

Seasonal Assessment Of River Water Quality Using Wqi In Chandel District Of Manipur, India

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Introduction

Freshwater rivers form the backbone of ecological stability and human survival, as they regulate hydrological cycles, sustain biodiversity, and provide essential resources for agriculture, industry, and domestic life (Allan, 2004). Yet, over the past few decades, these life-supporting systems have been placed under severe stress due to rapid urban expansion, industrialization, agricultural intensification, and rising demographic pressure. Such stressors have significantly altered natural flow regimes and water quality, threatening both ecological integrity and human livelihoods. Foundational ecological perspectives provide valuable insights into these transformations. Odum (1971) emphasized the concept of ecological carrying capacity, warning that ecosystems can only tolerate a limited degree of exploitation before degradation becomes irreversible. Building on this, Rees (1992) advanced the idea of the ecological footprint, underscoring how societies often consume resources far beyond the regenerative limits of natural ecosystems. These views highlight that rivers, despite being renewable, remain highly fragile resources whose misuse and mismanagement can lead to long-term ecological collapse. Within this global discourse, the vulnerability of river systems stands out as a pressing environmental challenge requiring continuous scientific scrutiny.

In the Indian context, rivers are deeply shaped by monsoonal hydrology, which confers both ecological vitality and vulnerability. Heavy monsoon rainfall often results in soil erosion, nutrient runoff, and organic loading into rivers, thereby causing drastic fluctuations in their ecological condition (Jain et al., 2005). Such seasonal variability leads to sudden declines in water quality, evidenced by increased turbidity, reduced dissolved oxygen levels, and higher biochemical oxygen demand (BOD). Large river systems such as the Ganga and Brahmaputra have attracted considerable research attention due to their immense socio-economic significance, yet smaller hill rivers despite being vital for local communities have been relatively neglected in scientific inquiry. This lack of systematic study is particularly concerning in Northeast India, a region characterized by ecological fragility and cultural reliance on natural water sources. Bora and Goswami (2017) observed that deforestation, shifting cultivation, and unsustainable land-use practices in the region magnify the impacts of heavy rainfall, leading to severe deterioration of river water quality. Singh et al. (2020) further reported that unsafe dependence on untreated river water in rural communities directly heightens health risks, illustrating the intertwined relationship between ecological processes and human well-being. Despite the significance of rivers in sustaining livelihoods, long-term

monitoring and systematic water quality assessments in this region remain limited, leaving important gaps in both ecological understanding and policy intervention.

To address these challenges, comprehensive and integrative assessment methods have become indispensable in evaluating river health. The Water Quality Index (WQI), introduced by Brown et al. (1972), has emerged as a widely accepted tool for consolidating multiple physico-chemical parameters into a single representative score. Its utility lies in simplifying complex data into accessible formats that can be easily interpreted by policymakers, scientists, and local stakeholders, thus bridging the gap between technical analysis and practical decision-making. By capturing seasonal and spatial variations, WQI offers an effective framework for managing fragile river ecosystems and promoting sustainable water use practices. Against this backdrop, the present study examines the seasonal variation in the water quality of three rivers namely Machi, Chakpi, and Maha in Chandel District, Manipur. Situated within the Indo-Burma biodiversity hotspot, this district is both ecologically sensitive and socio-culturally diverse. Its rivers, which provide drinking water, irrigation, and other domestic needs, face growing threats from deforestation, shifting cultivation, and soil erosion. By applying the Weighted Arithmetic WQI method, this study aims to analyze seasonal water quality dynamics, identify ecological and anthropogenic pressures contributing to deterioration, and provide scientific evidence to support sustainable river basin management in fragile hill ecosystems.

Review of Literatures

Globally, the Water Quality Index (WQI) has been extensively applied as a reliable tool for assessing and communicating the overall condition of aquatic ecosystems. Allan (2004) highlighted the role of ecological processes, including nutrient cycling and hydrological regulation, in maintaining riverine health, emphasizing that water quality assessment must account for both natural and anthropogenic drivers. Building on this perspective, Pal et al. (2017) demonstrated the application of WQI in tropical streams, where seasonal variations in rainfall and land use created distinct water quality patterns. In temperate regions, WQI applications have been particularly effective in identifying fluctuations linked to agricultural practices, urban runoff, and hydrological shifts, underscoring the index's versatility across climatic settings. Several studies in India have further refined the application of WQI under diverse ecological contexts. Koshy and Nayar (1999) investigated seasonal water quality changes in Kerala, pointing to the strong influence of monsoonal rainfall on nutrient loading and organic content. Ramakrishnaiah et al. (2009) applied WQI to evaluate groundwater contamination in Karnataka, revealing elevated levels of hardness, nitrate, and fluoride that posed serious risks to human health. Their findings underscored the utility of WQI in groundwater monitoring, complementing its application in surface water systems. Tiwari and Singh (2014) examined hydro-geochemical variations in semi-arid zones of India and concluded that WQI is a practical tool for evaluating long-term sustainability of scarce water resources, particularly in regions experiencing increasing agricultural and domestic water demand.

Other researchers have also emphasized the role of WQI in integrating complex physico-chemical data into a single representative value that is both scientifically robust and easily understood by policymakers. Brown et al. (1972), who originally proposed the weighted arithmetic WQI method, argued that simplification of data into index form allows for better communication between scientists and communities. Rees (1992) similarly noted that tools

such as WQI help societies recognize when ecological consumption exceeds regenerative capacity, thereby linking scientific assessment with sustainability concerns. For Northeast India, where rivers flow through fragile hill ecosystems and communities are heavily dependent on natural water sources, studies remain limited compared to other regions of the country. Bora and Goswami (2017) observed that heavy rainfall and associated soil erosion significantly deteriorate river water quality, often leading to unsafe levels of turbidity and organic loading. Their study highlighted the combined effects of natural monsoonal variability and poor sanitation practices in local settlements. Singh et al. (2020) further noted that contamination of river water in rural areas posed direct health risks, especially where untreated water was used for drinking and domestic purposes. Both studies emphasized the urgent need for integrated water management strategies, yet they also revealed the absence of systematic, long-term monitoring across many smaller rivers in the region.

Thus, the literature suggests that while WQI has proven to be a valuable and widely used approach globally and within India, the application of such assessments in Northeast India remains underdeveloped. The ecological fragility of the Indo-Burma biodiversity hotspot, combined with increasing anthropogenic pressures such as shifting cultivation and deforestation, makes the region particularly vulnerable. This research gap underscores the necessity of conducting region-specific, long-term studies to better understand seasonal water dynamics, inform sustainable management practices, and safeguard the health and livelihoods of local communities.

Objectives

The present study aims to assess the seasonal dynamics of river water quality in Chandel District by examining variations in key physico-chemical parameters such as turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), and related indicators. It further seeks to compute and interpret the Water Quality Index (WQI) of the Machi, Chakpi, and Maha rivers over a three-year period (2015–2018), thereby providing a comprehensive measure of their overall water quality status. In addition, the study endeavors to identify the underlying ecological and anthropogenic factors responsible for the deterioration of water quality, with a view to generating insights that can guide sustainable management and conservation of fragile hill river ecosystems.

Materials and Methods

The study was carried out in Chandel District of Manipur, situated within the Indo-Burma biodiversity hotspot, an ecologically fragile region characterized by forested hill catchments and high rainfall. Three rivers namely Machi, Chakpi, and Maha were selected as they provide essential water resources for drinking, irrigation, and domestic purposes to surrounding tribal villages. The district faces increasing ecological stress due to deforestation, shifting cultivation, and land-use change, which accelerate soil erosion and sediment inflow into rivers. To capture the spatial variability of water quality, sampling stations were established at upstream, midstream, and downstream stretches of each river. Monthly grab samples were collected from October 2015 to September 2018 using sterilized BOD bottles and polyethylene containers. Samples were transported under cold storage conditions and analysed within 24 hours to minimize alteration in water quality characteristics. In-situ measurements included water temperature, turbidity, pH, and dissolved oxygen (DO), while laboratory analysis covered free CO₂, biochemical oxygen demand (BOD, 5-day), total hardness, calcium, and

magnesium. Analytical procedures were performed in accordance with the guidelines of APHA (1998), BIS (2012), and WHO (2011). The Water Quality Index (WQI) was computed using the Weighted Arithmetic method (Brown et al., 1972), where each parameter's quality rating (qn) was calculated relative to permissible standards, weighted by its unit weight (wn), and aggregated to provide a single score. Water quality was categorized as excellent (0-25), good (26-50), medium (51-75), poor (76-100), and unsuitable (>100). To examine temporal patterns, descriptive statistics were employed to assess seasonal variations across the three-year period. Furthermore, Pearson's correlation coefficient (r) was applied to evaluate the degree and direction of association among physico-chemical parameters using seasonal mean values. Correlation coefficients close to +1 indicated strong positive relationships, -1 strong negative associations, and values near zero negligible correlations.

Analysis and Results

The seasonal dynamics of physico-chemical parameters in the Machi, Chakpi, and Maha Rivers between 2015 and 2018 reveal clear ecological patterns regulated by climate, hydrology, and catchment geology. As shown in Table 1, temperature followed predictable seasonal cycles, with maximum values during the rainy season (24.8–25.0 °C) and slightly lower but still elevated levels in summer (22.9–23.6 °C). Winter, in contrast, exhibited marked cooling, most prominent in the Maha River (16.5 °C). This trend underscores the strong atmospheric regulation of water temperature, with monsoon rains and solar heating driving rainy-season peaks, while winter reflects ambient climatic minima. Turbidity demonstrated the most pronounced seasonal variation, lowest in winter (≈19–21 NTU), rising moderately in summer (≈39–57 NTU), and surging during the monsoon (≈71–75 NTU). These peaks are indicative of soil erosion, sediment transport, and runoff processes typical of high-rainfall catchments. The pH remained relatively stable (7.3–7.7) across all rivers and seasons, reflecting robust buffering capacity and catchment lithology. However, Dissolved Oxygen (DO) levels remained low (≈5.0–5.6 mg/L), nearing ecological stress thresholds, while Biochemical Oxygen Demand (BOD) values (4.4–5.4 mg/L) showed a reciprocal relationship, peaking in summer due to enhanced microbial activity and declining in winter with reduced biological decomposition. Hardness, calcium, and magnesium followed predictable patterns, with maxima in summer (77–84 mg/L hardness) owing to mineral leaching under low flows, and dilution-driven declines in rainy and winter seasons. Spatially, Chakpi and Maha Rivers consistently showed higher hardness compared to Machi, pointing toward lithological differences in mineral contribution. These seasonal and spatial trends are further illustrated in Figure 1, where temperature, turbidity, oxygen, and hardness exhibit clear cyclic variability influenced by hydro-climatic controls.

Table 1: Seasonal mean physico-chemical parameters of Machi, Chakpi and Maha Rivers (2015-2018)

River / Season	Temp (°C)	Turbidity (NTU)	pH	DO (mg/L)	BOD (mg/L)	Total Hardness (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
Machi (Summer)	22.9	57.3	7.4	5.4	5.4	77.6	17.8	15.9
Machi	20.6	20.8	7.3	5.2	4.7	55.2	13.2	10.1

(Winter)								
Machi (Rainy)	24.8	71.5	7.7	5.1	4.4	55.5	10.7	10.9
Chakpi (Summer)	23.5	39.7	7.5	5.6	5.4	82.9	18.9	15.5
Chakpi (Winter)	20.8	20.1	7.4	5.3	4.8	55.3	13.2	10.1
Chakpi (Rainy)	25.0	73.3	7.5	5.3	4.7	65.1	13.0	12.6
Maha (Summer)	23.6	40.0	7.6	5.4	5.3	84.2	18.9	15.7
Maha (Winter)	16.5	19.4	7.4	5.1	4.6	56.6	12.9	10.4
Maha (Rainy)	24.9	75.3	7.5	5.0	4.6	57.0	12.6	10.1

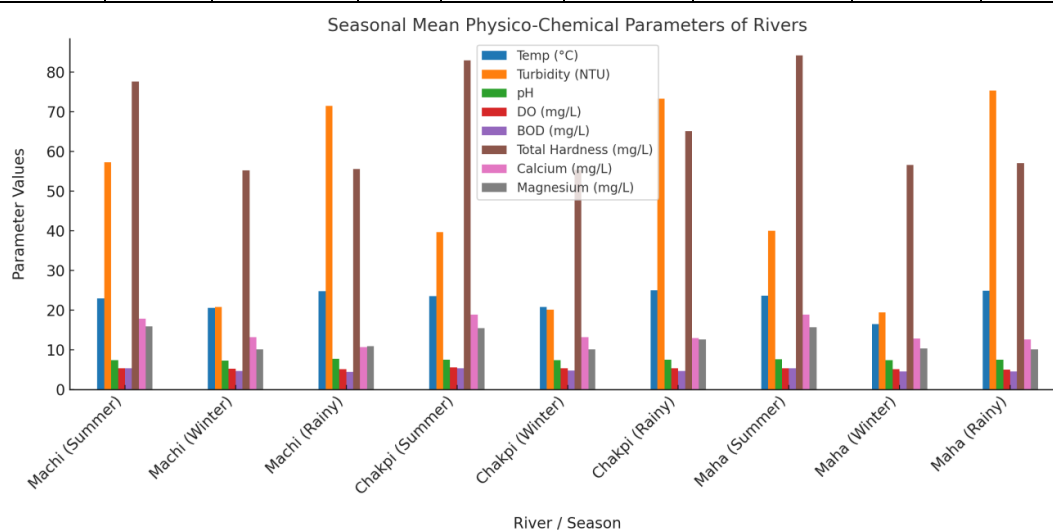


Figure 1: Graphical representation of Seasonal means physico-chemical parameters of Machi, Chakpi and Maha Rivers

The comparative evaluation of water quality using the Water Quality Index (WQI) highlights broader ecological implications. As shown in Table 2, the Machi River recorded poor quality in summer (WQI 104.22) and rainy season (107.48), while winter conditions were comparatively better (84.53). The Chakpi River displayed the widest seasonal range, with very poor quality in summer (96.88) and rainy season (107.27), but a striking improvement in winter (161.20), which represented the highest water quality index among all observations. This suggests that winter acts as a natural flushing period in Chakpi, improving ecological conditions after monsoon stress. The Maha River exhibited comparatively stable trends, with WQI values of 98.85 (summer), 82.09 (winter), and 108.28 (rainy). While summer and rainy seasons indicated poor quality, winter reflected notable improvement, suggesting higher ecological resilience relative to Machi and Chakpi. These river-specific trends confirm that monsoon runoff is the major stressor, whereas winter provides a window of recovery. The same patterns are statistically reinforced in Figure 2, where bar graphs display seasonal WQI

variation, demonstrating the poor summer and rainy season conditions contrasted against improved winter values. Notably, Chakpi showed extreme fluctuations, while Maha was the most stable, underscoring differing ecological vulnerabilities among the rivers.

Table 2: Comparative analysis of Water Quality Index (WQI) by season and river

River/Season	Summer WQI	Winter WQI	Rainy WQI	Seasonal Trend & Observation
Machi River	104.22	84.53	107.48	Poor in summer and rainy; better in winter
Chakpi River	96.88	161.20	107.27	Poor in summer & rainy; winter shows highest WQI
Maha River	98.85	82.09	108.28	Comparatively better; winter shows improved quality

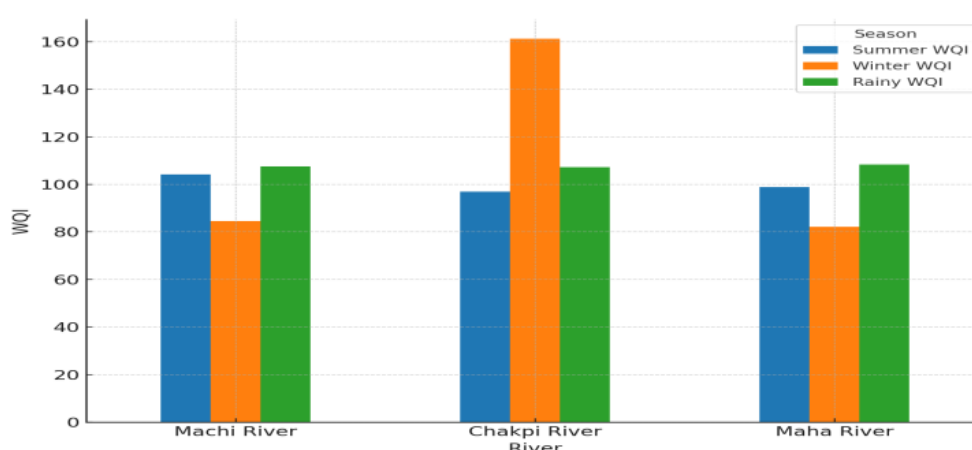


Figure 2: Bar graph showing comparative values of WQI

The statistical interpretation of WQI further underscores these trends. In Machi, the seasonal difference was moderate (22.95 points), confirming steady but poor summer and monsoon conditions. Chakpi showed the widest variation (64.32 points), with winter surging to the best water quality across all rivers, while summer and rainy conditions fell into poor categories. Maha recorded the narrowest range (26.19 points), suggesting relative ecological stability. River-wise ranking thus indicates that Chakpi exhibits the most variability, Machi is moderately stressed by monsoon and summer conditions, while Maha demonstrates resilience with less seasonal fluctuation. Overall, winter emerges as the best season for water quality, while the monsoon is the most critical period of ecological stress. These findings emphasize the need for seasonally targeted management: summer demands control of organic loads, while monsoon calls for soil conservation to limit sediment and nutrient influx.

Table 3: Correlation coefficients among physico-chemical parameters of

Parameter	Temp	Turbidity	pH	DO	BOD	Hardness	Calcium	Magnesium
Temp	1.000							
Turbidity	0.835	1.000						
pH	0.628	0.604	1.000					
DO	0.159	-0.206	-0.037	1.000				

BOD	0.131	-0.155	-0.093	0.877	1.000			
Hardness	0.317	0.068	0.218	0.833	0.925	1.000		
Calcium	0.113	-0.175	-0.029	0.845	0.982	0.945	1.000	
Magnesium	0.341	0.143	0.224	0.821	0.909	0.963	0.934	1.000

Correlation Levels: Strong (≥ 0.700); Moderate (0.500-0.700); Weak (<0.500)

The interrelationships among physico-chemical parameters presented in Table 3 provide further insights into ecological drivers. Temperature correlated strongly with turbidity ($r = 0.835$) and moderately with pH ($r = 0.628$), confirming that higher temperatures facilitate sediment resuspension and mild alkalinity. Turbidity, however, exhibited negative correlations with DO ($r = -0.206$) and BOD ($r = -0.155$), showing that suspended solids reduce oxygen exchange and microbial efficiency. DO and BOD showed a very strong positive relationship ($r = 0.877$), reflecting the close coupling of oxygen availability and organic matter decomposition. Hardness correlated strongly with DO ($r = 0.833$) and BOD ($r = 0.925$), suggesting mineral content influences oxygen dynamics through carbonate buffering and microbial interactions. Among ions, calcium displayed the highest correlation with BOD ($r = 0.982$) and hardness ($r = 0.945$), while magnesium was similarly linked to hardness ($r = 0.963$), calcium ($r = 0.934$), and BOD ($r = 0.909$). These correlations confirm carbonate weathering as the dominant hardness source and highlight the interplay of geochemistry and biological oxygen demand in shaping water quality.

Discussion

The present study of the Machi, Chakpi, and Maha rivers in Chandel District provides valuable insights into the seasonal dynamics of water quality in fragile hill ecosystems. Consistent with Allan's (2004) emphasis on the interplay of natural processes and anthropogenic stressors, the findings demonstrate that monsoonal hydrology strongly regulates temperature, turbidity, and nutrient inflow, while human activities such as shifting cultivation and deforestation magnify sediment and organic loading. Turbidity peaks during the rainy season clearly reflect soil erosion and runoff, supporting observations by Bora and Goswami (2017) that heavy rainfall in Northeast India exacerbates water quality deterioration. The seasonal WQI values reveal a distinct ecological pattern: poor conditions dominate in summer and monsoon, while winter offers a recovery phase with comparatively improved quality. This aligns with Pal et al. (2017), who noted that tropical rivers exhibit marked seasonal variation in response to rainfall and land-use dynamics. Among the studied rivers, Chakpi showed the greatest variability, underscoring its heightened sensitivity to hydrological shifts, whereas Maha displayed relative resilience, reflecting local catchment stability. The identification of winter as a natural flushing period highlights the importance of seasonal monitoring, as advocated by Koshy and Nayar (1999) for monsoon-influenced systems.

The correlation analysis further reinforces these seasonal dynamics. Strong positive relationships between BOD, hardness, and calcium suggest that carbonate geochemistry interacts closely with organic matter decomposition to influence oxygen dynamics. This coupling between physico-chemical and biological parameters supports Brown et al.'s (1972) argument that integrated indices like WQI are essential for capturing complex ecological interactions in a single, interpretable framework. Moreover, the negative relationship of turbidity with DO echoes Singh et al. (2020), who highlighted how sediment and organic matter

contamination directly threaten human health in rural communities reliant on untreated river water. The present findings emphasise the vulnerability of small hill rivers in the Indo-Burma biodiversity hotspot. They confirm Rees's (1992) caution that ecological systems can be pushed beyond their regenerative capacity when consumption and land-use pressures exceed natural limits. The study demonstrates that while WQI remains a powerful tool for communicating river health, region-specific, long-term monitoring is urgently needed to address both ecological fragility and community dependence on these water resources.

Summary and Conclusion

This study assessed the seasonal variation in water quality of the Machi, Chakpi, and Maha rivers in Chandel District, Manipur, using the Weighted Arithmetic Water Quality Index (WQI) method. Results highlight that water quality is strongly regulated by seasonal hydro-climatic conditions and intensified by human-induced pressures. Turbidity was highest during the monsoon, driven by soil erosion and surface runoff, while dissolved oxygen (DO) levels remained consistently low, indicating ecological stress. Biochemical Oxygen Demand (BOD) peaked in summer, reflecting greater microbial decomposition under elevated temperatures. Similarly, hardness, calcium, and magnesium exhibited seasonal fluctuations, largely influenced by mineral leaching during low flows and dilution during rainy periods.

WQI values revealed that all three rivers suffered poor water quality in summer and monsoon seasons, whereas winter consistently showed improvement. Among them, the Machi and Chakpi rivers were particularly vulnerable to monsoon-driven sediment and organic loading, while the Maha River displayed relative ecological resilience. The Chakpi River showed the widest variation, with winter conditions markedly improving due to hydrological flushing effects. Statistical analysis further identified two main clusters of water quality drivers: temperature and turbidity linked to climatic regulation, and DO, BOD, hardness, calcium, and magnesium shaped by geochemical–biological interactions. These findings confirm the sensitivity of hill river ecosystems to both natural fluctuations and anthropogenic activities such as deforestation, shifting cultivation, and land-use change. The study underscores the value of WQI as a practical tool for monitoring and communicating water quality. Effective river management requires season-specific interventions controlling organic loads in summer, conserving soil and watersheds during the monsoon, and strengthening long-term monitoring to safeguard ecological integrity and community livelihoods.

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