



Geospatial Technology for River Water Quality and Morphological Assessment: A Review of Recent Advances

Janwale Asaram Pandurang¹, Mayur Deshmukh²

^{1,2} Department of Computer Science, Faculty of Science and Technology, Vishwakarma University, Pune – 411048, Maharashtra, India
janwale26@gmail.com

Abstract. Urban rivers in India are showing sign of deterioration – murky water, collapsing banks, and increasing in pollution that far exceeds natural recovery rates. Industrial waste, populated cities' sewage, and agriculture runoffs enter rivers faster than they can recover. Field based monitoring is reliable but cannot be used for whole river basin, it is expensive, slow and fixed to specific points. Geographic Information System (GIS) systems like GIS, remote sensing and machine learning are used worldwide, but still their applications to peri urban rivers in Maharashtra remain unexplored. This review examines fifteen peer-reviewed papers published between 2022 – 2026, from Scopus and WOS indexed journals; to evaluate how GIS based models are used to assess river water quality and morphological analysis.

Four themes are found: GIS integrated Water Quality Index mapping, machine learning models, geospatial flood risk and basin change monitoring and GIS research on Indian rivers specifically.

WQI- GIS mapping integrated with Principal Component Analysis and Cluster Analysis mostly used approach for finding pollution hotspots across river basin. Machine learning models like Random Forest, XGBoost and LSTM – perform better combined with GIS variables are included. These models show accuracy from 0.91 – 0.93 in recent studies. GIS – AHP mostly used in flood mapping, though Random Forest based model generally gives higher accuracy.

The important gap is found that there is very little work done on Peri urban rivers in Maharashtra and especially rivers from Pune district, despite its significant impact on environment.

Keywords: GIS, Water Quality Assessment, machine learning, river Morphology, flood risk, Indian river.

1 Introduction

A causal observation of river in rapidly growing Indian cities shows a visible sign of environmental deterioration – murky water, floating solid waste, eroding and unstable banks and urban infrastructure development onto the riverbank. This deterioration extends well beyond visual concerns. Large sections of the urban population depend on this river system for drinking water, irrigation and daily livelihoods and the degradation is increasing. Industrial waste, Urban sewage and rainwater carrying fertilizers and

pesticides – all these are entering in river system at a rate that exceeds natural recovery capacity.

GIS fundamentally changes its methods to study and monitor rivers. Instead of working on points, GIS allows researchers to analyze river as a connected spatial system. Satellite images capture entire river basin, while spatial interpolation tools are used for measuring water quality at points and produce extended maps across the river basin. Hydrological models combined with GIS are used to simulate river behavior under different situations. Principal Component Analysis (PCA) and cluster analysis can identify patterns that would remain undetectable to conventional data table [1][2].

For basin level evaluation statistical tools like WQI, PCA and Cluster Analysis are now mostly used combined [4]. Indian rivers like the Ganga and Yamuna have started to use this type of analysis and given useful findings. However, the use of these methods across India is very uneven and limited, very little work is done particularly in urban and peri urban areas in Maharashtra [6] [11].

This paper reviews fifteen papers published between 2022 and March 2026, all sourced from Scopus and Web of Science ranked from Q1 to Q4. The review is focused on four research questions.

1. How effectively does GIS – WQI mapping work for spatial water quality assessment?
2. What additional analytical value does machine learning algorithms bring when combined with GIS tools?
3. How will GIS be used to study river basin changes and flood mappings?
4. What gaps remains in GIS based research specifically focuses on Indian River?

Addressing these four questions provides a structured basis for identifying current knowledge and gaps in these areas.

2 Literature review

The search keywords used here are ‘GIS water quality’, GIS river morphology’, ‘machine learning water quality spatial’, ‘Indian river GIS’, and ‘GIS flood risk’. Selected only those papers, indexed in Scopus or Web of Science (Q1 – Q4) journals, and use GIS as a core part of the methodology. Fifteen papers are selected across four topic areas. Table 1 gives a summary of all fifteen studies, by using selection process as shown in fig. 1.

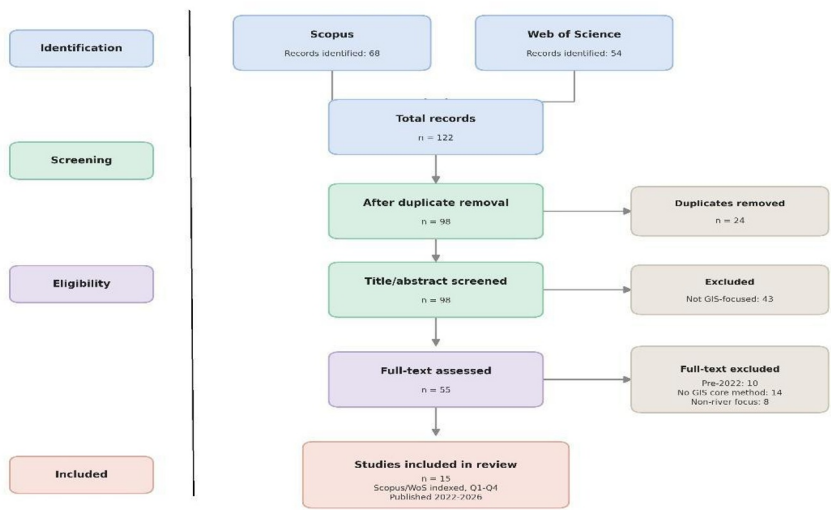


Fig. 1. PRISMA Flow showing study selection process

Table 1. Summary of Selected Studies

No.	Authors / Year	Title / Journal	Methods Used	Main Result	Theme
1	Chatrabhuj et al., 2024	RS-GIS in river management Discover Geoscience	ArcGIS, QGIS, GEE; multi-date satellite images	Real-time river monitoring improved when RS and GIS were combined; findings from over 50 case studies	RS-GIS
2	Patel et al., 2026	RS and GIS for watershed hydrology Journal of Hydrology	GIS with hydrological models	Runoff estimates improved by 15–30% with GIS-RS; biggest gains where field data is lacking	Watershed Hydrology
3	Patra et al., 2025	ML and GIS for Mahanadi River WQ Discover Sustainability	QGIS, GEE; RF, SVM, LSTM	Random Forest predicted WQ at over 90% accuracy.	GIS-ML India
4	Chidiac et al., 2023	Review of WQI models Rev. Env. Sci. Bio/Tech	Review of 30+ WQI models	No single WQI fits all river types; need for a common scoring standard	WQI Review
5	Hasanuzzaman et al., 2024	Spatiotemporal WQ using GIS Earth Science Informatics	ArcGIS, IDW; Entropy-WQI, PCA	Monsoon pollution 3× higher than dry season; PCA explained 78% of WQ variation	GIS-WQI
6	Singh & Tung, 2025	Gomti River WQ, Lucknow Air Soil Water Research	GIS spatial maps; weighted WQI	7 of 10 stations were Very Poor; BOD was 4–6× above CPCB limit	River WQ India

No.	Authors / Year	Title / Journal	Methods Used	Main Result	Theme
7	Das et al., 2022	Ganga WQ during COVID-19 J. Earth System Science	ENVI, ArcGIS; Sentinel-2, Landsat-8	COVID lockdown reduced turbidity 28%, TSS 31%; satellite caught changes quickly	RS-WQ Ganga
8	Zhi et al., 2024	Deep learning for water quality Nature Water	TensorFlow, PyTorch; LSTM, CNN	Deep learning beat standard ML by 15–40%; LSTM DO error below 0.3 mg/L	Deep Learning WQ
9	Rahat et al., 2023	ML for river WQ modelling Sci. Total Environment	GEE; XGBoost, RF, ANN	XGBoost reached $R^2=0.91$ for turbidity; ensemble models cut error by 30%	RS-ML WQ
10	Leggesse et al., 2025	ML and RS for WQ monitoring Sustainability	GEE, Python; RF, CNN, LSTM	Hybrid ML+RS averaged $R^2=0.88$ vs 0.74 for ML alone; cloud cover is a barrier	ML-RS Review
11	Wani & Husain, 2025	Groundwater quality, Maharashtra Appl. Water Science	ArcGIS, Piper diagram; PCA, HCA	WQI scores ranged 52–175; fluoride over WHO limit in 30% of samples	GIS-WQI Maharashtra
12	Sibandze et al., 2025	Global flood risk mapping trends Environmental Management	ArcGIS, QGIS; bibliometric methods	MCDA-GIS used in 42% of studies; flood GIS research grew 300% post-2015	Flood Review
13	Hagos et al., 2022	Flood hazard, Awash Basin Ethiopia Appl. Water Science	ArcGIS; AHP and weighted overlay	18% of basins are high flood risk; 87% match with historical flood records	Flood Mapping
14	Abbass et al., 2023	River shape change, Iraq Civil Engineering Journal	ArcGIS, HEC-RAS; change detection	35% channel narrowing over 30 yr; GIS-HEC-RAS cut flood depth error by 20%	River Morphology
15	Saikh & Mondal, 2023	Flood risk, Pagla River India Nat. Hazards Research	ArcGIS; Random Forest, SVM	RF scored AUC=0.93; outperformed AHP alone	Flood ML India

3 **GIS- Based Spatial Water Quality Assessment**

3.1 **What WQI Does and Why GIS makes it much more useful**

The Water Quality Index takes a set of water measurements — pH, dissolved oxygen, BOD, turbidity, TDS, nitrate, phosphate — and turns them into one number. That single number tells you, in broad terms, whether the water is safe or not. It is much easier to communicate with politicians, journalists, or members of the public than a table showing fifteen different chemical parameters with different units and different safe limits [4].

The problem with WQI on its own is that you still only know what the water is like at your sampling points. An important role of GIS in water quality is its ability to apply spatial interpolation techniques such as Inverse Distance Weighting (IDW) and ordinary kriging to fill the gaps between discrete sampling location. This process

generates a continuous WQI map of entire river basin, clearly identifying zones where water quality sharply deteriorates. Such spatial patterns mostly correspond to the location of drain outfalls or industrial discharge points that require priority attention of authority.

A study conducted by Bangladesh using entropy- weighted WQI combined with GIS found that pollution during monsoon season increased than dry seasons. PCA is used to explain three factors, linked with organic loading, salt content and turbidity, which together accounted for 78 percent of the total variation in water quality across the study area [5]. A separate study on Gomti river in Lucknow applied GIS – WQI mapping across the urban rivers and found that seven out of ten stations fell into very poor category. BOD at this at these stations found at four to six times higher than CPCB safe limit, and maps made it easy to find the worse stations in populated urban zones [6].

The study conducted on the Ganga River during COVID – 19 lockdown period shows how quickly satellite – linked GIS can detect measurable changes in river water quality. When industrial activity across India came to near- complete halt during nationwide lockdown in March 2020, turbidity levels on Ganga declined by 28% and total suspended solids dropped by 31% compared to period of previous year. These changes were detected using Sentinel – 2 and Landsat – 8 imageries processed using GIS, and the results become spatially visible within just few weeks of lockdown [8].

A separate study conducted in Maharashtra examined groundwater quality across a semi-arid area using GIS and WQI. Computed WQI ranges from 52 to 175 depending on the seasons and fluoride was above the WHO safe level in 30% of all samples. PCA and Hierarchical cluster analysis were applied to classify sampling locations into four distinct hydrochemical groups, each associated with specific geological formations or land use [11].

3.2 Linking GIS to Bigger Water Quality Models

GIS serves as critical data preparation and integration platforms for processes-based simulation models like QUAL2K and SWAT. These models require spatial inputs which cannot be obtained through conventional field methods alone, including digital elevation models, land cover grids, soil property maps, and drainage network layers. A comprehensive review covering more than 200 watersheds, studies confirmed that integrating GIS with remote sensing data runs off estimation accuracy by 15 to 30 % on average. The most improvements were recorded in regions where ground based hydrological monitoring networks are sparse, which is a condition that characterizes many river basins across India [2].

4 GIS-Integrated Machine Learning for Water Quality Prediction

4.1 Why basin Geography Matters for Predictions

Water quality at any location along river does not develop in isolation. It shows the effect of anything happened in upstream basin – how much land paved over, where industries are discharging waste, how steep the land is, how well-connected drainage network is. Any predictive model that ignores the upstream spatial context will produce

incomplete and inaccurate results. GIS address these gaps by allowing researchers to systematically extract basin level variables and feed them directly to machine learning models. This gives models a working understanding of why quality is poor at a given location, not just finding values at those points.

A study from Mahananda river from Orisa used an LSTM model paired with Synthetic Pollution Index and GIS generated spatial maps across nineteen points for periods of two years. GIS models helped them to recognize basin wide spatial pollution patterns rather than simply fitting trends at individual points [3]. In United States, an XGBoost model trained remotely sensed imagery and GIS basin attributes reached $R^2 = 0.91$ for turbidity across multiple rivers. Combining multiple models together instead of using just one, reduced prediction error by thirty percent and Sentinel – 3 and 4 emerged as most useful channels for estimating water quality from satellite data [9]. A review of over 120 studies on machine learning and remote sensing for water quality concluded that hybrid CNN-LSTM model outperformed other approaches up to $R^2=0.93$. Adding hyperspectral data to deep learning results increased by 40 percent over standard multispectral inputs [10].

4.2 Spotting Long-Term Trends

One of the most powerful things you can do with GIS and machine learning together is to trace how water quality has changed over time and try to link those changes to specific land-use shifts. If GIS maps show that the urban area's catchment doubled between 2005 and 2020, and water quality records from the same period show a corresponding rise in BOD and turbidity, that is a connection worth documenting — and it is the kind of analysis that cannot be done without GIS.

LSTM networks, when given long enough time series to train on, can predict dissolved oxygen with errors below 0.3 mg/L [8]. Hybrid ML-RS models consistently outperform standalone machine learning, with published R^2 averages of 0.88 versus 0.74. The main barriers are cloud cover — which can render satellite data useless for weeks during the Indian monsoon — and a shortage of labelled training data [10].

4.3 Where These Methods Struggle

The accuracy of GIS based WQI maps is directly dependent on the number of water quality monitoring stations available and the distance between them. River monitoring networks managed in India by Central Pollution Control Board, are not dense as per the international standards. As stations are far apart, the interpolated maps carry higher risk of failing to detect pollution near to discharge points or drain outfalls. IDW operates on the assumptions that water quality conditions change gradually with increasing distance from these points. In practice, this assumption really holds in urban areas, where heavily polluted rivers can cause deuteriation in water quality in short distance- spatial patterns are unable to find these patterns

Neighboring monitoring stations tend to have similar water quality values just because they are close to each other, not because of any causal relationship. If training and test data come from nearby stations, a model may look more accurate than it really is. Proper spatial cross-validation — testing on stations that are geographically distant from the training data — avoids this problem but is rarely done. Monthly or quarterly land use maps miss the short-term events that matter most for water quality, particularly

the first flush of the monsoon. And any error in the underlying GIS layers — a misclassified land cover patch, a missing drain — feeds directly into the predictions.

5 GIS-Based River Morphological Analysis and Flood Mapping

5.1 How Rivers Change Shape, and How GIS Tracks It

A river is a dynamic and continuously changing system rather than a fixed physical structure. Riverbank erosion occurs continuously on the outer edge of channel bends while sediment deposition builds up on the inner sides. Flood events distribute large volumes of the material across the basin and floodplain. Human activities such as sand extraction, bank stabilization work, and dam construction in upstream reaches — introduces changes in natural geomorphic processes. Over a period or decades, these changes become large enough to manage flood risk and infrastructure planning, but short-term monitoring fails to identify these changes.

GIS addresses this problem by overlaying satellite imagery or arial photographs acquired over the period and measuring how the channel boundary has shifted between dates. A study done on rivers in Iraq using ArcGIS combined with HEC-RAS flood modeling found that river channel had narrowed by 35 percent over the period of 30 years, and lateral bank erosion had found that loss of 12 km² of land [14]. GIS tool Digital Shoreline Analysis System (DSAS) is commonly used to calculate the overall movement and rate of change for riverbanks between any two dates and even can handle lot of cross sections at a time.

5.2 Mapping Flood Risk with GIS

GIS flood risk mapping works by combining several factors that determine how likely a piece of land is to flood — elevation, slope, distance from the river, soil drainage, land cover, and rainfall. The Analytical Hierarchy Process (AHP) is the most common method for weighting these factors and combining them into a single risk score. A review of over 850 published flood risk studies found that MCDA-GIS — which includes AHP — is used in 42% of them. The volume of flood GIS research tripled after 2015. Notably, Africa and Asia together account for less than a quarter of global publications, despite being the regions most exposed to flood risk [12].

A flood hazard study of the Awash River Basin in Ethiopia used GIS-AHP and found that 18% of the basin area — about 2,340 km² — falls in the high or very high-risk category. Cross-checking against ten historical flood events gave 87% agreement. Slope and drainage density were identified as the two most important risk factors [13]. A study of the Pagla River in eastern India took a different approach and used Random Forest within a GIS framework instead of AHP. The accuracy was AUC=0.93, which was clearly better than the AHP-only result. The lowest-lying land next to the main channel was the highest-risk zone [15]. Both methods have been tested and validated in comparable environments, which means both could be applied to the Mula-Mutha relatively straightforwardly.

6 Geospatial Studies of Indian Rivers

6.1 What Has Been Done in India

There has been a real increase in GIS-based river monitoring research in India since around 2018. Better satellite coverage — especially free data from Sentinel-2 and Landsat — and the growing availability of free GIS software like QGIS, have made this kind of work more accessible for university research groups. Ganga gets the most attention, partly because it is nationally important and partly because the CPCB monitoring program provides a ready-made dataset to work with. The COVID-19 lockdown also generated some genuinely interesting natural-experiment data: when industrial and transport activity stopped almost overnight in 2020 [7].

A GIS based study on River Gomti in Lucknow showed that spatial interpolation across ten monitoring points was sufficient to define three distinct water quality zones along with urban river basin- an upstream zone, an intermediate transition zone and a heavily polluted urban zone. These spatial patterns would not have been identified from raw monitoring data presented in tabular form [6]. A separate study from Maharashtra applied GIS – WQI method to semi – arid groundwater system and successfully characterized spatial variation in water chemistry across large geographic area, identifying specific hotspots for specific contaminants like fluoride [11].

What is missing is any surface water study using these methods for the urban rivers of Maharashtra. The floodplain has been progressively encroached upon by construction over the past thirty years. A search of Scopus and Web of Science finds no GIS-based water quality or morphological study for this river. This is genuinely surprising given its size, its pollution load, and its public health significance.

6.2 Why This Gap Matters

The absence of a GIS-based study on the rivers from Maharashtra is not just an academic gap. It means that the people responsible for managing the river — the Maharashtra Pollution Control Board, and other agencies — are working without the spatial information that GIS analysis would provide. They do not have a continuous map of where along the river water quality is worst. They do not have a quantified record of how the channel has changed over time. They do not have a validated flood susceptibility map that reflects current land use. All these things are achievable with existing tools and data.

7 **Summary of Findings and Research Gaps**

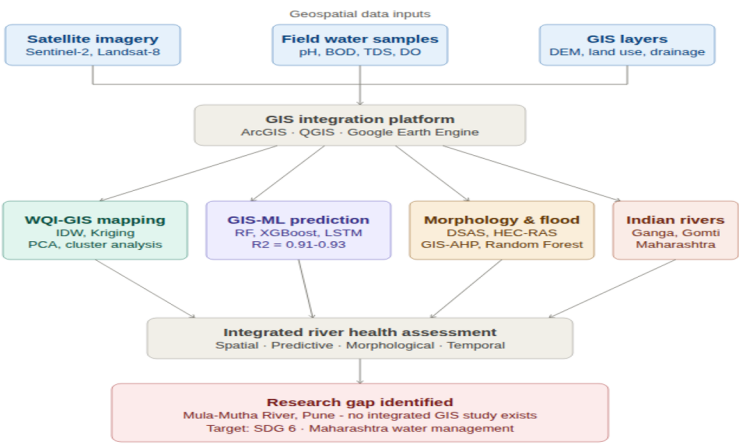


Fig. 2. Thematic distribution of the selected studies across four review categories

Finding 1: Across the reviewed studies, GIS based WQI mapping supported by PCA and cluster analysis emerged as the most dependable framework for spatial water quality assessment. This combined approach generates continuous maps across entire river basin from relatively sparse monitoring networks, brining pollution hotspots into spatial focus – patterns that remain completely hidden conventional tabular datasets [4], [5], [6], [11].

Finding 2: Machine Learning model particularly LSTM, Random Forest, and XGBoost, showed considerably good performance when GIS derived basin variables were incorporated as model inputs. These models are capable to capture complex, non-linear relationships between the upstream land use conditions to downstream water quality outcomes, which is not handled by conventional ML statistical models [3], [8], [9], [10].

Finding 3: Among risk mapping approaches, the GIS – AHP combination remains the most used method in current literature. However, machine learning models integrated within GIS frameworks achieved higher accuracy than AHP – based approaches [12],[13],[15].

Finding 4: Multi – temporal GIS analysis, using satellite imagery and historical map datasets acquired across different time periods, demonstrated a reliable capacity to document long term changes in river channel geometry and platform. The outputs of such analysis provide useful spatial information for flood risk analysis, river corridor management and infrastructure planning decisions [14].

Research gaps: The most significant gap through this review is the absence of any GIS based assessment for water quality or morphological changes for peri urban rivers in

Maharashtra. Beyond this specific geographic gap, a broader methodological limitation is also evident across the reviewed literature. Most published studies treat water quality assessment, river basin morphology, and flood risk mapping as separate and independent research problems, each addressed in isolation. No integrated study combined all three components with a unified GIS based framework in Indian river. Regarding temporal coverage of existing studies, most papers have limited span of only one to three years of monitoring, which is too short for trends estimation.

8 Conclusions

This review of fifteen peer-reviewed studies confirms several things about the current state of GIS-based river assessment. WQI-GIS mapping with multivariate statistics is the most reliable and widely validated approach for spatial water quality work. Adding machine learning improves predictive power considerably, especially when catchment-level variables derived from GIS are included as model inputs. GIS-based flood risk mapping and channel change analysis produce outputs that river managers and city planners can use.

The gap in Indian research is real. GIS work on the Ganga and Yamuna is accumulating. GIS works on urban and peri-urban rivers in Maharashtra —simply does not exist in published literature. All the methods needed to close this gap have been tested and validated elsewhere. An integrated GIS study combining water quality mapping, machine learning prediction, channel change monitoring, and flood risk assessment for the Mula-Mutha would fill a clear hole in the literature and give river managers in Pune information they currently do not have. It would also contribute to Sustainable Development Goal 6, which calls for clean and accessible water for all.

Conflicts of Interest. The authors declare no conflicts of interest.

References

1. Chatrabhuj K, Meshram K, Mishra U, Omar PJ (2024) Integration of remote sensing data and GIS technologies in river management system. *Discov Geosci* 2:67. <https://doi.org/10.1007/s44288-024-00080-8>
2. Patel RK, Soni P, Singh P (2026) Advances in remote sensing and GIS applications in watershed hydrology: a systematic review. *J Hydrol* 664. <https://doi.org/10.1016/j.jhydrol.2025.134459>
3. Patra S, Mishra P, Mahapatra SC (2025) A data-driven approach utilising machine learning and GIS-based time series analysis for water quality assessment in Mahanadi River Basin, Odisha, India. *Discov Sustain*. <https://doi.org/10.1007/s43621-025-01464-7>
4. Chidiac S, El Najjar P, Ouaini N, El Rayess Y, El Azzi D (2023) A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives. *Rev Environ Sci Bio/Technol* 22(2):457–535. <https://doi.org/10.1007/s11157-023-09650-7>
5. Hasanuzzaman M, Song X, Han D, Zhang B, Anwar S (2024) Comparative evaluation of spatiotemporal variations of surface water quality using water quality indices and GIS. *Earth Sci Inform* 17(3):2265–2280. <https://doi.org/10.1007/s12145-024-01389-1>
6. Singh N, Tung S (2025) Assessment of water quality of Gomti River at Lucknow. *Air Soil Water Res* 18. <https://doi.org/10.1177/11786221251328589>

7. Das N, Bhattacharjee R, Choubey A, Agnihotri AK, Ohri A (2022) Analysing the change in water quality parameters along River Ganga using Sentinel-2 and Landsat-8 during COVID-19. *J Earth Syst Sci* 131(2):102. <https://doi.org/10.1007/s12040-022-01825-0>
8. Zhi W, Appling AP, Golden HE, Podgorski J, Li L (2024) Deep learning for water quality. *Nat Water* 2:228–241. <https://doi.org/10.1038/s44221-024-00202-z>
9. Rahat SH, Steissberg T, Chang W et al (2023) Remote sensing-enabled machine learning for river water quality modelling under multidimensional uncertainty. *Sci Total Environ* 900:165504. <https://doi.org/10.1016/j.scitotenv.2023.165504>
10. Leggesse ES, Zimale FA, Sultan D et al (2025) Integration of machine learning and remote sensing for water quality monitoring and prediction: a review. *Sustainability* 17(3):998. <https://doi.org/10.3390/su17030998>
11. Wani AL, Husain R (2025) Implications of seasonal variations of hydrogeochemical analysis using GIS, WQI, and statistical analysis method for the semi-arid region, Maharashtra, India. *Appl Water Sci* 15. <https://doi.org/10.1007/s13201-025-02387-4>
12. Sibandze P, Kalumba AM, Aljaddani AH et al (2025) Geospatial mapping and meteorological flood risk assessment: a global research trend analysis. *Environ Manag* 75:137–154. <https://doi.org/10.1007/s00267-024-02059-0>
13. Hagos YG, Andualem TG, Yibeltal M et al (2022) Flood hazard assessment and mapping using GIS integrated with multi-criteria decision analysis in upper Awash River basin, Ethiopia. *Appl Water Sci* 12:148. <https://doi.org/10.1007/s13201-022-01674-8>
14. Abbass ZD, Maatooq JS, Al-Mukhtar MM (2023) Monitoring and modelling morphological changes in rivers using remote sensing and GIS techniques. *Civ Eng J* 9(3):531–543. <https://doi.org/10.28991/CEJ-2023-09-03-03>
15. Saikh S, Mondal P (2023) GIS-based machine learning algorithm for flood susceptibility analysis in the Pagla river basin, Eastern India. *Nat Hazards Res* 3(3):420–433. <https://doi.org/10.1016/j.nhres.2023.03.002>

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

