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From Monitoring to Meaning: Translating Long-Term River Water Quality Data and Earth Observation into SDG-Aligned Policy Intelligence

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Abstract

River water quality assessments in developing regions are often constrained by limited monitoring infrastructure, yet long-term field-based datasets remain critical for understanding basin-scale dynamics. This study presents a decade-long (2006–2016) spatio-temporal analysis of river water quality in the Mahi River Basin, western India, using routine monitoring data collected across four representative sub-basins. Twelve key physicochemical, nutrient, and sediment-related parameters were analysed to characterise seasonal behaviour, intra-annual variability, and episodic extremes under a monsoon-dominated hydrological regime. Results reveal a well-defined seasonal structure, with wet-season conditions exhibiting pronounced increases in turbidity, suspended solids, organic load indicators, and nutrients, driven by runoff-induced mobilisation of catchment materials. In contrast, dissolved constituents and pH displayed comparatively stable behaviour, reflecting buffering by basin geology and baseflow contributions. Box–whisker analysis further highlights substantial intra-annual variability and short-duration pollution pulses during monsoon months that are not evident from seasonal or annual averages alone. Spatial patterns indicate gradual downstream accumulation of dissolved and organic constituents, suggesting basin-scale rather than point-source dominance. Despite reliance on legacy, field-operable monitoring methods, the consistency of trends across seasons and locations underscores the robustness of the dataset. The study demonstrates the enduring value of long-term observational records for river water quality assessment in data-poor tropical basins and provides a practical baseline to inform monitoring design, irrigation planning, & water quality management under swelling hydro-climatic variability.

1. Introduction

River water quality is a critical indicator of basin health and directly influences ecosystem integrity, irrigation sustainability, and human well-being, particularly in developing regions where rivers continue to serve as primary sources of water for agriculture and domestic use (Chapman, 1996; World Health Organization, 2017; Vörösmarty et al., 2018). In tropical and semi-arid regions, river systems experience strong seasonal hydrological variability driven by monsoon rainfall, compounded by increasing anthropogenic pressures associated with agricultural intensification, urbanisation, and land-use change. A large proportion of river water quality studies rely on short-term monitoring campaigns or data derived from intensively instrumented catchments. While such studies provide valuable process-level insights, they often fail to capture long-term variability and may not adequately represent conditions in data-poor basins where sustained monitoring infrastructure is limited. Long-term observational datasets therefore remain indispensable for identifying baseline conditions, seasonal behaviour, and gradual changes in water quality (Meybeck et al., 2016; Ouyang, 2005; Wang et al., 2019).

In India, extensive research has focused on major river systems; however, medium-sized tropical basins with heterogeneous land use and strong seasonal hydrology remain comparatively under-represented in long-term assessments (Singh et al., 2005; Sharma & Kansal, 2011; Kumar et al., 2020). National river monitoring programmes provide valuable datasets, yet many basins lack detailed spatio-temporal

synthesis of water quality behaviour across seasons and locations (Central Pollution Control Board, 2014; Central Water Commission, 2016).

Spatio-temporal analysis of river water quality offers insights into dominant controlling factors, including dilution during high-flow periods, concentration effects during low-flow conditions, and cumulative impacts of upstream activities along the river continuum (Zhang et al., 2011; Nguyen et al., 2019). Such analyses are particularly valuable in data-limited contexts, where management decisions must rely on consistent interpretation of observed trends rather than complex modelling approaches. Against this background, the present study analyses a decade-long dataset of river water quality observations from the Mahi River basin in western India. By examining temporal, seasonal, and spatial variability of key physicochemical parameters, the study aims to provide field-grounded evidence to support river monitoring, irrigation planning, and water quality managing in tropical, data-poor basins.

2. Study Area

The Mahi River basin is located in western India and drains parts of the semi-arid to sub-humid regions of Gujarat and adjoining areas. The basin supports a diverse range of land uses, including irrigated agriculture, rainfed farming, forested tracts, and expanding urban settlements. Climatic conditions are characterised by a distinct monsoon season, with the majority of annual rainfall occurring between July and September, followed by extended dry periods. The river and its tributaries play a vital role in sustaining irrigation and domestic water supply across the basin. Variations in rainfall, land use, and hydrological regime contribute to pronounced seasonal and spatial heterogeneity in river flow and water quality. For the present study, four monitoring locations representing three constituent sub-basins (Rangeli, Mataji, and Paderdibadi) and the main basin outlet at Khanpur were selected to capture upstream–downstream variability.

The Mahi River Basin, located in western India, represents a monsoon-dominated tropical river system characterised by pronounced seasonal variability in flow and water quality. Figure 2 illustrates the geographical location of the basin, the spatial configuration of its major sub-basins, the positions of river water quality monitoring stations, and the associated drainage network. The selected monitoring locations provide representative coverage of upstream, midstream, and downstream conditions, enabling assessment of spatial and seasonal variability in river water quality across the basin.

3. Data and Methods

3.1 Data origin and monitoring framework

The present study is based on long-term river water quality monitoring data collected from the Mahi River Basin in western India over a period of approximately ten years. The dataset was obtained from the routine river water quality monitoring programme implemented by the Central Water Commission (CWC), Government of India, the apex national agency responsible for hydrological and water quality

observations in major river basins across the country. The CWC conducts systematic monitoring at designated river stations following standardised national protocols to ensure temporal consistency and comparability of observations.

Within the Mahi River Basin, water quality observations were recorded at four strategically located monitoring stations representing three major sub-basins;Rangeli, Mataji, and Paderdibadi;and the main basin outlet at Khanpur (Fig. 2). These stations were selected to capture upstream, midstream, and downstream conditions and to reflect spatial heterogeneity arising from differences in land use intensity, drainage characteristics, and physiographic setting. The spatial configuration of stations allows assessment of cumulative basin-scale influences as well as sub-basin-level variability, thereby enhancing interpretation of observed water quality patterns beyond isolated point measurements.

At each monitoring location, river water samples were collected at regular monthly intervals using grab sampling methods from midstream locations, following established national guidelines. Sample collection, preservation, transport, and laboratory analysis were conducted in accordance with standard procedures prescribed by the CWC, which are broadly aligned with internationally accepted methods for river water quality monitoring. Parameters such as pH, electrical conductivity, dissolved oxygen, and water temperature were measured either in situ or immediately after sampling, while other physicochemical, nutrient, sediment-related, and microbiological parameters were analysed in accredited laboratories using standard analytical techniques (APHA, 2017).

The long-term consistency of sampling locations, analytical methods, and observation frequency across the study period provides a robust basis for spatio-temporal assessment of river water quality. Although the monitoring programme was not specifically designed for experimental research purposes, its systematic and sustained implementation makes it particularly valuable for basin-scale analysis under real field conditions, especially in data-limited regions.

3.2 Selection of water quality parameters

The original monitoring dataset comprised measurements of eighteen physicochemical, nutrient, sediment-related, and microbial water quality parameters. For detailed analysis and interpretation, a subset of twelve key parameters was selected based on their relevance to river water quality assessment, sensitivity to hydrological and seasonal variability, and widespread use in national and international monitoring frameworks. The selected parameters include dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC), pH, nitrate–nitrogen (NO_3–N), nitrate (NO_3), sodium (Na), suspended solids (SS), turbidity (TUR), water temperature (TEMP), and total dissolved solids (TDS). Together, these indicators represent major dimensions of river water quality, including organic pollution, nutrient status, salinity, sediment load, and general physicochemical condition. Parameters exhibiting strong geochemical buffering (e.g., pH) were retained to assess system stability, while parameters known to respond rapidly to runoff and anthropogenic inputs (e.g., SS, TUR, BOD, COD, and nutrients) were included to characterise event-driven variability.

Although results for additional monitored parameters are not presented in detail, they were examined during preliminary analysis and were found to exhibit patterns broadly consistent with those reported for the selected indicators. Focusing on a reduced parameter set was therefore adopted to enhance analytical clarity while retaining the essential information content of the dataset.

3.3 Seasonal classification and data aggregation

To examine seasonal contrasts in water quality behaviour, the monitoring period was divided into two hydrologically meaningful halves: a dry season (January–June) and a wet season (July–December), corresponding broadly to pre-monsoon and monsoon/post-monsoon conditions in the basin. Monthly observations were pooled within these seasonal categories to assess differences in central tendency and variability between dry and wet periods. In addition to seasonal aggregation, annual averages were computed for selected parameters to examine longer-term behaviour and to reduce the influence of short-term fluctuations. This multi-scale analytical approach;combining monthly, seasonal, and annual perspectives;enabled identification of dominant hydrological signals as well as episodic departures from average conditions.

3.4 Statistical and graphical analysis

The analysis relied primarily on descriptive statistical techniques, including calculation of minimum, maximum, mean, and range values for each parameter at all monitoring locations. Given the objectives of the study and the nature of the dataset, emphasis was placed on identifying structured spatio-temporal variability rather than establishing causal relationships through complex statistical or process-based modelling. Box-and-whisker plots were employed to visualise intra-annual variability and to highlight the distributional characteristics of key parameters, including median values, interquartile ranges, and extreme observations. This graphical approach is particularly effective for long-term monitoring datasets, as it facilitates identification of seasonal dispersion, skewness, and short-duration high-magnitude events that may not be evident from mean values alone. Comparative analyses across monitoring stations were used to assess spatial patterns and downstream evolution of water quality parameters, with observed differences interpreted in the context of basin-scale hydrology, land use distribution, and seasonal processes rather than isolated point-source effects.

3.5 Data consistency and analytical philosophy

Although the dataset represents legacy monitoring records collected prior to widespread adoption of high-frequency sensors and advanced analytics, several features enhance its reliability for the present analysis. The long duration of observations reduces sensitivity to anomalous years, while the use of standardised sampling and analytical protocols ensures internal consistency across space and time. Extreme values and outliers were retained in the analysis, as they reflect real field conditions and are often hydrologically meaningful in monsoon-influenced river systems. The methodological approach adopted in this study prioritises transparency and field realism over analytical complexity. Rather than imposing advanced statistical transformations or model-based assumptions, the analysis focuses on preserving observed variability and identifying coherent patterns across time and space. This philosophy

aligns the analytical framework with the practical objectives of river water quality assessment under real-world monitoring constraints, particularly in data-limited tropical basins.

3.6 Scope and limitations

The methods employed are well suited for characterising spatio-temporal patterns and identifying dominant drivers of variability, but they do not aim to establish detailed process-level causality. The absence of concurrent discharge measurements and high-resolution land-use data limits quantitative attribution of observed patterns to specific hydrological or anthropogenic drivers. Nevertheless, the combination of long-term coverage, spatial representation, and consistent methodology provides a robust basis for interpreting river water quality dynamics and for informing monitoring design, irrigation planning, and water quality management strategies in similar tropical river basins.

4. Discussion

4.1 Overview of spatio-temporal water quality variability

Analysis of decade-long monthly observations revealed pronounced spatio-temporal variability in river water quality across the Mahi River Basin. The observed variations were structured rather than random, with clear contrasts between dry and wet seasons and coherent patterns along upstream, midstream, and downstream reaches. While most parameters remained within broadly acceptable ranges, their magnitudes and dispersion reflected strong hydrological control under the monsoon-dominated climatic regime. Seasonal aggregation indicated that wet-season conditions were generally characterised by elevated concentrations of sediment-related, organic, and nutrient parameters, whereas dry-season conditions exhibited comparatively stable behaviour for most dissolved constituents. These patterns were consistently observed across all monitoring stations, suggesting basin-scale hydrological forcing rather than dominance of isolated point-source inputs.

Table 1 provides a consolidated summary of the minimum, maximum, and mean values of key river water quality parameters across all four monitoring stations over the ten-year period, forming the baseline for subsequent seasonal and spatial comparisons. Considerable variability is evident among parameters, reflecting differences in their sensitivity to hydrological, geochemical, and anthropogenic controls. Conservative parameters such as pH showed narrow ranges, whereas indicators linked to sediment transport, organic matter, and runoff exhibited wider ranges, highlighting their responsiveness to seasonal flow dynamics and catchment processes.

Table 1
Long-term descriptive statistics of key river water quality parameters (2006–2016) *(Values represent minimum, maximum, and mean across four monitoring locations in Mahi River basin.)*

Parameter	Unit	Minimum	Maximum	Mean
pH	–	7.1	9.0	8.2
EC	µS cm⁻¹	188	982	451
TDS	mg L⁻¹	116	1648	297
DO	mg L⁻¹	3.4	14.0	7.9
BOD	mg L⁻¹	0.1	8.8	2.1
COD	mg L⁻¹	2.0	191.5	38.5
Turbidity	NTU	1.0	862.0	26.7
Suspended Solids	mg L⁻¹	4.0	306.0	42.0
Secchi Depth	cm	56.1	208.4	117.5
Nitrate–N	mg L⁻¹	0.03	7.45	1.83
Sodium	mg L⁻¹	7.0	105.7	29.3
Water Temperature	°C	28	68	51

4.2 Summary statistics and spatial variability

Descriptive statistics reveal clear contrasts in variability among the monitored parameters across space and time. Parameters exhibiting strong geochemical buffering, such as pH and dissolved oxygen, displayed relatively low dispersion, indicating stable background conditions within the basin. In contrast, parameters associated with organic load, suspended matter, and dissolved salts;such as BOD, COD, turbidity, suspended solids, EC, and TDS;showed broader ranges and higher variability, reflecting sensitivity to runoff, erosion, and seasonal dilution–concentration effects.

Spatial comparison of mean parameter values across monitoring locations, as presented in Table 2, reveals gradual downstream changes rather than abrupt discontinuities. Upstream stations generally recorded lower mean concentrations and reduced variability, while midstream and downstream stations reflected cumulative basin-scale influences from land use, hydrology, and in-stream transport processes. The absence of sharp spatial breaks suggests that diffuse sources and basin-wide processes exert stronger control on water quality than localised point discharges.

Table 2
Spatial variability of key water quality parameters across monitoring locations

Parameter	Rangeli (Upstream)	Mataji	Paderdibadi	Khanpur (Basin outlet)
pH	8.2	8.1	8.2	8.3
EC	522	361	469	453
TDS	357	250	297	287
DO	7.7	7.9	8.1	7.8
BOD	2.2	2.1	2.2	1.7
COD	35.0	42.6	42.1	34.1
Turbidity	18.1	54.6	21.0	13.2
Suspended Solids	46.8	45.7	37.1	38.0
Secchi Depth	130.0	103.2	120.4	116.4
Nitrate–N	1.35	3.06	1.29	1.62
Sodium	37.2	21.2	29.4	29.5
Water Temp	48	51	51	52

4.3 Seasonal contrasts between dry and wet periods

Clear seasonal contrasts are evident when comparing pooled dry and wet period data. Figure 3 illustrates average dry- and wet-season values of key water quality parameters across the four monitoring stations. Most parameters exhibit systematically higher magnitudes during the wet half of the year. Indicators associated with sediment transport, organic loading, and nutrient mobilisation;such as turbidity, suspended solids, BOD, COD, and nitrate;show pronounced increases during the wet season, reflecting enhanced surface runoff, soil erosion, and catchment wash-off during monsoon rainfall.

In contrast, parameters primarily governed by geochemical buffering and baseflow contributions, including pH and TDS, display comparatively muted seasonal contrasts. Water temperature shows expected climatic seasonality, with higher values during pre-monsoon and summer months and lower values during monsoon and winter periods. These seasonal responses, summarised directionally in Table 3, confirm consistent wet-season amplification of sediment, organic, and nutrient indicators across the basin

(Note: Average values of selected water quality parameters during dry (January–June) and wet (July–December) periods at four monitoring locations. The figure highlights systematic seasonal shifts and spatial differences associated with monsoon-driven hydrological processes across the basin)

Table 3
Seasonal variation of selected river water quality parameters (Dry vs Wet halves of the year)
(Direction of change based on decade-long pooled comparisons.)

Parameter	Dry Half (Jan–Jun)	Wet Half (Jul–Dec)	Dominant Seasonal Trend
EC	Lower	Higher	Increase during wet season
TDS	Lower	Higher	Increase during wet season
DO	Moderate	Higher	Increase during wet season
BOD	Moderate	Higher	Increase during wet season
COD	Lower	Higher	Increase during wet season
Turbidity	Low	High	Strong increase during wet season
Suspended Solids	Low	High	Strong increase during wet season
Nitrate–N	Lower	Higher	Increase during wet season
Sodium	Lower	Higher	Moderate increase during wet season
Water Temp	Slightly higher	Slightly lower	Minor seasonal contrast

4.4 Intra-annual variability and episodic behaviour

Beyond seasonal averages, substantial intra-annual variability is evident in the monthly distributions of several parameters. Figure 4 presents box-and-whisker plots illustrating the distributional characteristics of selected indicators over the ten-year period. The plots reveal wider interquartile ranges and extended upper whiskers during monsoon and post-monsoon months for parameters such as COD, BOD, turbidity, and suspended solids. These features indicate the occurrence of short-duration, high-magnitude pollution pulses associated with rainfall-driven runoff, channel resuspension, and episodic catchment inputs.

(Note : Conversely, relatively narrow distributions during dry months reflect more stable water quality conditions governed by reduced flow variability and sustained baseflow contributions. The presence of outliers, particularly during wet-season months, highlights the importance of long-term monthly monitoring for capturing episodic water quality stress that may not be apparent from seasonal or annual mean values alone)

4.5 Behaviour of additional physicochemical, nutrient, and sediment indicators

Patterns observed for the primary indicators were broadly consistent with those recorded for additional physicochemical, nutrient, and sediment-related parameters. Dissolved oxygen exhibited predictable seasonal behaviour, with relatively higher values during high-flow periods due to enhanced reaeration

and dilution, and increased variability during low-flow conditions. Electrical conductivity and major ions, including sodium, showed moderate seasonal dispersion, reflecting mobilisation of dissolved salts during runoff events and concentration effects during dry periods. Nutrient indicators displayed wider variability and frequent upper-end excursions during monsoon and post-monsoon months, suggesting episodic inputs from agricultural land, soil leaching, and surface wash-off. Suspended solids and turbidity were particularly sensitive to hydrological forcing, exhibiting large dispersion and extreme values during wet months due to sediment mobilisation and channel resuspension. In contrast, chemically buffered parameters such as pH remained comparatively stable throughout the year, indicating resilience of the river system to short-term hydrological disturbances.

4.6 Synthesis of observed patterns

Taken together, the results demonstrate that river water quality in the Mahi River Basin is governed by a combination of strong seasonal hydrological forcing and episodic event-driven inputs. Seasonal averages capture dominant wet–dry contrasts, while distributional analyses reveal substantial intra-annual variability and short-duration extremes, particularly during monsoon months. These findings emphasise that reliance on mean values alone may underestimate the frequency and magnitude of water quality stress events, and that long-term, monthly-scale observations are essential for reliable assessment of river water quality dynamics in tropical, data-limited basins.

Consistent patterns of seasonal structure, intra-annual variability, and episodic extremes observed in Figs. 4.1 and 4.2 were also evident across the remaining water quality parameters, including dissolved oxygen, electrical conductivity, major ions, nutrients, suspended matter, and microbial indicators. Parameters governed primarily by hydrological and climatic controls, such as dissolved oxygen and water temperature, exhibited predictable seasonal cycles with relatively narrow dispersion.

In contrast, indicators associated with sediment transport, organic loading, nutrient mobilisation, and microbial contamination, such as suspended solids, turbidity, biochemical and chemical oxygen demand, nitrate, and total coliforms, displayed wider interquartile ranges and frequent upper-end excursions during monsoon and post-monsoon months, reflecting runoff-driven inputs and short-duration pollution pulses. Chemically buffered parameters, including pH and alkalinity, remained comparatively stable throughout the year, underscoring the basin’s geochemical resilience despite pronounced hydrological variability. Overall, the analysis indicates that while mean seasonal behaviour captures dominant trends, episodic high-magnitude events play a critical role in shaping river water quality dynamics, reinforcing the importance of long-term, monthly-scale observations for reliable assessment and management.

5. Discussion

5.1 Dominant role of hydrology and seasonality

The results clearly demonstrate that river water quality dynamics in the Mahi River Basin are primarily governed by hydrological seasonality associated with the monsoon regime. Across all monitoring

stations, wet-season conditions consistently exhibit elevated concentrations of sediment-related, organic, and nutrient parameters, while dry-season conditions show comparatively stable and moderated behaviour. This pattern reflects the fundamental role of rainfall-driven runoff, soil erosion, and catchment wash-off processes during monsoon months, which mobilise both natural and anthropogenic materials into the river system. In contrast, dry-season water quality is largely influenced by baseflow contributions, geochemical buffering, and reduced surface connectivity, leading to lower variability and greater stability in most parameters. Importantly, the coherence of seasonal patterns across upstream, midstream, and downstream stations suggests that basin-scale hydrological forcing dominates over isolated point-source influences. This finding reinforces the need to interpret river water quality in monsoon-dominated basins through a hydrological lens, rather than relying solely on static regulatory thresholds or short-term observations.

5.2 Significance of intra-annual variability and episodic events

Beyond seasonal averages, the pronounced intra-annual variability observed for several parameters underscores the importance of episodic events in shaping river water quality. The wide dispersion and frequent upper-end excursions in sediment, organic, and nutrient indicators during wet months indicate that short-duration, high-magnitude inputs play a disproportionate role in determining overall water quality conditions. Such events are typically associated with intense rainfall, first-flush effects, channel resuspension, and transient inflows from agricultural and urban landscapes. These findings highlight a critical limitation of assessments based solely on mean or seasonal values, which may underestimate the frequency and ecological significance of episodic water quality stress. From a management perspective, this underscores the value of long-term, monthly monitoring programmes that are capable of capturing extreme events and variability, even when advanced high-frequency instrumentation is not available.

5.3 Spatial integration and cumulative basin-scale effects

The gradual downstream evolution of several water quality parameters reflects cumulative basin-scale influences rather than abrupt localised changes. As water moves downstream, contributions from diverse land uses, tributaries, and human activities integrate progressively, leading to spatially coherent patterns in water quality. The absence of sharp discontinuities between stations suggests that diffuse sources and natural processes collectively exert stronger influence than discrete point discharges at the basin scale.

This spatial integration is characteristic of medium-sized tropical river basins, where hydrological connectivity during monsoon periods facilitates widespread material transport. The findings therefore support basin-wide management approaches that address diffuse pollution sources and land-use practices, rather than focusing exclusively on isolated control points.

5.4 Implications for monitoring strategies and data interpretation

The study demonstrates the continued value of routine, long-term monitoring datasets for understanding river water quality dynamics in data-limited regions. Although the dataset predates widespread deployment of real-time sensors and advanced analytics, its consistency in sampling locations, methods, and temporal coverage enables robust identification of dominant patterns and controlling processes. Retaining extreme values and natural variability, rather than artificially smoothing the data, provides a more realistic representation of river behaviour under monsoon influence.

These results also emphasise that monitoring strategies should prioritise temporal coverage and seasonal representativeness, particularly during high-risk periods such as the onset and peak of the monsoon. Strategic enhancement of monitoring during these periods may yield greater management value than uniform sampling throughout the year.

5.5 Broader relevance for river management and policy

From an applied perspective, the findings offer important insights for river water quality management in semi-arid and monsoon-dominated regions. The observed sensitivity of key parameters to hydrological forcing implies that effective management must integrate land-use planning, soil conservation, and runoff control measures alongside conventional pollution regulation. Moreover, the study provides a valuable pre-digital baseline against which modern sensor-based monitoring systems and modelling approaches can be evaluated.

By demonstrating that structured, interpretable patterns can be extracted from long-term field monitoring data, this work reinforces the relevance of legacy datasets for contemporary water resource planning, extension, and policy formulation. Such datasets remain particularly important in regions where technical capacity and financial resources constrain adoption of advanced monitoring technologies.

6. Implications for Monitoring and Water Management

The findings of this study highlight the continued importance of consistent, long-term river water quality monitoring for effective water resource management in monsoon-dominated, data-limited regions. The structured seasonal patterns and recurrent episodic variability observed across the Mahi River Basin demonstrate that water quality dynamics cannot be adequately captured through short-term surveys or infrequent sampling. Sustained monthly monitoring, even when based on field-operable methods rather than advanced instrumentation, provides critical insights into both baseline conditions and high-risk periods of water quality stress.

Several parameters identified in this study;particularly turbidity, suspended solids, biochemical oxygen demand, chemical oxygen demand, and nitrate;emerge as effective early-warning indicators of hydrologically driven water quality deterioration. Their rapid response to rainfall, runoff, and catchment

disturbance makes them especially valuable for operational monitoring during monsoon and post-monsoon periods. Routine tracking of these parameters can support timely identification of pollution pulses, sediment mobilisation, and nutrient enrichment events that may have downstream ecological and human-use implications.

From a water-use perspective, the observed seasonal variability has direct relevance for both irrigation and drinking water planning. Elevated sediment loads and organic matter during wet periods can impair treatment efficiency, increase filtration costs, and affect suitability for domestic supply. Conversely, higher concentrations of dissolved salts and nutrients during low-flow periods may influence irrigation water quality and soil salinity management. Integrating seasonal water quality behaviour into planning frameworks can therefore enhance resilience of irrigation scheduling, water treatment operations, and source protection strategies.

More broadly, the study underscores the value of legacy monitoring datasets for contemporary decision-making. When analysed with an emphasis on variability, seasonality, and extremes, such datasets offer actionable insights that complement modern sensor-based systems. Strengthening routine monitoring networks, prioritising key parameters, and aligning sampling strategies with hydrological risk periods can substantially improve the effectiveness of river water quality management in similar tropical and semi-arid basins.

8. Limitations and Directions for Future Research

The findings of this study should be interpreted in light of certain limitations inherent to the nature of the dataset and analytical approach. The analysis is based on routine river water quality monitoring records collected at monthly intervals, which, while valuable for capturing long-term trends and seasonal variability, may not fully resolve short-duration extreme events associated with high-intensity rainfall or sudden pollutant releases. In addition, the absence of concurrent discharge measurements limits quantitative assessment of mass loads and restricts precise attribution of observed water quality changes to specific hydrological processes.

The study relied on physicochemical and nutrient indicators without detailed linkage to high-resolution land-use dynamics, point-source inventories, or real-time meteorological inputs. As a result, interpretations are primarily qualitative and process-oriented rather than strictly causal. Furthermore, although the long-term consistency of monitoring protocols strengthens comparability, the dataset predates widespread adoption of continuous sensors and advanced analytical techniques that are now increasingly used in river monitoring.

Future research could build upon the present findings by integrating water quality observations with simultaneous flow measurements, rainfall intensity data, and spatially explicit land-use information to improve process-level understanding. High-frequency sensor deployments, combined with traditional grab sampling, may help bridge gaps between episodic event detection and long-term trend analysis. Linking water quality dynamics with ecological indicators, irrigation suitability, and drinking water

treatment performance would further enhance applied relevance. For research scholars, the present study offers a valuable baseline and methodological framework for comparative analysis with modern monitoring systems, facilitating evaluation of how technological advancements refine, rather than replace, insights derived from sustained field-based observations.

9. Conclusions

This study provides a comprehensive field-based assessment of river water quality dynamics in the Mahi River Basin using long-term monitoring data. Analysis of decade-long monthly observations revealed that river water quality is governed by strong seasonal hydrological forcing, with wet-season conditions characterised by elevated sediment, organic, and nutrient indicators, and dry-season conditions exhibiting relatively stable behaviour for most dissolved constituents. In addition to clear wet–dry contrasts, substantial intra-annual variability and episodic high-magnitude events were observed, particularly during monsoon and post-monsoon periods. Spatial analysis across monitoring locations indicated gradual downstream integration of water quality signals rather than abrupt discontinuities, suggesting dominance of diffuse, basin-scale influences over isolated point-source effects. Conservative parameters such as pH and dissolved oxygen showed comparatively low variability, while sediment- and runoff-sensitive indicators displayed pronounced dispersion and extremes. These patterns highlight the importance of long-term, temporally consistent monitoring for capturing both baseline conditions and transient water quality stress.

Although based on routine monitoring data collected prior to widespread adoption of high-frequency sensing technologies, the study demonstrates that structured and meaningful insights can be derived from legacy datasets when analysed with attention to variability and seasonality. The findings reinforce the relevance of sustained monthly monitoring programmes for river water quality assessment and provide a robust baseline for comparison with modern monitoring approaches. Overall, the study contributes practical, field-grounded evidence to support informed water resource planning, monitoring design, and management in monsoon-dominated river basins.

Declarations

Conflict of interest :

The authors declare no conflict of interest.

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Figures



Figure 1

Graphical Abstract

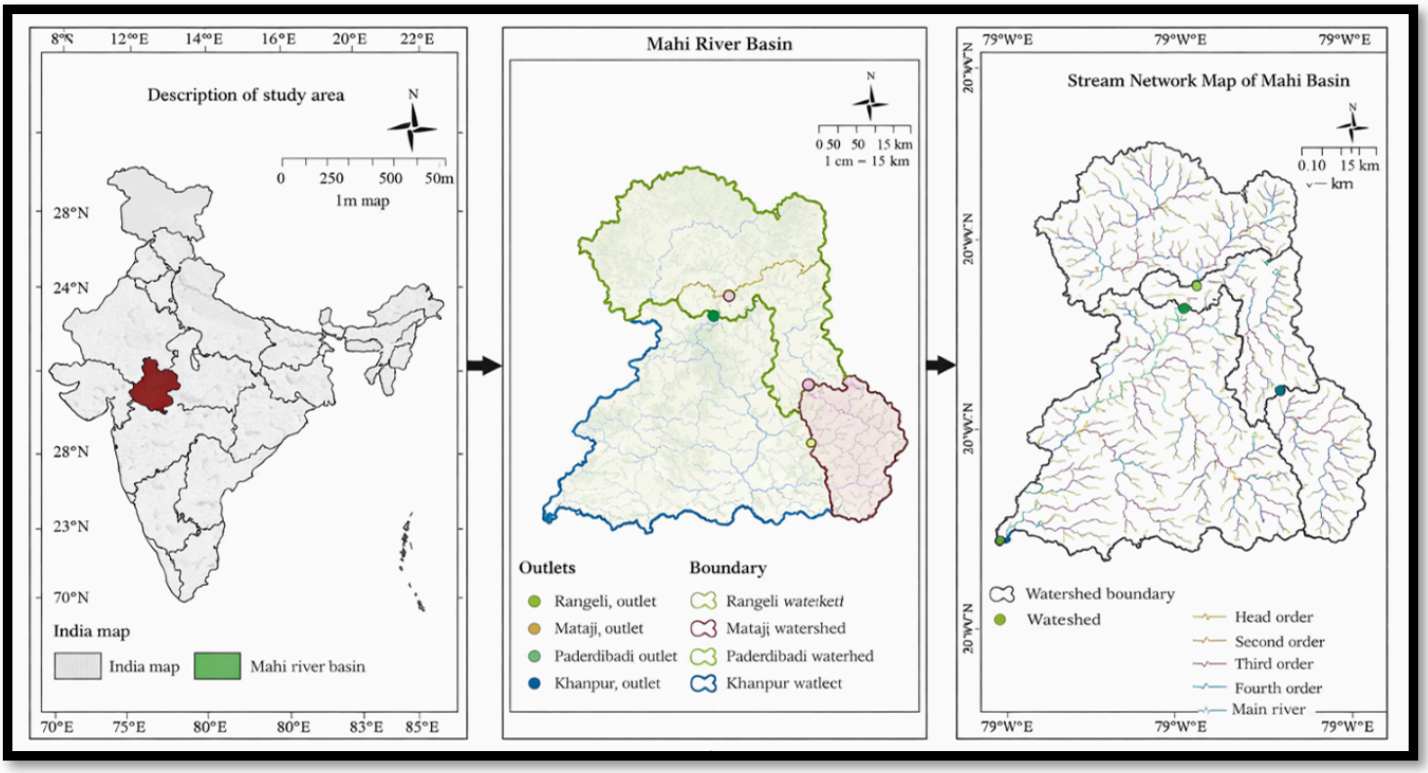


Figure 2

Location of the Mahi River Basin showing monitoring stations and sub-basin boundaries in western India

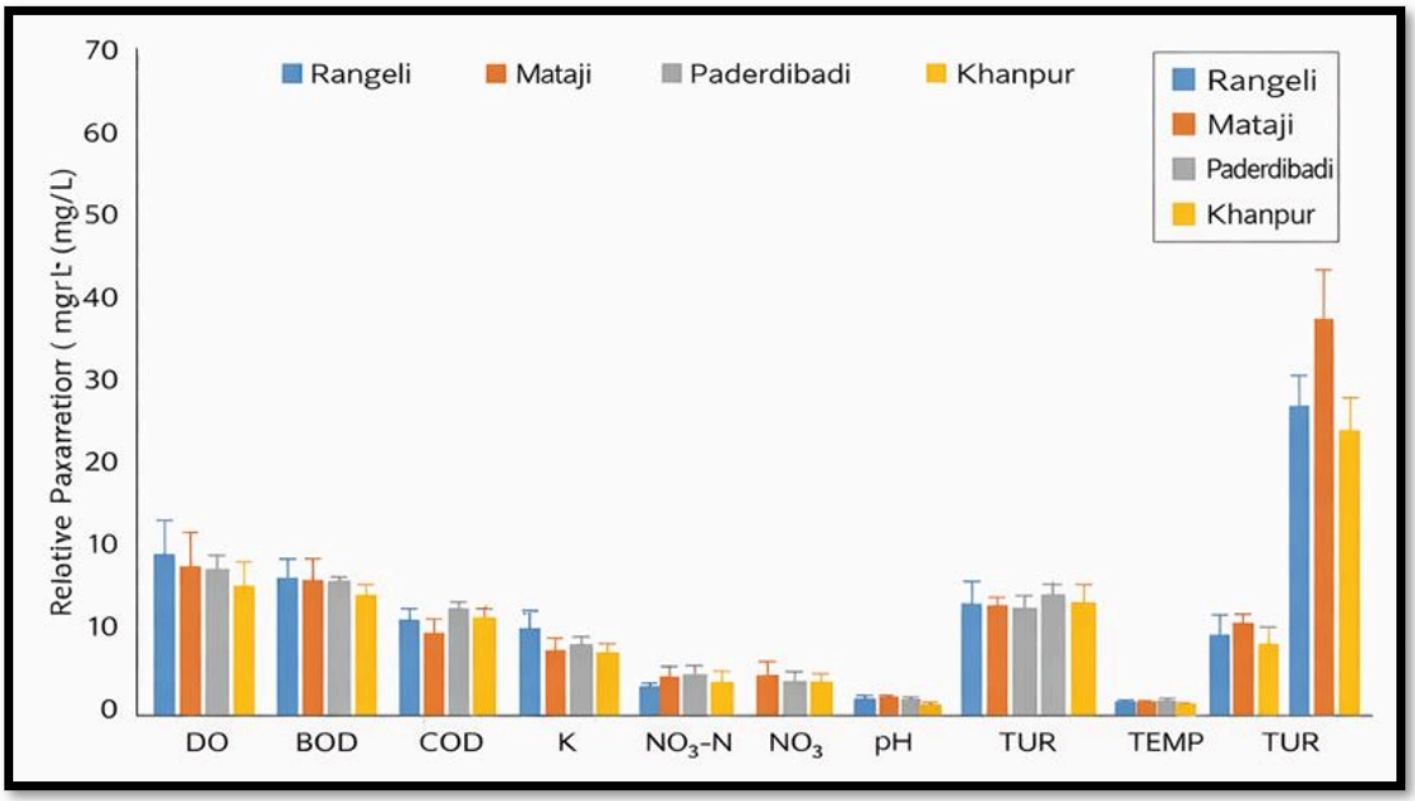


Figure 3

Seasonal contrasts in key river water quality parameters across 4 sub-basins of Mahi River.

(Note: Average values of selected water quality parameters during dry (January–June) and wet (July–December) periods at four monitoring locations. The figure highlights systematic seasonal shifts and spatial differences associated with monsoon-driven hydrological processes across the basin)

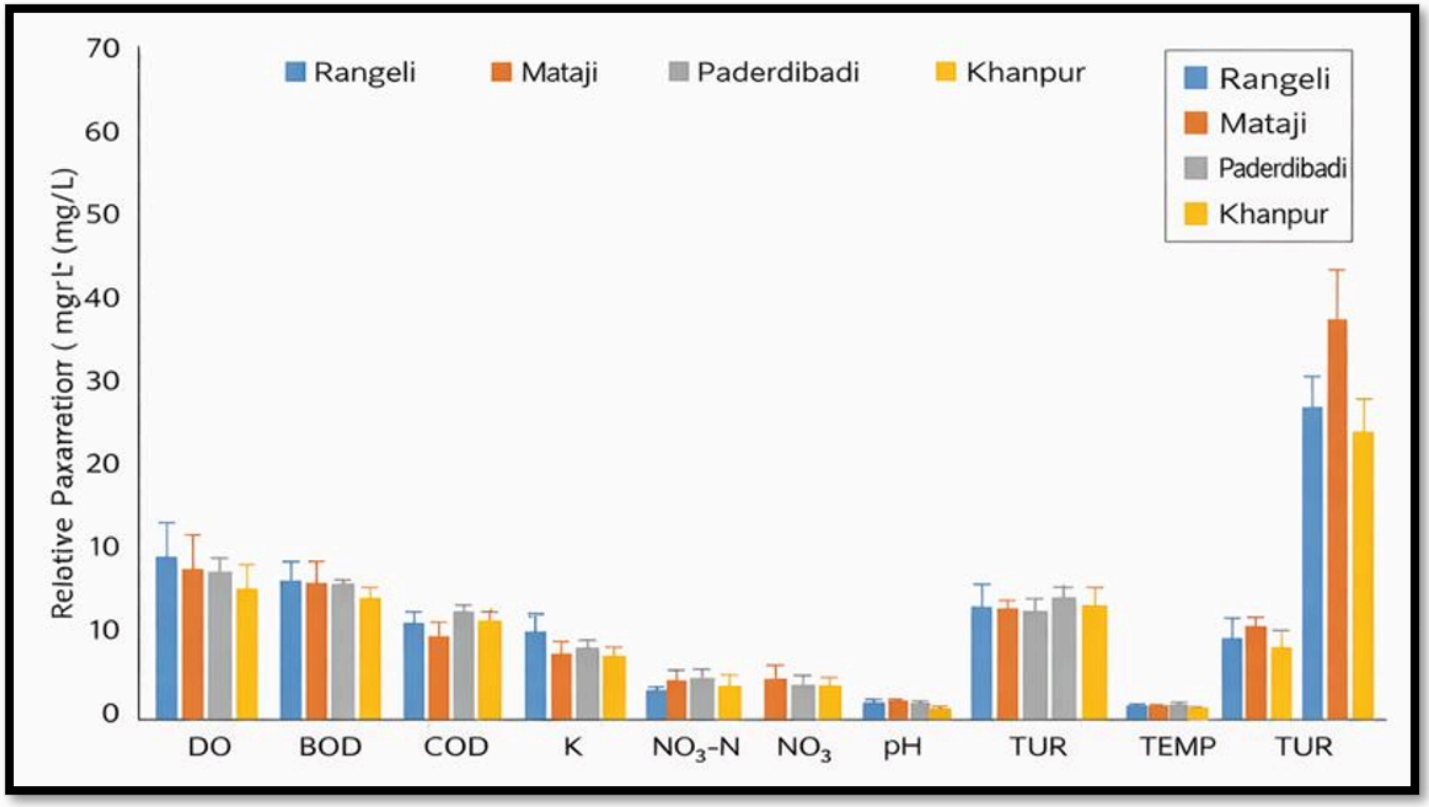


Figure 4

Seasonal contrasts in key river water quality parameters across four sub-basins of the Mahi River

(Note : Conversely, relatively narrow distributions during dry months reflect more stable water quality conditions governed by reduced flow variability and sustained baseflow contributions. The presence of outliers, particularly during wet-season months, highlights the importance of long-term monthly monitoring for capturing episodic water quality stress that may not be apparent from seasonal or annual mean values alone)