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Monitoring Changes of Rivers Using Remote Sensing Technique: Articles Review

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ABSTRACT

The morphological changes of rivers and lakes continue as a result of several factors, including natural and human. These changes include rivers' pathways, deposition of sediment, erosion, and flooding due to water level fluctuation. It is therefore necessary to understand these changes, which are the basis for the sustainable management of water resources. The Remote Sensing (RS) technique is often regarded as very efficient for monitoring natural events, including the morphological characteristics of river basins. This study has addressed the worldwide morphological changes of rivers and lakes. It has monitored them using modern techniques such as remote sensing techniques and its effectiveness in assessing these changes. Remote sensing technology is an advanced tool brought about a significant shift in the field of studying the morphological changes of rivers and lakes. This technology has provided the capability to collect and analyze data on a large scale, offering precise and up-to-date information about morphological changes not only for aquatic systems but also for landforms and physical alterations. This technology relies on multiple applications for assessing morphological changes, including satellite imaging, LiDAR (Light Detection and Ranging) techniques, and radar systems. The results show the effectiveness of remote sensing techniques and geographic information systems in analyzing and monitoring the morphological changes of rivers, lakes, and the aquatic environment in general, as these techniques save effort, time, and accuracy compared to traditional methods and fieldwork. The findings of this research indicate that remote sensing technology and geographic information systems are highly effective in monitoring morphological changes in rivers and lakes. These methods provide precise results in a significantly shorter timeframe compared to conventional approaches. Additionally, they offer precise and dependable outcomes capable of encompassing extensive regions and gathering crucial and varied information such as terrain heights, water movement, sediment dispersion, and early identification of geological problems.

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مراجعة ادبية لمراقبة التغيرات المورفولوجية للانهار باستخدام تقنية التحسس النائي

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الملخص

تستمر التغيرات المورفولوجية في الأنهار والبحيرات نتيجة لعدة عوامل التي تشمل الطبيعة والبشر. تشمل هذه العوامل تغيير مسارات الأنهار، وترسيب الرواسب، والتعرية، والفيضانات نتيجة لتغير مستويات المياه. لذا فمن الضروري فهم هذه التغيرات التي تشكل أساس إدارة الموارد المائية بطريقة مستدامة. تُعتبر أساليب التحسس النائي (RS) فعالة لمراقبة الأحداث الطبيعية بما في ذلك الخصائص المورفولوجية لحوض الأنهار . قدمت هذه الدراسة تقييماً للتغيرات المورفولوجية في الأنهار والبحيرات باستخدام تقنيات حديثة مثل تقنيات التحسس النائي، وفعالية هذه التقنيات في تقييم هذه التغيرات. أظهرت النتائج فعالية تقنيات التحسس النائي وأنظمة المعلومات الجغرافية في تحليل ومراقبة التغيرات المورفولوجية في الأنهار والبحيرات، حيث توفر هذه التقنيات جهدًا ووقتًا ودقة أكبر مقارنة بالأساليب التقليدية والعمل الميداني. تشير نتائج هذه الورقة البحثية إلى أن تقنيات التحسس النائي وأنظمة المعلومات الجغرافية فعالة للغاية في مراقبة التغيرات المورفولوجية في الأنهار والبحيرات، حيث توفر هذه الأساليب نتائج دقيقة في فترة زمنية أقصر بشكل كبير مقارنة بالطرق التقليدية. بالإضافة إلى ذلك، تقدم نتائج دقيقة وموثوقة، وتتمتع بالقدرة على شمول مناطق واسعة وجمع معلومات حيوية ومتنوعة مثل ارتفاعات التضاريس، وحركة المياه، وتوزيع الرواسب، والكشف المبكر عن المشاكل الجيولوجية.

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Introduction

Rivers' Morphology (RM) has a decisive role in the planning and upkeep of infrastructure projects like levees, dams, and bridges. Meander patterns are often presented in straight rivers, where the meandering of rivers is sinuous in plan, with efficient equilibrium features (Southard, 1984). The meander patterns are characterized by the non-linear geometry of the river plan, which is influenced by the stability of the riverbanks and the presence of midstream bars, along with potential obstructions.

Various elements, including water discharge, water velocity, water surface slope, width, and depth of the riverbed material, determine river morphology (RM). These factors shape the patterns, forms, and banks of the river. These elements are interconnected and cannot be considered separately (Rinaldi et al., 2016).

Rivers are natural channels that convey a large amount of water flow from catchment areas as runoff. This water streams from the mountains, runs through the plains, and eventually joins the sea or ocean. Rivers play a significant role in the hydrological cycle, and transport a considerable amount of silt or sediment carried down from the catchment region and eroded from the riverbed and banks, in addition to water. In alluvial soils, silt plays a crucial role in river behavior (Kim et al., 2009). Floods in rivers create enormous havoc and misery for human beings when there is no river control in the early days. River behavior is now well understood because of advances in science and technology with RS and GIS, and many river training methods are applied.

Remote sensing technology is an advanced tool that has brought about a significant shift in the field of studying the morphological changes of rivers and lakes. These technologies have provided the capability to collect and analyze data on a large scale, offering precise and up-to-date information about morphological changes not only for aquatic systems but also for landforms and physical alterations.

This technology relies on multiple applications for assessing morphological changes, including satellite imaging, LiDAR (Light Detection and Ranging) techniques, and radar systems.

Remote sensors commonly record wavelengths throughout a wide range, including visible and infrared rays (near, medium, and far), ultraviolet rays, and other categories. The energy is transformed, recorded as data, and saved for later use (Forestier et al., 2012).

These technologies can facilitate the adaptive development of all fields. At the same time, remote sensing techniques are necessary to regularly supply information about the condition and nature of the research area at various levels. Recent innovations have enhanced remote sensing (RS) technology, enabling it to better address multiple stakeholders' needs in agricultural applications. These applications include monitoring agricultural land use, predicting crop productivity and species distribution, and assessing ecosystem services related to soil and water resources and biodiversity loss. RS offers a range of substantial and effective solutions and services to enhance and deliver long-term, cost-efficient operational services for applications in green lands (Weiss et al., 2020).

It is worth mentioning that traditional methods require extensive field efforts, which result in higher costs and lower accuracy, whereas remote sensing techniques provide the ability to analyze large areas with higher efficiency.

Previous studies

Previous research on river and gulf morphological changes has explored potential negative impacts like flooding, air pollution, water supply loss, agricultural land degradation, and Earth's average surface temperature. Remote sensing and geographic information systems could be crucial tools.

Ghoshal et al. (2010) focused on the velocities and types of channels and floodplain change analysis, emphasizing the importance of examining historical records from the latter half of the 19th century in the Sierra Nevada of northeastern California. The current area held great importance because of the swift accumulation of sediment in channels and the transformation of floodplains caused by hydraulic mining operations. The temporal scope of this investigation, during which accurate topographic data were accessible, was from 1906 to 2006 (Fig. 1).

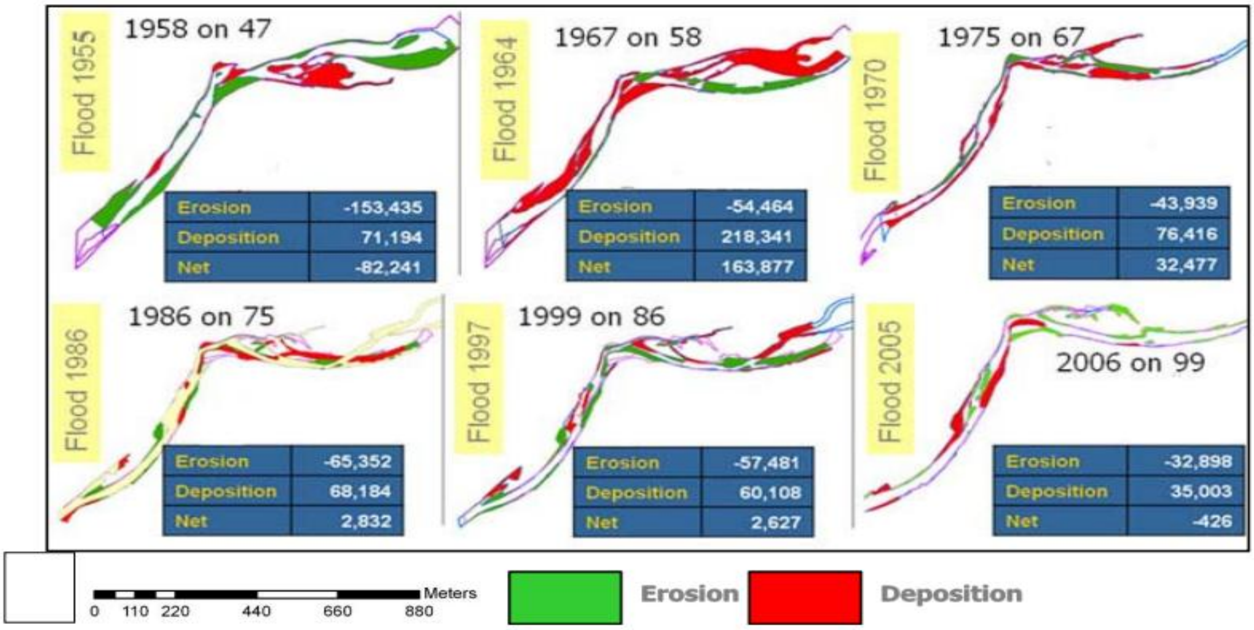

Fig. 1. Deposition and erosion polygons showing areas (m^2) of sediment reworked by each flood (Ghoshal et al., 2010).

The piedmont deposits originating from “the Yuba, Bear, and lower Feather Rivers” were found to contain an estimated 38% of the high-magnitude sediment produced in the northern Sierra Nevada region. Before mining activities, the rivers in the Sacramento Valley exhibited distinct features, including high, steep banks and relatively restricted areas of healthy and nutrient-rich soil.

The Yuba River revealed substantial and prolonged modifications to its channel due to the unexpected influx of sediment from the Hydraulic Mining System (HMS) and human interventions aimed at its management (Ghoshal et al., 2010).

Farooq and Siddique (2015) examined the morphology of the river Jamuna in Bangladesh by means of (GIS) and (RS) methodologies. Vulnerabilities and changes were identified over five years, including 2010, 2003, 1989, 1980, and 1973 (Fig. 2). Settlement identification and analysis were conducted using Landsat Enhanced Thematic Mapper Plus, Multispectral Scanner images, and Thematic Mapper. Topographic maps from 1947 were employed to map river channels. Image classification was performed using eCognition/Definiens object-based methods for river mapping, while ArcGIS provided data on river channel dynamics and bank erosion. The average rates of bank erosion and siltation were significantly elevated. The average bank erosion and siltation rates were quantified and determined to be exceptionally elevated. The annual average erosion measured 1235.25 square kilometers, whereas siltation amounted to 29.82 square kilometers. The highest recorded river displacement was 35,847 m in 2003, while the lowest was 16,415m in 2010.

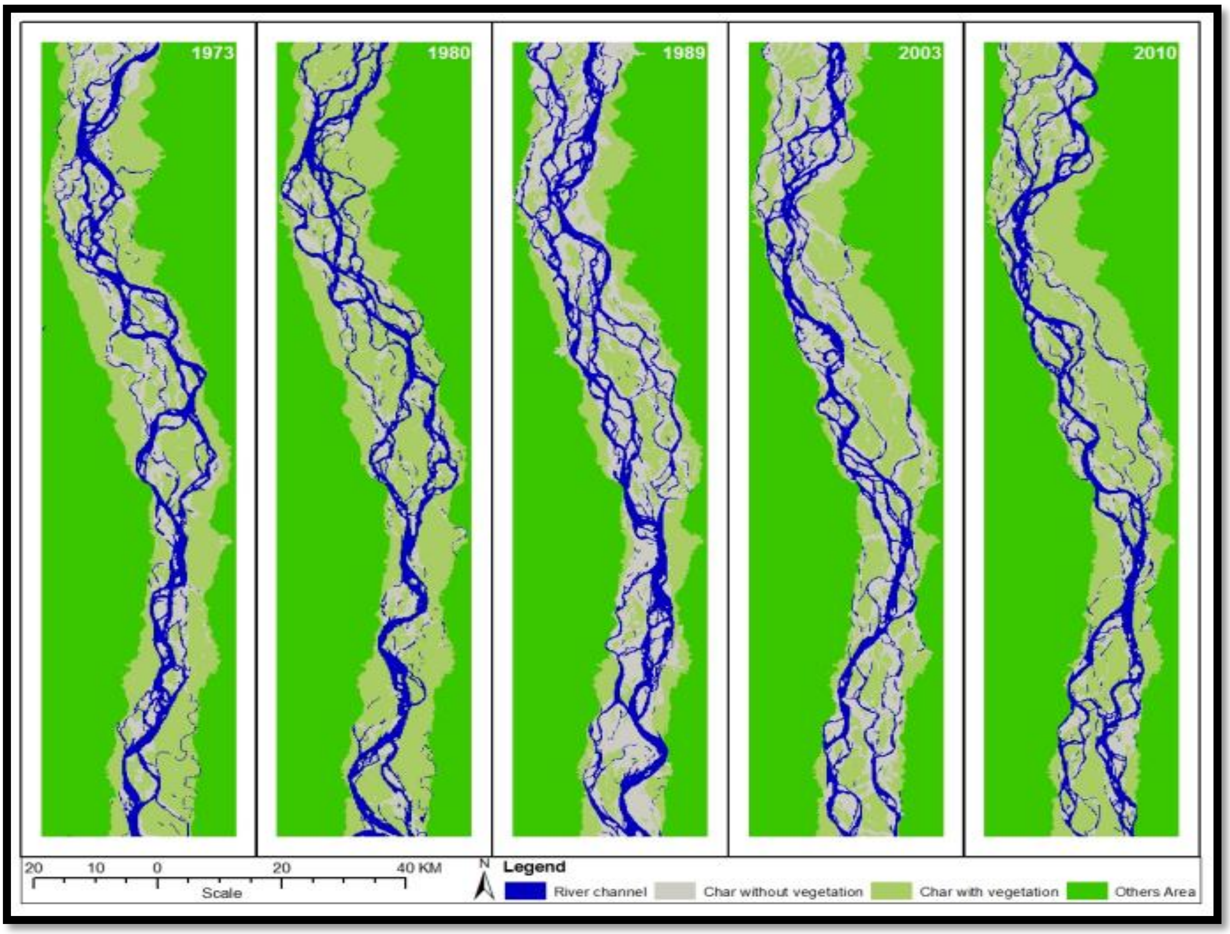

Fig. 2. Map of Jamuna River channel (1973-2010) with associated land cover (Farooq and Siddique, 2015).

Fashae and Faniran (2015) examined the physical characteristics of the river channels of the Ogun River, Nigeria. The collection of data about the morphological parameters of the channel involved the measurement of the river's bank full cross-sectional qualities as well as the determination of its longitudinal characteristics. Sonar equipment mounted on a boat was utilized to measure the maximum depth and width of the river at each of the cross-sections. The bank full width exhibited a strong positive association of 0.8 for the wetted perimeter and 0.9 cross-sectional area. The study additionally demonstrated a strong positive correlation of 0.9 between the gradient and discharge. The study assessed the extent of variation in the physical features of the Ogun River, providing a scientific basis for the management and maintenance of the river (Fig. 3).

Fig. 3. Migratory sand bars along the Lower River Ogun channel (Fashae and Faniran, 2015).

Donovan et al. (2019) examined river systems and suggested optimal methodologies for quantifying boundary alterations, including glacier retreat, erosion, and vegetation expansion. To avoid spatial autocorrelation, it is recommended to assess planform changes over spatial intervals bigger than the coherent units of adjustment. Remotely sensed imaging enhanced the precision of analyzing the movement and breadth changes of the Root River, located in southeastern Minnesota within the region of North America. Nevertheless, there needed to be a framework specifically designed to address this dataset's uncertainty issue. The primary factor contributing to uncertainty in manual riverbank delineations was the inconsistency among users rather than the image quality or environmental circumstances. The digitations traced the vegetation boundary that most closely represented the river's width at the bank full stage. The study also suggested utilizing a spatially variable threshold for error detection to improve data accuracy. The investigation revealed little to no spatial autocorrelation in the rates at which channels migrate over distances of 1-4 channel widths (50-200 m). This finding was consistent with the observed patterns of irregularity in user digitizing (Fig. 4).

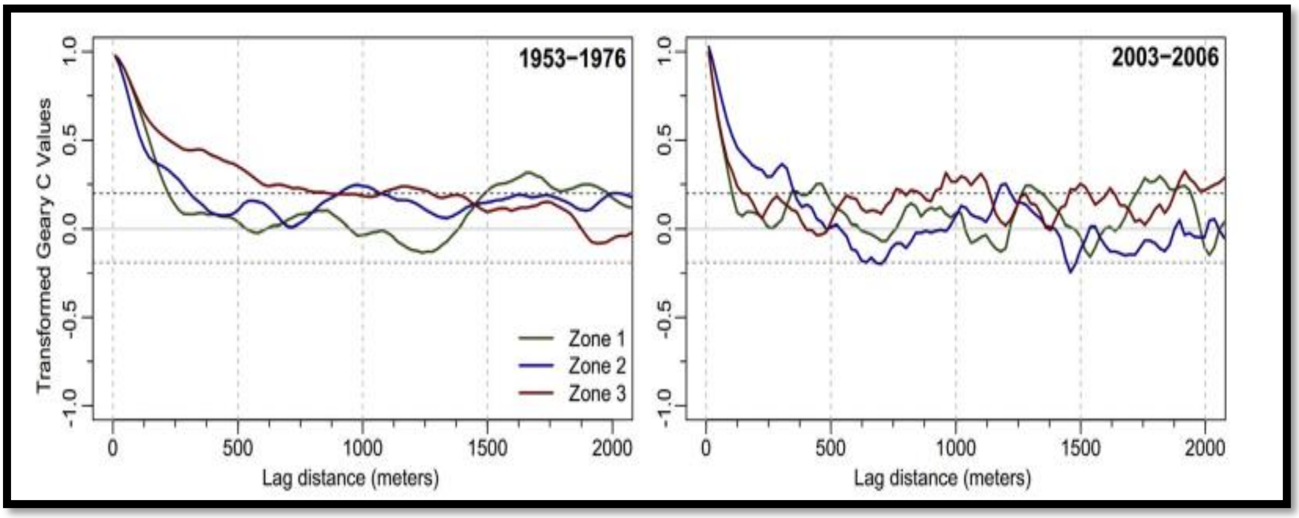

Fig. 4. Correlograms showing spatial autocorrelation to measure channel movement. Lag distance denotes the length over which autocorrelation was measured. Geary's C values, generally ranging from 0 to 2, were changed to the standard correlation range of -1 to 1 (Donovan et al., 2019).

Langat et al. (2019) conducted the flow duration curve using geospatial methodologies to examine the Tana River's current hydromorphological properties in Kenya. The goal was to obtain a clearer knowledge of human impacts during the last twenty years and the consequences for future development projects. For 17 years, the results indicated that all extreme peak, low, and average discharges exhibited significant upward trends. The analysis of hydrological changes after regulations showed a significant rise of 56% and 40% in high and low flows, respectively. However, the construction of the dam equipment led to a notable decline of 13% in the highest level of discharge and a substantial 30% drop in low flows. The primary water flow has had a 33% increase in the previous decade compared to the present decade (Fig. 5).

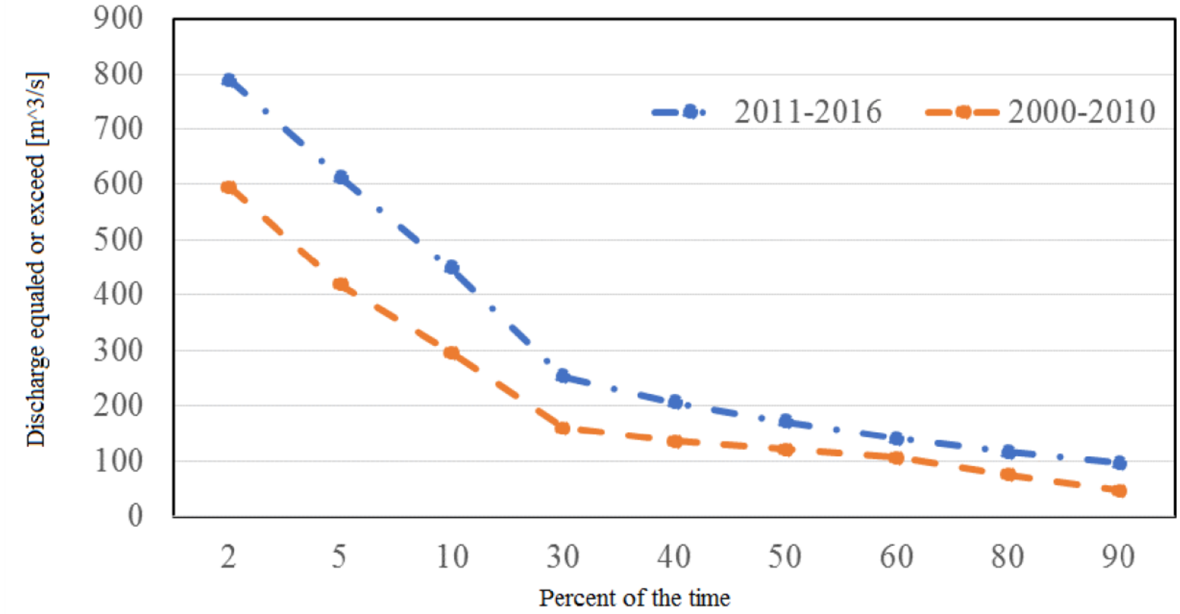

Fig. 5. Flow characteristics of the Garissa gauging station, including the discharge equaled or surpassed and the proportion of time (%) for the periods 2000-2010 and 2011-2016 (Langat et al., 2019).

Aziz et al. (2020) analyzed the structural characteristics of the Diyala River and the parameters of its basin using geographic information systems (GIS) and image processing. The study was able to define watersheds and examine their physical characteristics using GIS hydrology methods and DEM information collected by the Shuttle Radar Topography Mission (SRTM). As part of this study focused on geometry, the morphometric aspects of the sub-basins were also analyzed, such as their area, perimeter, frequency of streams, maximum breadth and length, drainage density, and stream orders. Five distinct sub-basins were identified, each with its stream order and drainage density ranging from 0.47 to 0.99 km/km^2**,** as shown in Fig. 6.

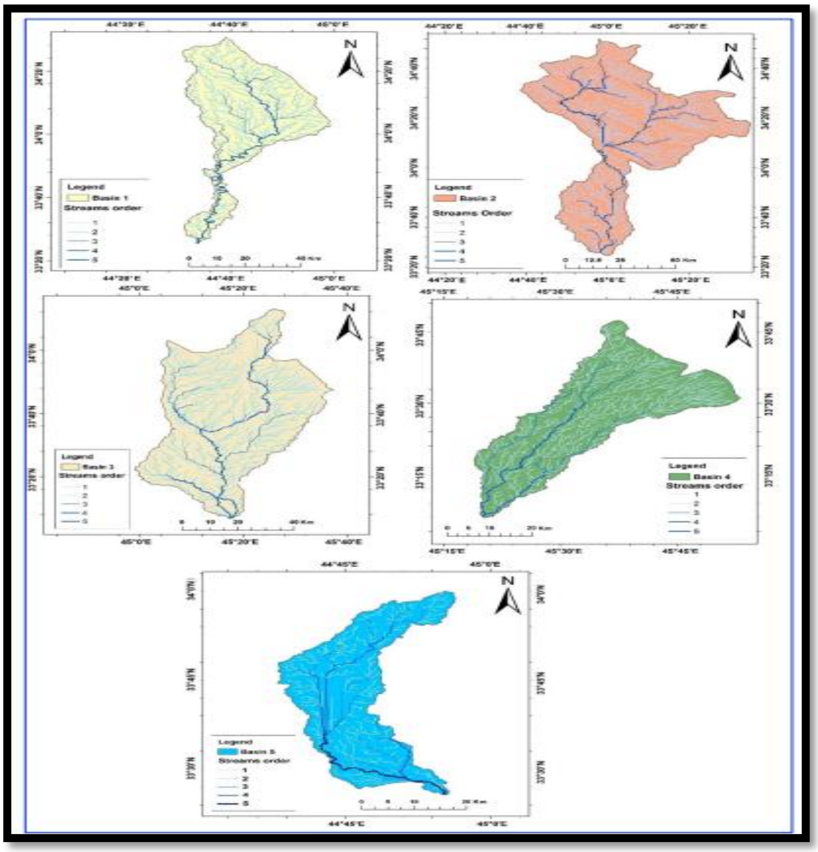

Fig. 6. Stream order of the sub-basins 1, 2, 3, 4, and 5 (Aziz et al., 2020).

Li et al. (2021) studied a comprehensive analysis of the physical structure and form of the Yongding River across its 92 km stretch in Beijing, China, during four separate periods spanning from 1964 to 2018. The changes in the river channel's structure were rebuilt at both the macro and micro levels using data analysis by Geographic Information System (GIS). The results indicated a substantial alteration in the morphology of the river. The channel's diameter had decreased by 31%, and there were discernible changes in the temporal and spatial patterns (Fig. 7). By evaluating the impact of human actions on climate change over various historical periods, it was determined that human involvement is the primary governing force.

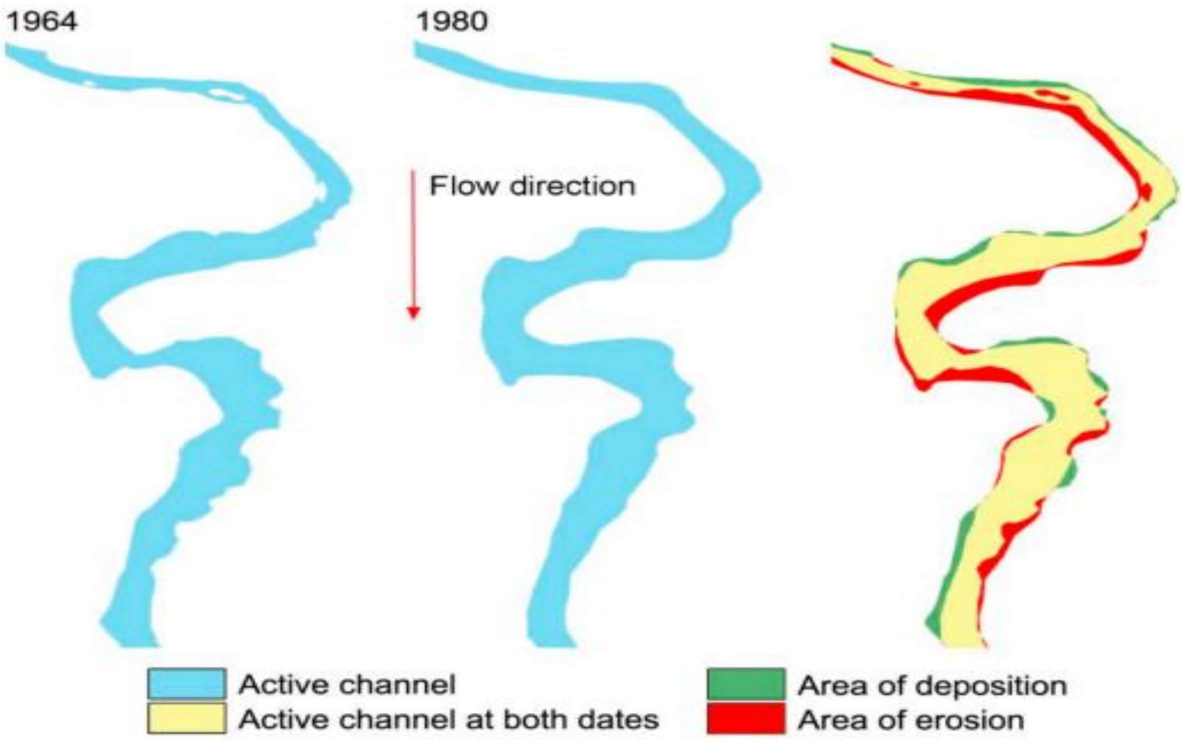

Fig. 7. Erosion/deposition area determined by superimposing two channel positions (Li et al., 2021).

Ibitoye (2021) analyzed the morphological features of the Niger River by utilizing Landsat images captured in 1990, 2002, and 2017. Between 1990 and 2017, the data showed a 27.64% reduction in water bodies and a 9.77% drop in riparian vegetation. Nevertheless, there was a significant 75.61% increase in sediment yield. The river channel exhibited substantial spatial variations, with the central axis migrating 1347.3 meters eastward in the upper segment and westward in the lower section. The study determined that the channel had seen significant structural alterations, primarily due to erosion and accretion processes, which were well documented using remote sensing imagery (Fig. 8).

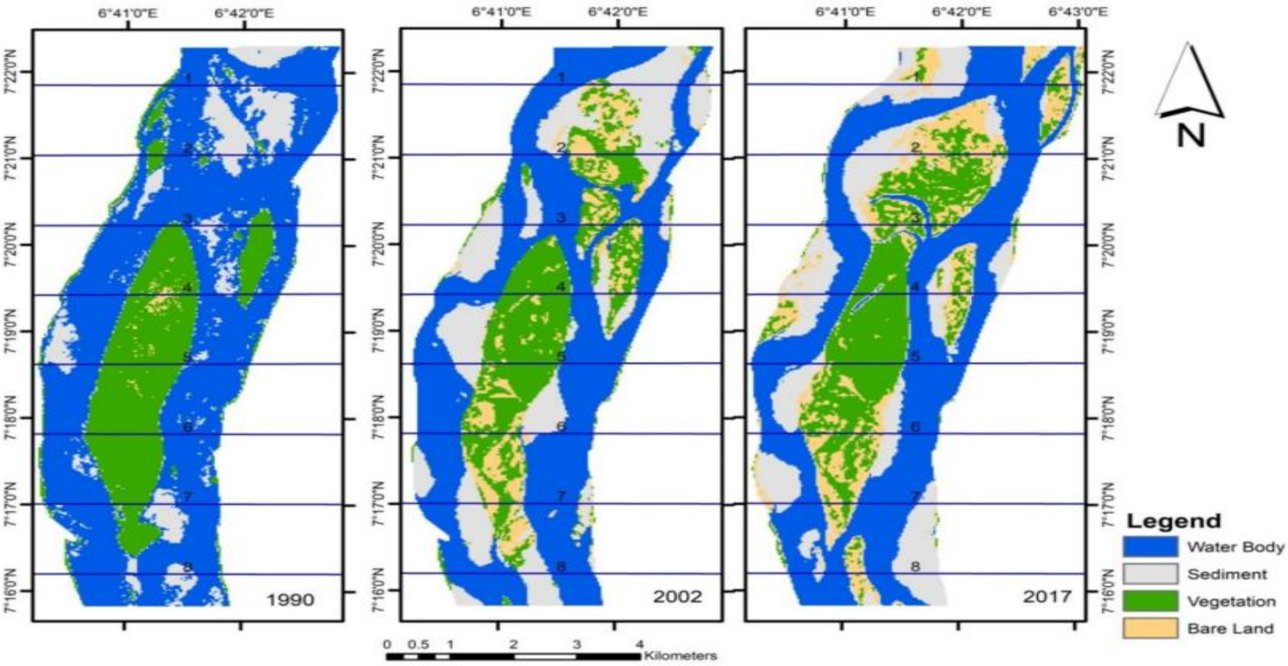

Fig. 8. Land cover classification over the study period (Ibitoye, 2021).

Zhang et al. (2022) investigated the reported variations in water levels and modifications in the principal river channel that links Wuzhou and Zhaoqing, China, over the past few decades. Throughout a continuous 27-year period from 1987 to 2013, the quantities of suspended sediment ejected consistently surpassed the quantities imported. The observed phenomena could be attributed to a significant decrease in the concentration of suspended silt particles. Consequently, a notable occurrence of riverbed erosion took place, transforming the riverbed into a primarily silt-based reservoir. Between 2004 and 2014, a noticeable decrease in the average elevation of the riverbed was noticed, amounting to a magnitude of 2.21 meters.

Hossain et al. (2023) examined the possibility of morphological alterations in land use, erosion-sedimentation patterns, coastal dynamics, and sediment accumulation on Sonadia Island in Southeast Bangladesh. To assess the phenomenon of unusually high sediment accumulation, the researchers employed various methodologies, including the analysis of toposheets, historical maps, multiple satellite pictures, and on-site fieldwork observations. The findings of the inquiry indicated that the coastline of the island experienced frequent and rapid alterations. In 1779, the island had an area coverage of 1.65 km², which subsequently expanded by a factor of 21 to reach 36 km² in 2021. The study conducted between 1972 and 2021 examined the alterations in land use and land cover on Sonadia Island as seen in Figs. 9 and 10.

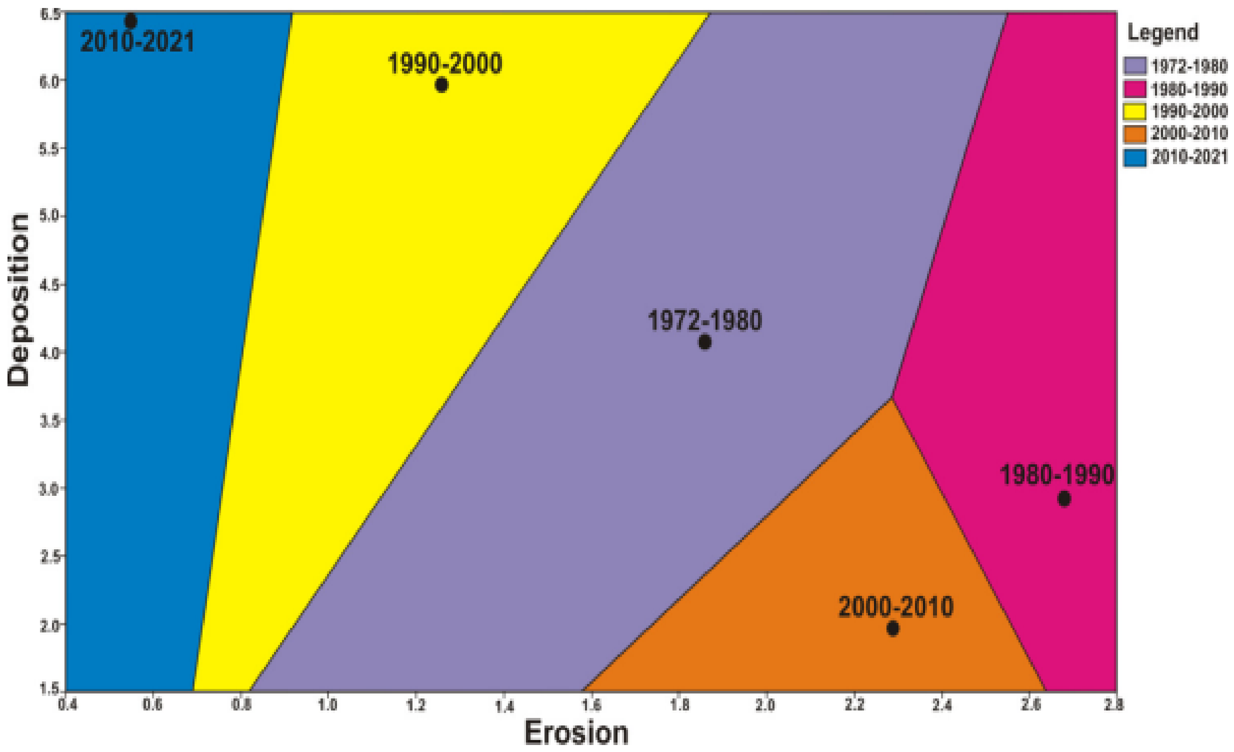

Fig. 9. Analyzed erosion and sedimentation trends of Sonadia Island from 1972 to 2021 by employing a Voronoi diagram (Hossain et al., 2023).

Vu et al. (2024) investigated the significant morphological changes in the Vietnamese Mekong Delta and their impacts on local economic and social conditions. Utilizing satellite data from 1988 to 2020 and population density and (LU/LC) maps from 2002, 2008, and 2015, the study provided a comprehensive analysis of these changes. The islets in the delta showed a trend of accretion, with an increase in area by 13.3 km^2. This accretion led to a narrowing of the river width over the years.

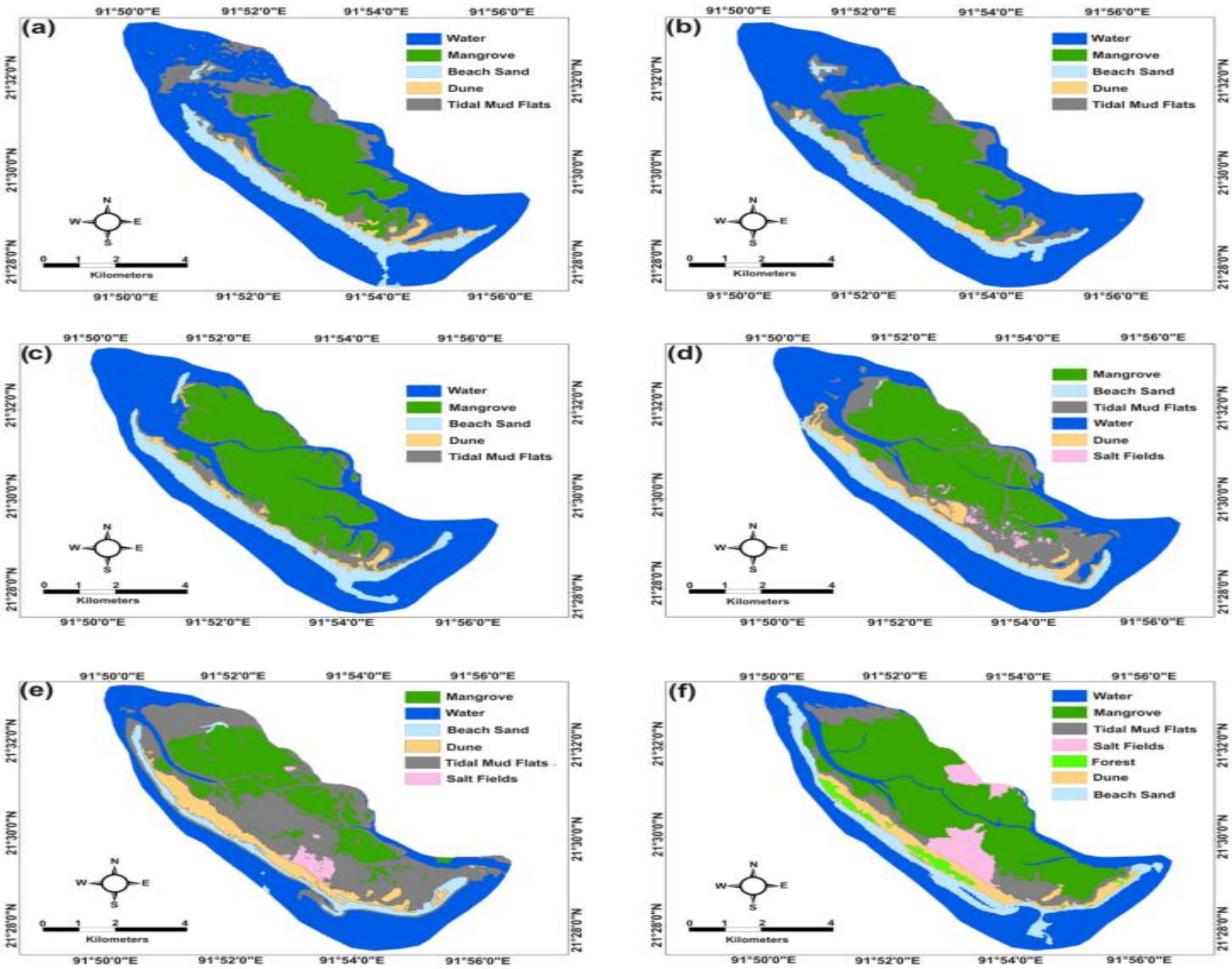

Fig.10. Morphological change maps of Sonadia Island's study area (a) 1972, (b) 1980, (c) 1990, (d) 2000, (e) 2010, and (f) 2021(Hossain et al., 2023).

River Meandering

Meandering rivers are highly dynamic sedimentary processes on Earth. River bends, particularly those with high sediment discharge, can move several meters annually (Constantine et al., 2014). Predicting how meanders develop over time has significant engineering and geological ramifications, such as managing agricultural land, reducing infrastructure loss, designing bridges, and distributing heterogeneities in porous sediments and rocks. The meandering process is characterized by erosion occurring on the outer bank and deposition occurring on the inner bank. An uneven distribution of flow velocity and shear stress in curved segments of the channel produces this (Sylvester et al., 2019).

Riverbank Erosion

Riverbank erosion has a significant detrimental influence on the river's ecosystem and floodplain. Riverbank erosion is an important issue with long-term effects on human life and the river ecosystem. Riparian land loss, capital expenditure damage, sediment generation and deposition downstream are among the most significant repercussions (Das et al., 2014).

The river bank side slope affects the erosion process, where a steep slope is taken as a trigger of erosion, the steep slope will increase the number and speed of runoff, causing erosion to accelerate owing to more carried and dissolved materials (Kumsa and Assen, 2022). There are many effective erosion control solutions to keep soil from washing away on a side slope;

these include riprap, baffles, barriers, terraces, plants, and erosion control wattles. The soil type can be considered to specify the maximum slope to prevent soil erosion (Ali et al., 2012).

Sediment Transport

Sediment serves as the fundamental component for fluvial processes. Sediment transport initiates the process of soil erosion. Hence, the implementation of erosion control measures is crucial for the stabilization of river networks. The sediment load of rivers originates from the hilly region due to slope erosion, rill erosion, gully erosion, and erosion of the channel bed and banks.

Sand-bed rivers convey a comparatively substantial quantity of sediment as suspended load. On the contrary, gravel-bed rivers typically exhibit the opposite trend, with bed-load accounting for 10 to 50 percent of the total burden (Peckham, 2003).

Rive Banks Riprap

Riprap is a commonly used method for protecting riverbanks (Fig. 12). Various techniques exist for designing riprap effectively, but they typically involve using medium-sized chunks dropped into place. However, enhanced protection against erosion may be attained by strategically positioning individual stones in one or more layers instead of haphazardly depositing them (Jafarnejad et al., 2019).

Fig. 12. Riprap with blocks of 4 to 4.5 t individually laid by a machine atop a geotextile functioning as a filter (Jafarnejad et al., 2019).

Impacts of climate and land use/land cover change on river hydromorphology

Fig. 13 shows the interrelationships between the various components. Land cover changes impact the atmosphere's energy balance, influencing rainfall and temperature patterns. Similarly, weather patterns impact LULC, which affects both watershed hydrology and river morphology through an exact feedback mechanism. Climate change and hydrology unidirectionally impact river morphology. To achieve effective and sustainable land and water resource management, it is crucial to comprehend the hydro-morphological reactions of watersheds to climate and land use/land cover change (LULC), especially in tropical nations that experience alternating wet and dry seasons. While there has been substantial research on the impact of LULC and CC on basin hydrology, less attention has been given to morphological and hydrological feedback in tropical settings (Watershed, 2020).

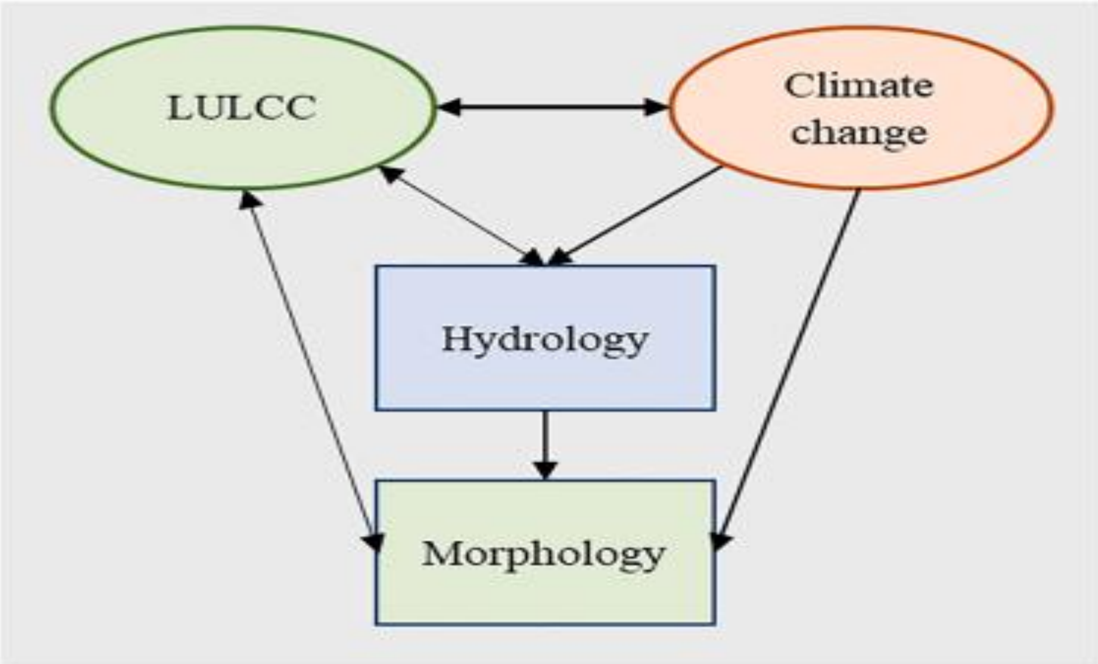

Fig. 13. LULC, CC, hydrology, and morphological interactions. Arrows indicate the direction of causality (Watershed, 2020).

Results and discussion

The results of this study, through the analysis of previous studies, have shown that the use of modern remote sensing technology and geographic information systems has made it possible to accurately determine the morphological changes in water bodies such as rivers and lakes over specific periods. It is also found that Landsat data have been widely used in the study and analysis of water bodies, and the best tool was the remote sensing technique, especially when analyzing long-term time series with high spatial resolution, because the Landsat satellite provides the longest continuous time series of any environmental satellite program, making it an effective and primary tool in studies spanning long periods. Consequently, all newer remote sensing technology has yet to reach the same level of usage as the Landsat satellite.

The results show that this technology represents a revolution in monitoring and analyzing the morphological changes of water bodies, as it has been able to provide accurate, detailed, and rapid data compared to traditional methods. Using satellite images and analyzing them with geographic information systems allows for the assessment and monitoring of changes in river courses and lake boundaries, as well as identifying areas of erosion and deposition over long and consistent time periods.

The utilization of these technologies yields precise, rapid, and dependable outcomes. This technology can cover large areas and capture important data such as land elevations, water flow patterns, and sediment distribution. Additionally, it aids in the prompt identification of morphological issues, facilitating swift intervention. Therefore, this technology greatly enhanced water resource planning and management, thereby improving the efficiency of decision-makers and individuals involved in the management of rivers and lakes.

Conclusion

The following points can be concluded from the current review:

1. The effectiveness of the remote sensing (RS) technique and geographic information system (GIS) in assessing and monitoring morphological changes in aquatic environments such as lakes and rivers.
2. These capabilities contribute to providing accurate and comprehensive data that have aided in the development of sustainable water resource management.
3. It is essential to monitor the morphological changes in rivers and lakes to reduce the occurrence of floods.
4. The use of remote sensing technologies, such as Landsat-8 satellite images and Google Earth Pro, in monitoring the morphological changes of water areas, detecting violations along the banks of rivers and lakes.
5. More data must be obtained from GIS and RS for buildings with a unified database among the concerned departments for updating it continuously, accurately, and systematically due to the social, economic, and urban changes. Developing appropriate solutions to problems before they occur accurately and thoughtfully.

Effective water resource management requires the use of modern remote sensing technologies and advanced data analysis tools. By expanding the use of these technologies, developing integrated analytical tools, and enhancing training programs, the ability to monitor and analyze morphological changes in rivers and lakes will be improved, leading to more sustainable water resource management.

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References

Ali, A.A., Al-Ansari, N.A., and Knutsson, S., 2012. Morphology of Tigris River within Baghdad City. Hydrology and Earth System Sciences, 16(10), pp. 3783–3790. https://doi.org/10.5194/hess-16-3783-2012

Aziz, N.A., Abdulrazzaq, Z.T., and Mansur, M.N., 2020. GIS-based watershed morphometric analysis using DEM data in Diyala River, Iraq. Iraqi Geological Journal, 53(1), pp. 36–49. https://doi.org/10.46717/igj.53.1c.3rx-2020.04.03.

Constantine, J.A., Dunne, T., Ahmed, J., Legleiter, C., and Lazarus, E.D., 2014. Sediment supply as a driver of river meandering and floodplain evolution in the Amazon Basin. Nature Geoscience, 7(12), pp. 899–903. https://doi.org/10.1038/NGEO2282

Das, T.K., Haldar, S.K., Gupta, I.D., and Sen, S., 2014. Riverbank erosion induced human displacement and its consequences. Living Reviews in Landscape Research, 8(1), pp. 1–35. https://doi.org/10.12942/lrlr-2014-3

Donovan, M., Belmont, P., Notebaert, B., Coombs, T., Larson, P., and Souffront, M., 2019. Accounting for uncertainty in remotely-sensed measurements of river planform change. Earth-Science Reviews, 193 (December 2018), pp. 220–236. https://doi.org/10.1016/j.earscirev.2019.04.009

Farooq, M., and Siddique, K.H.M., 2015. Conservation agriculture. Conservation Agriculture, 1(1), 665. https://doi.org/10.1007/978-3-319-11620-4

Fashae, O.A., and Faniran, A., 2015. Downstream Morphologic Characteristics of the Alluvial Section of Lower River Ogun, Nigeria. Journal of Environmental Geography, 8(1–2), pp. 1–10. https://doi.org/10.1515/jengeo-2015-0001

Forestier, G., Puissant, A., Wemmert, C., and Gançarski, P., 2012. Knowledge-based region labeling for remote sensing image interpretation. Computers, Environment and Urban Systems, 36(5), pp. 470–480. https://doi.org/http://dx.doi.org/10.1016/j.compenvurbsys.2012.01.003.

Ghoshal, S., James, L.A., Singer, M.B., and Aalto, R., 2010. Channel and floodplain change analysis over a 100-year period: Lower Yuba River, California. Remote Sensing, 2(7), pp. 1797–1825. https://doi.org/10.3390/rs2071797

Li, H., Xu, X., Wu, M. and Liu, Z., 2021. Spatiotemporal evolution trajectory of channel morphology and controlling factors of Yongding River, Beijing, China. Water, 13(11), p.1489. https://doi.org/https://doi.org/10.3390/w13111489 Academic

Hossain, M.S., Yasir, M., Shahriar, M.S., Jahan, M., Liu, S., and Niang, A.J., 2023. Morphological change assessment of a coastal island in SE Bangladesh reveal high accumulation rates. Regional Studies in Marine Science, 62, 102969. https://doi.org/10.1016/j.rsma.2023.102969

Ibitoye, M.O., 2021. A remote sensing-based evaluation of channel morphological characteristics of part of lower River Niger, Nigeria. SN Applied Sciences, 3(3), pp. 1–12. https://doi.org/10.1007/s42452-021-04215-1

Jafarnejad, M., Franca, M.J., Pfister, M., and Schleiss, A.J., 2019. Design of Riverbank Riprap Using Large, Individually Placed Blocks. Journal of Hydraulic Engineering, 145(12), pp. 1–12. https://doi.org/10.1061/(asce)hy.1943-7900.0001641

Kim, H., Yeh, P.J.F., Oki, T., and Kanae, S., 2009. Role of rivers in the seasonal variations of terrestrial water storage over global basins. Geophysical Research Letters, 36(17), pp. 2–6. https://doi.org/10.1029/2009GL039006

Kumsa, A., and Assen, M., 2022. GIS and Remote Sensing Based Land Degradation Assessment and Mapping: Case Study Adea Woreda. Journal of Electrical Electronics Engineering, 1(1), pp. 21–30. https://doi.org/10.33140/jeee.01.01.01

Langat, P.K., Kumar, L., Koech, R., and Ghosh, M.K., 2019. Hydro-morphological characteristics using flow duration curve, Historical data and remote sensing: Effects of land use and climate. Water (Switzerland), 11(2), pp. 1–18. https://doi.org/10.3390/w11020309

Peckham, S.D., 2003. Fluvial landscape models and catchment-scale sediment transport, Global and Planetary Change, 39(1-2), pp. 31–51. https://doi.org/10.1016/S0921-8181(03)00014-6

Rinaldi, M., Gurnell, A.M., Del Tánago, M.G., Bussettini, M., and Hendriks, D., 2016. Classification of river morphology and hydrology to support management and restoration. Aquatic Sciences, 78, pp. 17–33. https://doi.org/10.1007/s00027-015-0438-z

Southard, J., 1984. The environment of medicine. Ohio State Medical Journal, 80(4), pp. 258–261, 302. https://doi.org/10.5014/ajot.44.7.668c

Sylvester, Z., Durkin, P., Covault, J.A., and Sharman, G.R., 2019. High curvatures drive river meandering. Geology, 47(10), pp. e486–e486. https://doi.org/10.1130/G46838Y.1

Vu, T.H., Binh, D. Van, Tran, H.N., Khan, M.A., Bui, D.Du, and Stamm, J., 2024. Quantifying Spatio-Temporal River Morphological Change and Its Consequences in the Vietnamese Mekong River Delta Using Remote Sensing and Geographical Information System Techniques. Remote Sensing, 16(4). https://doi.org/10.3390/rs16040707

Watershed, G., 2020. Impacts of Climate and Land Use Change on Hydrological. In Ecohydrology and Hydrobiology. https://doi.org/10.1016/j.ecohyd.2020.12.001

Weiss, M., Jacob, F., and Duveiller, G., 2020. Remote sensing for agricultural applications: A meta-review. Remote Sensing of Environment, 236, 111402. https://doi.org/https://doi.org/10.1016/j.rse.2019.111402

Zhang, M., Feng, X., Yan, T., and Wang, X., 2022. Human impacts on riverbed morphology and hydrology in the lower reaches of the West River, China. River Research and Applications, 38(5), pp. 952–964. https://doi.org/10.1002/rra.3960