, SMOS, SEBAS and GRACE).

Both GIS and Remote sensing technologies can be brought in use for managing the river ecosystems more effectively and efficiently as the demand on natural resources increases due to the growing human population. Factors affecting river use can be identified and analysed using geographic information systems (GIS). In other words, it is possible

to arrive at sound decisions for ensuring the sustainable and efficient usage of the water resources for meeting the requirements of present as well as future generations with a detailed understanding of these factors.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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