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Spatio-Temporal assessment of water quality and metal pollution in the Chathe and Intanki Tributaries of the Dhansiri River, Nagaland, India

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Abstract

This study evaluates the spatio-temporal variations in water quality and metal pollution in the Chathe and Intanki tributaries of the Dhansiri River, Nagaland. Six sampling sites were selected along a gradient from upstream forested zones within Intanki National Park to downstream urban and semi-urban areas near Chümoukedima. Water samples were collected during winter (January) and summer (June) and analyzed for physicochemical parameters and trace metals. The Water Quality Index (WQI) and Metal Pollution Index (MPI) were applied to assess overall water quality and heavy metal contamination. Results revealed that WQI values (37.95–42.66) indicated poor to very poor water quality across all sites, with significant spatial variation but no statistically significant seasonal differences. MPI values ranged from 0.693 to 0.928, reflecting the presence of metal pollutants at all sites, with Site 6 consistently showing the highest contamination. Spatial variation was more pronounced than seasonal variation, underscoring the influence of local anthropogenic pressures such as agricultural runoff, wastewater discharge, and land use changes. As the first systematic study on these tributaries, which have remained largely unexplored in previous research, the findings provide critical baseline data for future monitoring. The study emphasizes the need for site-specific management strategies, stricter pollution control, and continuous monitoring to safeguard the ecological and socio-economic importance of these rivers.

Keywords: WQI, MPI, Spatio-temporal variation, physicochemical parameter, heavy metals, Dhansiri River, Chathe, Intanki tributary.

Introduction

Freshwater ecosystems, particularly rivers and their tributaries, play a vital role in maintaining ecological balance, supporting biodiversity, and supplying water for agricultural, industrial, and domestic uses. However, increasing anthropogenic pressures such as urbanization, deforestation, agricultural runoff, mining, and improper waste disposal have led to significant deterioration in river water quality worldwide[1,2]. Monitoring and assessment of riverine systems are therefore essential for sustainable water resource management, especially in ecologically sensitive and under-researched regions like Northeast India.

Rivers in Northeast India, including those in Nagaland, are characterized by unique hydro-ecological features due to the region's complex topography, rich biodiversity, and monsoonal climate. Despite their ecological significance, many of these rivers and their tributaries are increasingly threatened by human-induced activities[3].

The Dhansiri River, a significant sub-basin of the Brahmaputra, and its tributaries such as the Chathe and Intanki Rivers are vital for supporting both local ecosystems and communities in Nagaland. These tributaries are now facing stress due to rapid land use changes and development activities, particularly in areas like Chümoukedima and the buffer zones of Intanki National Park.

Evaluating water quality involves analyzing key physicochemical parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), nutrients (e.g., nitrates), and major ions (e.g., chloride, calcium, sodium), which serve as reliable indicators of pollution and ecosystem health[4,5]. In addition, contamination by heavy metals, originating from both natural geological sources and human activities—poses serious long-term risks due to their toxicity, persistence, and potential for bioaccumulation. Even at trace levels, elements like lead, cadmium, iron, copper, and zinc can harm aquatic life and human health[6,7].

To simplify complex datasets and facilitate assessment, index-based approaches like the Water Quality Index (WQI) and Metal Pollution Index (MPI) are commonly used. The WQI condenses multiple water quality variables into a single value to reflect overall water status in an easily interpretable form[8], while MPI specifically evaluates the extent of heavy metal contamination against standard thresholds[9]. These indices are particularly effective in capturing spatial and seasonal trends, and in identifying pollution hotspots.

Several studies across India have demonstrated the utility of WQI and MPI in assessing river health across different seasons and locations[10,11]. However, there remains a noticeable gap in such assessments for rivers in Nagaland. To date, no systematic

WQI- and MPI-based evaluation has been conducted on the Chathe and Intanki tributaries, despite their ecological and socio-economic importance.

This study addresses that gap by evaluating the spatio-temporal variations in water quality and metal pollution along the Chathe and Intanki tributaries of the Dhansiri River. Six sampling sites were strategically selected along a gradient from upstream forest zones within Intanki National Park to downstream sites near urban and semi-urban settlements in the Chümoukedima region. Water samples were collected during two distinct seasons- winter (January) and summer (June) to capture seasonal variability. The samples were analyzed for selected physicochemical and heavy metal parameters. WQI and MPI were applied to assess the suitability of water for human and ecological use and to identify pollution hotspots. The findings provide baseline data essential for water quality monitoring, river basin management, and environmental policy formulation in the region.

Materials and Methods

Sampling Design and site collection: Water samples were collected from six selected stations along the Chathe and Intanki tributaries of the Dhansiri River in Nagaland. Figure-1 shows the map of the sampling stations. The sampling sites represent a gradient of ecological and anthropogenic conditions ranging from forested upstream zones within Intanki National Park to downstream areas near urban and semi-urban settlements such as Chümoukedima. Table-1 Geographic Coordinates and Elevation of Sample Locations. Sampling was conducted during two distinct seasons: winter (January) and summer (June), to capture seasonal variability in water quality.

Table-1: Geographic Coordinates and Elevation of Sample Locations.

Sampling station	Location	Coordinates	Elevation (MSL)
Site 1	Zangdi Area, Below Jalukie Zandi gate	25°42'00.3"N 93°32'32.9"E	350 m±15 m
Site 2	Forest Protection Camp Area, Intanki National Park	25°41'32.5"N 93°31'25.6"E	335 m±20 m
Site 3	Lungru Junction Area, Intanki National Park	25°41'13.9"N 93°30'58.3"E	320 m±15 m
Site 4	Near Chümoukedima (upstream site)	25°42'36.7"N, 93°44'49.6"E	290 m±12 m
Site 5	Below Chathe Bridge (NH29 bridge)	25°43'00.1"N, 93°45'09.3"E	275 m±15 m
Site 6	Before confluence with Dhansiri	25°44'52.4"N, 93°46'06.2"E	240 m±10 m

Figure-1: Satellite images of the sampling stations.

Sample collection and preservation: Water samples were collected in pre-cleaned, acid-washed 1 L polyethylene bottles. For physicochemical analysis, samples were collected directly from flowing water midstream at a depth of 15–20 cm below the surface to avoid surface contamination. Bottles were rinsed three times with sample water before final collection. For heavy metal analysis, separate samples were preserved with 1 mL of nitric acid (HNO_3) per litre to maintain a pH below 2 and prevent metal precipitation. All samples were stored in iceboxes during transportation and analyzed within 24–48 hours of collection.

Physicochemical analysis: The following parameters were analyzed using APHA standard methods[12]: pH: Digital pH meter, Electrical Conductivity (EC): Conductivity meter, Total Dissolved Solids (TDS): TDS meter, Dissolved Oxygen (DO): Winkler titration method, Total Hardness: EDTA titration method, Total Alkalinity: Titration with methyl orange indicator, Nitrate (NO_3^-). Spectrophotometric method, viii. Chloride (Cl^-): Argentometric titration, Calcium (Ca^{2+}), Sodium (Na^+): Atomic Absorption Spectroscopy (AAS).

Heavy metal analysis: Heavy metals including Iron (Fe), Zinc (Zn), Copper (Cu), Lead (Pb), and Cadmium (Cd) were analyzed using Inductively Coupled Plasma–Optical Emission Spectrophotometry (ICP-OES). Calibration was performed using standard solutions, and blanks were run to ensure accuracy.

Statistical analysis: Descriptive statistics, correlation analysis, and seasonal comparisons were conducted using SPSS software: i. Paired t-test: to assess seasonal differences, ii. One-way ANOVA: to test spatial differences across sites, iii. Pearson's correlation: to examine WQI–MPI relationship.

Results and Discussion

Water Quality Index (WQI): WQI was calculated following the weighted arithmetic mean method[13], which incorporates multiple physicochemical parameters and provides a single value reflecting overall water quality. Table-2 shows the water parameters studied. Each parameter was assigned a weight based on its relative importance to health.

The WQI was computed using the weighted arithmetic index method:

$$WQI = \frac{\sum W_n X Q_n}{\sum W_n} \quad (1)$$

Where, W_n is the unit weight for n^{th} parameter, W_n is calculated using the formula

$$W_n = \frac{K}{S_n} \quad (2)$$

where, S_n is BIS permissible value of that parameter, K is constant of proportionality calculated using the formula

$$K = \frac{1}{\sum(1/S_n)} \quad (3)$$

And Q_n is the quality rating scale for each parameter, calculated as

$$Q_n = \frac{(V_n - V_i)}{(S_n - V_i)} X100 \quad (4)$$

Where V_n is the measured value, S_n is the BIS standard and V_i is the ideal value of the parameters (usually 7.0 for pH and 0 for most other parameters). Table-2 shows the WQI of the parameters studied. pH values were within WHO and BIS permissible limits,[14,15] indicating neutral to slightly alkaline conditions. EC and TDS values were higher at downstream sites (S5, S6) compared to upstream forested sites (S1, S2), reflecting greater anthropogenic inputs. Similar downstream ionic increases have been reported in other Indian rivers[16,17].

DO was higher in winter due to lower temperatures but dropped at downstream summer sites, suggesting higher organic load. Comparable DO stress has been reported for the Ganga and Mahanadi Rivers[18,19]. Hardness, alkalinity, chloride, and nitrate levels were higher downstream and during summer, indicating agricultural runoff and sewage contributions. Elevated nitrate, a cause of eutrophication, is consistent with findings in Northeast Indian rivers[20]. Table-3 shows the WQI of both winter and summer. WQI values showed "good" quality at upstream sites (S1, S2) but "poor" at downstream sites (S5, S6), particularly in summer. Such seasonal deterioration aligns with reports from rivers in Rajasthan and Odisha[21,22].

Spatio-temporal assessment of WQI: The Water Quality Index (WQI) was used to assess the overall quality of water at six sampling sites during two different seasons- winter and summer. The WQI values ranged from 37.95 to 42.66**,** indicating poor to very poor water quality across all the sites in both seasons.

In the winter season, Site 1 recorded the lowest WQI value of 37.95, while Site 6 had the highest at 42.51. During summer, the lowest WQI was again at Site 1 (38.13), and the highest remained at Site 6 (42.66). This shows that Site 6 consistently experienced the worst water quality, while Site 1 had relatively better conditions in both seasons.

To examine the significance of seasonal differences, a paired sample t-test was conducted in SPSS. The results showed that the changes in WQI between winter and summer were not statistically significant**.** This means that while some sites showed small increases or decreases in WQI, the seasonal variation across all sites was not strong enough to indicate a meaningful overall difference. The slight changes could be due to minor variations in water flow, rainfall, or pollutant concentration during the two seasons.

Table-2: Water parameters (Mg/L).

Site	Seasons	Total hardness	Ammo-nia	DO	Total alkalinity	pH	TDS	EC	NO_3	Cl	Na	Ca
1	Winter	170	0.1	10	115	6.50	400	210	25	210	115	64.3
1	Summer	180	0.2	10	120	6.50	450	220	25	210	120	64.80
2	Winter	180	0.25	10	120	6.00	450	230	26.10	220	120	66.10
2	Summer	190	0.25	10	120	6.10	470	230	26.5	220	125	66.50
3	Winter	190	0.25	10	130	6.20	470	240	26.7	230	130	70.00
3	Summer	190	0.30	10	130	6.40	480	250	28.9	230	135	70.20
4	Winter	200	0.30	10	140	6.60	480	260	30.10	240	140	74.30
4	Summer	200	0.30	10	140	6.80	490	260	31.00	240	140	75.00
5	Winter	200	0.40	10	140	6./0	500	280	32	250	150	75.05
5	Summer	200	0.40	10	180	7.80	500	280	37.19	250	160	75.05
6	Winter	200	0.40	10	180	7.80	500	290	38.14	250	165	75.10
6	Summer	200	0.40	10	180	7.80	500	290	38.9	260	165	75.10

Table-3: Water Quality Index (WQI).

Stations	WQI (Winter)	WQI (Summer)
Site 1	37.95	38.13
Site 2	40.66	40.36
Site 3	40.21	39.62
Site 4	39.24	38.50
Site 5	42.33	42.38
Site 6	42.51	42.66

However, when the spatial variation (differences between the sites) was analyzed using one-way ANOVA, the results showed that there were significant differences in WQI values among the six sites in both seasons. This indicates that location has a strong influence on water quality, and different sites are affected differently based on local conditions.

Site 6, which consistently had the highest WQI values, appears to be the most polluted. This could be due to factors like agricultural runoff, domestic wastewater discharge, or other human activities. On the other hand, Site 1 had the lowest WQI values in both seasons, suggesting it may be less affected by pollution sources and possibly located in a more protected or upstream area. Figure-2 shows Seasonal comparison of WQI.

Overall, the analysis shows that while seasonal changes in water quality were minimal**,** the variation from site to site was more significant**.** This highlights the need for site-specific water management plans**.** Sites like 5 and 6, where the water quality is poorer, should be prioritized for pollution control and mitigation measures. Regular monitoring and community awareness efforts are essential to protect and improve water quality in these areas.

Metal Pollution Index (MPI): MPI quantifies the cumulative effect of trace metal concentrations in water. The index was calculated using the formula proposed by Caeiro et al. (2005), with reference to BIS permissible limits. MPI values were interpreted as follows: MPI < 1 indicates low risk; 1–2 moderate; >2 high risk.

The Metal Pollution Index (MPI) was calculated using the geometric mean formula:

$$MPI= \sqrt[n]{M_1 X M_2 X \dots M_n} \quad (5)$$

where $M_i = C_i/S_i$ with Ci representing the concentration of the i^{th} metal and Si is the BIS (Bureau of Indian Standards) recommended limit. Seven heavy metals-Copper (Cu), Arsenic (As), Lead (Pb), Manganese (Mn), Zinc (Zn), Cobalt (Co), and Iron (Fe)-were analyzed across six sampling sites during winter and summer seasons to evaluate the spatio-temporal variations in metal contamination levels. Table-4 shows the metals studied and its concentration and 5 shows the Metal Pollution index. Fe was relatively high but within safe limits. Zn and Cu were within WHO standards, while Pb and Cd exceeded limits at certain downstream summer sites, likely from vehicular emissions, dumping, and agriculture. Similar spatial variations have been reported in other Indian rivers[23,24]. The persistence of Pb and Cd is concerning due to their bioaccumulative effects[25]. MPI values were lower upstream but higher downstream, especially in summer. Some sites exceeded MPI = 1, indicating potential health risk. Similar MPI-based hotspot detection has been reported for the Yamuna and Sabarmati Rivers[26,27].

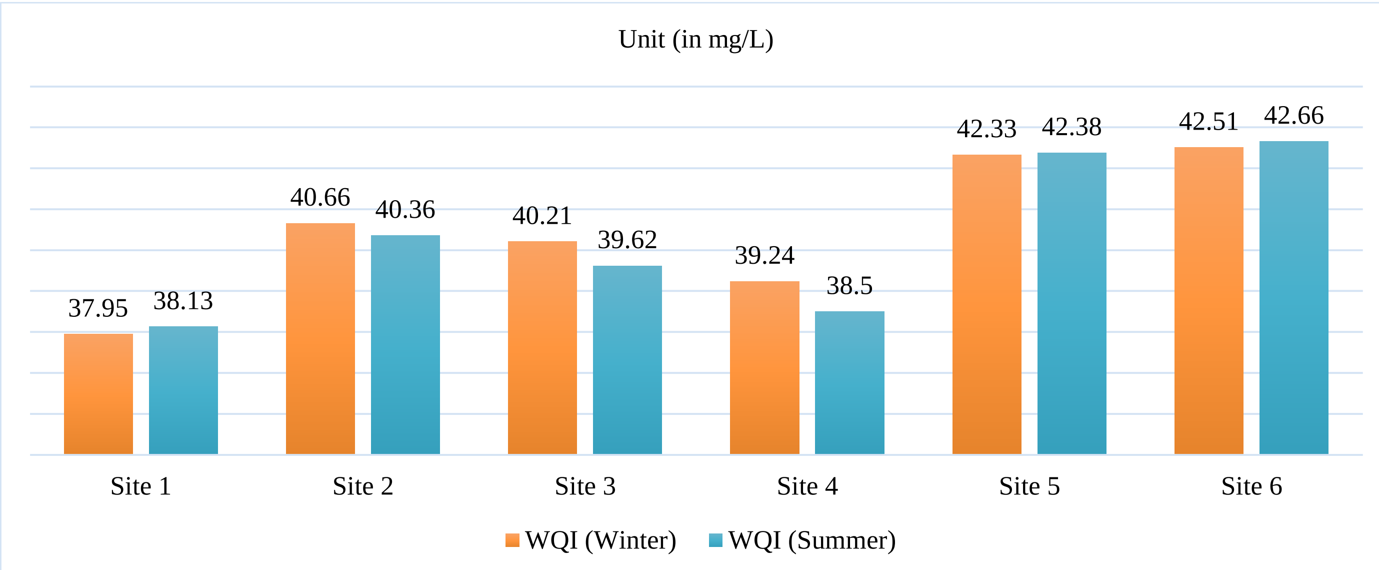

Figure-2: Seasonal comparison of WQI.

Table-4: Concentration of heavy metals.

Sites	Seasons	Copper	Arsenic	Lead	Manganese	Zinc	Cobalt	Iron
Site 1	Winter	0.020	0.001	0.004	0.034	1.2	0.02	0.12
Site 1	Summer	0.020	0.002	0.004	0.034	1.4	0.028	0.22
Site 2	Winter	0.020	0.001	0.004	0.036	1.4	0.025	0.15
Site 2	Summer	0.022	0.002	0.004	0.036	1.55	0.031	0.2
Site 3	Winter	0.022	0.001	0.005	0.039	1.65	0.028	0.2
Site 3	Summer	0.025	0.002	0.005	0.039	1.69	0.032	0.26
Site 4	Winter	0.025	0.001	0.005	0.04	2.20	0.03	0.26
Site 4	Summer	0.025	0.002	0.005	0.04	2.90	0.03	0.30
Site 5	Winter	0.025	0.001	0.006	0.045	3.10	0.03	0.30
Site 5	Summer	0.025	0.002	0.006	0.045	3.15	0.035	0.39
Site 6	Winter	0.025	0.001	0.006	0.045	3.15	0.038	0.33
Site 6	Summer	0.025	0.002	0.006	0.045	3.50	0.049	0.40

Spatio-temporal assessment of MPI: The Metal Pollution Index (MPI) was calculated for six sampling sites to assess the level of heavy metal contamination in water during both the winter and summer seasons. As shown at Table-5. The MPI values ranged from 0.693 to 0.928, which indicates the presence of metal pollutants at all sites, although with varying levels.

Table-5: Metal Pollution Index (MPI).

Stations	MPI (Winter)	MPI (Summer)
Site 1	0.693	0.701
Site 2	0.721	0.732
Site 3	0.759	0.782
Site 4	0.817	0.825
Site 5	0.855	0.902
Site 6	0.915	0.928

During the winter season, the lowest MPI value was recorded at Site 1 (0.693), while the highest was observed at Site 6 (0.915). A similar pattern was found in the summer season, where Site 1 again had the lowest MPI (0.701) and Site 6 had the highest (0.928). This consistency suggests that Site 6 is the most contaminated location, possibly due to nearby human activities, agricultural runoff, or wastewater discharge, while Site 1 appears to be less polluted, likely due to its upstream position or limited exposure to contaminants.

When comparing the two seasons, there was a slight increase in MPI values at all sites during summer. For instance, the MPI at Site 5 increased from 0.855 in winter to 0.902 in summer, and at Site 3 from 0.759 to 0.782. This seasonal rise in MPI may be due to lower water flow in summer, which reduces dilution and causes pollutants to become more concentrated. In contrast, during the winter, increased flow and runoff may help disperse some of the pollutants, resulting in slightly lower MPI values.

The spatial trend observed is clear: MPI values generally increase from Site 1 to Site 6. This suggests a cumulative effect of pollution along the flow path of the river or stream, with contaminants possibly building up as the water moves downstream. Sites located in downstream or more populated areas are likely more vulnerable to pollution from nearby settlements, agriculture, and other land use practices. Figure-3: Seasonal comparison of MPI.

Overall, the MPI results indicate that while seasonal changes are not drastic, the differences between sites are quite significant. These findings emphasize the need for site-specific monitoring and management, especially at sites with higher MPI values, to prevent further degradation of water quality due to metal pollution.

Pearson's test revealed an almost perfect positive correlation between WQI and MPI (r ≈ 1.00, p < 0.01). This shows heavy metal pollution directly drives overall water quality deterioration. Similar strong associations have been reported in other river studies[28,29].

Correlation between WQI and MPI: The relationship between the Water Quality Index (WQI) and the Metal Pollution Index (MPI) was examined to understand the role of heavy metal contamination in determining overall water quality. Both indices were assessed across six sampling sites during winter and summer seasons. Figure-4 and 5 indicates winter and summer linear trends of WQI and MPI.

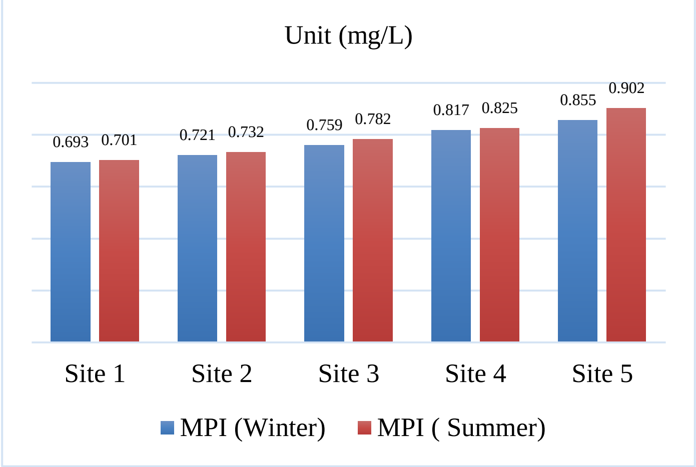

Figure-3: Seasonal comparison of MPI.

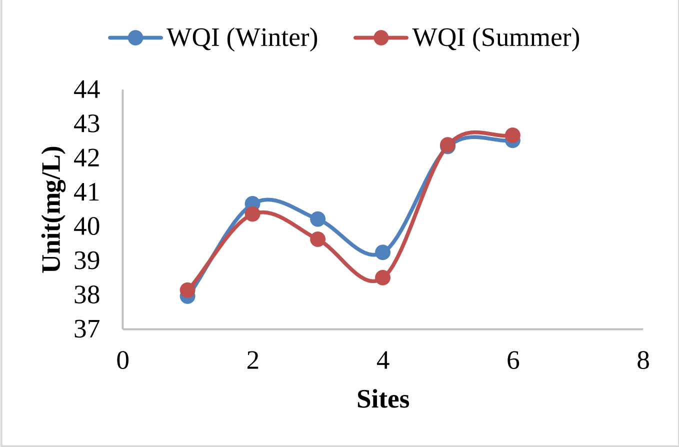

Figure-4: Winter and summer linear trend of WQI.

Pearson's test revealed an almost perfect positive correlation between WQI and MPI (r ≈ 1.00, p < 0.01). This shows heavy metal pollution directly drives overall water quality deterioration. Similar strong associations have been reported in other river studies[22]. i. Winter: WQI ranged 37.95–42.51; MPI ranged 0.693–0.915, both increasing downstream. ii. Summer: WQI ranged 38.13–42.66; MPI ranged 0.701–0.928, with slightly higher values due to lower dilution. iii. Downstream sites (S5, S6) consistently recorded highest WQI and MPI, showing cumulative effects of pollution, while S1 (upstream forest) remained least polluted. iv. This strong linear WQI–MPI relationship underscores the need to include heavy metals in water quality assessments. Targeted strategies such as effluent regulation, sustainable agriculture, and riparian buffer restoration are recommended.

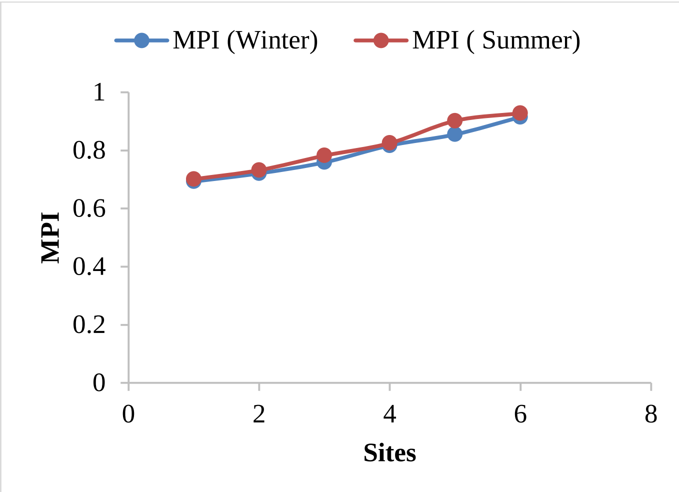

Figure-5: Winter and summer linear trend of MPI.

Conclusion

This study provides a comprehensive assessment of the spatio-temporal dynamics of water quality in the selected tributaries of the Doyang River, Nagaland, using the WQI and MPI. The findings clearly demonstrate that water quality across all six sampling sites falls within the poor to very poor category, with significant spatial variations but minimal seasonal differences. Site 6 consistently recorded the highest WQI and MPI values, reflecting the severe impact of downstream pollution sources, while Site 1 exhibited comparatively lower values, suggesting protection from upstream positioning and reduced anthropogenic interference.

The statistical analyses further revealed that seasonal variations in WQI and MPI were not significant, indicating that the quality of water remains consistently degraded throughout the year. However, spatial differences were highly significant, highlighting the influence of localized factors such as agricultural runoff, untreated domestic wastewater, and land use pressures. The consistent downstream increase in both indices suggests a cumulative accumulation of pollutants, exacerbating water quality degradation as the river flows through more intensively used landscapes.

The strong positive correlation ($r \approx 1.00$) between WQI and MPI emphasizes that heavy metal contamination plays a critical role in shaping overall water quality status. This suggests that heavy metals, likely derived from agricultural inputs, soil erosion, and effluent discharges, are among the most significant pollutants in these tributaries. Addressing heavy metal pollution, therefore, becomes central to any strategy aimed at improving water quality and sustaining aquatic ecosystem health.

From a management perspective, the results highlight the urgent need for site-specific interventions. Downstream sites, particularly Sites 5 and 6, should be prioritized for pollution control measures such as the establishment of riparian buffer zones, adoption of eco-friendly agricultural practices, improved wastewater treatment, and community-based awareness and conservation programs. Furthermore, the implementation of continuous monitoring systems is critical for detecting emerging threats, evaluating the effectiveness of mitigation measures, and ensuring long-term water security.

Beyond the local context, this study contributes to the broader understanding of riverine water quality in Northeast India, a region that is ecologically sensitive yet underexplored in terms of scientific research. The findings underscore the importance of integrating physicochemical assessments with heavy metal monitoring to capture the complexity of water pollution. They also provide valuable baseline data for future research, policymaking, and sustainable water resource management in the region.

In conclusion, the study highlights that poor water quality and significant heavy metal contamination pose serious ecological and public health risks in the studied tributaries. Immediate, coordinated, and science-based interventions are required to mitigate pollution sources, restore ecological integrity, and safeguard these freshwater systems for future generations.

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