



Spatial and Seasonal Assessment of Water Quality of Selected Streams in Mizoram, India

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Abstract: This study evaluates the spatio-seasonal variation of water quality in three streams Chite, Lawibual, and Tuikual in Mizoram, India, influenced primarily by domestic effluent discharge. Water samples were collected for four seasons, and statistical analysis include Principal Component Analysis and the Water Quality Index. Descriptive data revealed considerable fluctuation in turbidity, ionic components, and nutrient concentrations, which were attribute both natural processes and human activities. Principal component analysis identified three principal components explaining 80.16% of the total variance, identifying ionic enrichment, nutrient pollution, and hydrochemical–biogeochemical interactions as the dominant controlling factors. Water quality index showed that Chite stream fall under unsuitable classification for drinking, while Lawibual and Tuikual streams show seasonal fluctuation, ranging from good to highly polluted. The elevated water quality index values were largely driven by nutrient parameters, specifically phosphate and ammonia-N concentration, confirming domestic effluent as the principal source of pollution. The statistical approaches clarify the water quality variation and show substantial influenced of domestic wastewater. The results supported the use of wastewater management strategies and continuous monitoring to ensure sustainable water resources utilization.

IndexTerms – domestic effluents, nutrient content, pollution, sewage, water quality.

I. INTRODUCTION

Rapid urbanization, population growth, and poor wastewater management are putting stress on freshwater resources, especially in developing areas. Streams and small river systems are more prone, as they often get untreated domestic effluents and surface runoff directly. The discharge of municipal wastewater introduces elevated concentrations of nutrients such as ammonia and phosphate, along with dissolved ions, which significantly alter the physicochemical characteristics of aquatic systems and degrade water quality [1], [2]. These inputs can cause eutrophication, oxygen depletion, and deterioration of water suitability for drinking and ecological functions.

Domestic effluent is recognized as primary contributor to surface water pollution, especially in peri-urban and rural catchments that lack centralized treatment facilities. Research studies have shown that untreated sewage and domestic wastewater elevated nutrient levels and disrupt ion balance in streams, often resulting in deteriorated water quality and related health risks [2], [3]. Natural processes like rock weathering and hydrological fluctuations further change water chemistry, resulting in complex interactions that regulate overall water quality [4], [5].

Multivariate statistical techniques such as Principal Component Analysis (PCA) have been widely used to find the dominant factors that affect water quality and to distinguish between natural and anthropogenic sources of pollution. PCA effectively reduces dimensionality and reveals intrinsic correlations among water

quality parameters, facilitating the identification of key pollution sources, including nutrient loading and mineral dissolution processes [6]. The Water Quality Index (WQI) provides a simplified yet comprehensive measure of overall water quality by combining several parameters into one value, making it easier to compare sites and seasons and helping with decision on water resource management [7].

Extensive research has been done on river water quality; there remains a lack of focused investigations on small streams that are mostly affected by domestic effluent. Furthermore, comparative evaluation that integrate primary field data with secondary monitoring datasets under a common pollution framework are limited. This approach is necessary for understanding spatial variability across streams with similar pollution sources, as well, as for making the best use of environmental monitoring data. In this context, the present study focuses on three selected streams—Chite, Lawibual, and Tuikual situated in Mizoram, India. Therefore, this study aims to find out the physicochemical characteristics of the selected streams, analysed spatial and seasonal variations in water quality, identify dominant factors influencing water through PCA, quantify the water quality status using WQI, and compare primary and secondary datasets to understand variability and consistency in pollution patterns across streams affected by similar anthropogenic sources.

II. MATERIALS AND METHOD

2.1 Study Area

The research took place in three streams in Aizawl, Mizoram, located in northeast India - Chite, Lawibual, and Tuikual. These streams were selected due to their common exposure to domestic effluent, which is a significant contributor of pollution in the area.

2.2 Data Collection and Sources

Water data for Chite stream were collected seasonally (winter, spring, summer, and autumn) throughout the year 2023. Lawibual and Tuikual streams, seasonal water data were obtained from the Mizoram Pollution Control Board (MPCB), a publicly accessible governmental database for the same year. These datasets were collected and analysed by the regulatory authority following standardized monitoring procedures, ensuring reliability and consistency for comparative analysis.

2.3 Physicochemical Analysis

It examined essential physicochemical parameters such as turbidity, total alkalinity, total hardness, chloride, sodium, phosphate, ammonia-N, and nitrite-N. Analyses for the stream water were conducted following standard procedures, turbidity was measured using a nephelometric method; total alkalinity, hardness and chloride were determined by titrimetric methods, while nutrients such as phosphate and nitrogen species were measured using standard colorimetric techniques. These methods are widely accepted for water quality assessment and ensure accuracy [8].

2.4 PCA

It was employed to find the underlying relationships among water quality parameters, which helped identify the main factors affecting water quality. PCA reduces the dimensionality of multivariate datasets by transforming correlated variables into a smaller number of uncorrelated components, thereby simplifying data interpretation [9]. The dataset was standardized using z-score transformation, this was done to eliminate the influence of differing measurement units. PCA was performed using the covariance matrix, and components with eigenvalues greater than 1 were retained according to the Kaiser criterion. To improve the interpretability of the extracted components, Varimax rotation was used. The datasets suitability for PCA was evaluated using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s test of sphericity [10].

2.5 WQI

We used the weighted arithmetic method to find out if the water was suitable for drinking. This method combines different water quality measurement into a single number, which provides a complete picture of water quality [11].

The WQI was determined using the following equation:

$$WQI = \frac{\sum(W_i \times Q_i)}{\sum W_i}$$

where W_i represents the unit weight of each parameter and Q_i denotes the quality rating. The quality rating (Q_i) was calculated as:

$$Q_i = \left(\frac{V_i}{S_i} \right) \times 100$$

where V_i signifies the observed value and S_i represents the standard permissible limit, as stipulated by drinking water guidelines.

The unit weight (W_i) was derived as the inverse of the standard value:

$$W_i = \frac{1}{S_i}$$

Standard values for each parameter were adopted from established drinking water guidelines, including those established by the World Health Organization and Bureau of Indian Standards. Based on the computed WQI values, water quality was classified into categories such as excellent, good, poor, very poor, and unsuitable for drinking.

2.6 Data Analysis

All statistical analyses, including PCA, were conducted using IBM SPSS software.

III. RESULTS AND DISCUSSION

Table 3.1 Descriptive statistics of physicochemical parameters of the studied streams

Parameter	Minimum	Maximum	Mean	Std. Deviation
Turbidity (NTU)	5.20	163	39.81	49.40
Total Alkalinity (mg/L)	104	503.07	309.20	151.43
Total Hardness (mg/L)	68	260	155.22	58.37
Chloride (mg/L)	45.50	204.38	125.40	57.40
Sodium (mg/L)	16.50	104.33	44.99	31.35
Phosphate (mg/L)	0.04	1.66	0.65	0.61
Ammonia-N (mg/L)	0.09	4.27	1.39	1.21
Nitrite-N (mg/L)	0.04	1.38	0.60	0.47

N = 12

Highest variation was seen in turbidity (5.20–163.00 NTU; SD = 49.40) (Table 1), which suggest fluctuations in the amount of suspended particulate matter, associated with surface runoff, erosion, and sediment transport during period of high flow. Studies has shown that turbidity in river systems elevates during runoff events due to the transport of suspended solids and pollutants, showing sensitivity to hydrological variability [12]. The total alkalinity shows high value (309.20 mg/L) with a wide range (104.00–503.07 mg/L), indicating strong ability to resist buffering capacity. High alkalinity in surface waters is generally linked to carbonate weathering processes; however, it may also be enhanced by domestic wastewater inputs, which increase dissolved inorganic carbon and ionic content. Studies on river systems influenced by wastewater discharge have reported similar increases in alkalinity alongside other dissolved constituents [12].

The average concentration of chloride and sodium were 125.40 mg/L and 44.99 mg/L respectively. These ions are widely known as indicators of domestic sewage contamination due to their persistence and prevalence in household wastewater. Increasing level of concentrations of these dissolved ions have been linked to discharge of wastewater and urban influences in river systems [13]. Total hardness ranged from 68.00 to 260.00 mg/L (mean: 155.22 mg/L), which means that mineral content was in moderate to high. Hardness varied are primarily controlled by geochemical processes such as mineral dissolution, however, they can also be affected by seasonal changes and anthropogenic activities, as shown in recent studies of river water quality [13].

Phosphate concentrations (0.04–1.66 mg/L; mean: 0.65 mg/L) and ammonia-N (0.09–4.27 mg/L; mean: 1.39 mg/L) were high in several samples, indicating enrichment of nutrients in the water body. Domestic wastewater is a major source of nitrogen and phosphorus in river water; it causes eutrophication and depleting water quality [14]. High nutrient levels are often linked to sewage inputs that are untreated or partially treated, causing an issue in many river systems [15]. Nitrite-N (0.04–1.38 mg/L) further reflects active nitrogen transformation processes, influenced by microbial activity and environmental conditions, which often sped up in systems receiving nutrient-rich wastewater inputs [16]. The high standard deviations for turbidity and nutrient parameters show strong spatial-seasonal variability, which is characteristic of streams influenced by domestic sewage discharge. Changes in the number of pollutants entering the system, the flow conditions, and the ability to dilute leads to fluctuating water quality patterns in such systems [13].

Principal Component Analysis was used to identify the primary factors influencing variation in water quality in the studied streams. The Kaiser–Meyer–Olkin (KMO) value (0.393) indicates good sampling size, and Bartlett’s test was significant ($p < 0.001$), which shows the dataset is applicable for multivariate analysis. This method is often used for water quality research to reduce the dimension of data and identifying river systems pollution source [17]. Three principal components with eigenvalues greater than 1 were extracted, which accounted for 80.16% of the total variance (Table 2). This highlighted that the selected components are good representation of the dataset. Report had been made in recent studies where PCA effectively captured seasonal and spatial variation in water quality [3].

Table 3.2 Rotated Component Matrix of physicochemical parameters

Parameter	PC1	PC2	PC3
Turbidity	-0.178	0.369	-0.276
Total Alkalinity	0.957	0.239	-0.097
Total Hardness	-0.053	0.251	0.904
Chloride	0.969	0.078	-0.133
Sodium	0.967	0.022	0.128
Phosphate	0.212	0.876	0.376
Ammonia-N	0.259	0.796	-0.175
Nitrite-N	-0.093	-0.318	0.773

Note: Extraction method: PCA; Rotation: Varimax; loadings ≥ 0.60 considered significant.

As shown in Table 2, the first component (PC1) showed strong loadings of sodium, chloride, and total alkalinity, indicating an ionic or mineral component. This result reflects the influence exerted by dissolved salts from both geological weathering and input of domestic wastewater. Similarly, it had been reported that major ions are primary indicators of hydrochemical processes, elevating wastewater impact in river water [2]. The second component (PC2) was dominant of both phosphate and ammonia-N. It shows a specific nutrient pollution. The two parameters are extensively reported as primary contributors to degradation of water quality. Furthermore, rising level of nutrients in river water consistently associate with anthropogenic inputs, from untreated wastewater [18].

Third component (PC3) had high loadings for both total hardness and nitrite-N, possibly due to geochemical and nitrogen component, hardness reflects mineral dissolution processes, whereas nitrite signifies intermediate nitrogen cycling. It suggests interaction between natural hydrochemical conditions and biological nitrogen transformation processes in nutrient-impacted river water [17]. Turbidity did not exhibit significant loading in any component, which suggest that it operates independently and is mostly regulated by physical processes

such as runoff and sediment transport. It was reported in another study that turbidity was mostly affected by hydrological variation than by chemical composition [19].

The computed WQI values exhibited pronounced spatial and seasonal variation, reflecting differences in pollutant loading, hydrological conditions, and dilution capacity. The WQI was calculated using standard permissible limits and assigned unit weights (Table 3). Water quality classification was performed based on standard WQI ranges (Table 4). The computed WQI values for all streams and seasons are presented in Table 5.

Table 3.3 Standards and unit weights used for WQI calculation

Parameter	Standard (Si)	Unit Weight (Wi = 1/Si)
Turbidity	5	0.200
Total Alkalinity	200	0.005
Total Hardness	300	0.003
Chloride	250	0.004
Sodium	200	0.005
Phosphate	0.1	10.000
Ammonia-N	0.5	2.000
Nitrite-N	1	1.000

Standards adopted from WHO (2017) and BIS (2012) drinking water guidelines.

Table 3.4 Classification of water quality based on WQI

WQI Range	Water Quality Status
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very Poor
> 300	Unsuitable

Table 3.5 Seasonal WQI values and classification of studied streams

Stream	Season	WQI	Category
Chite	Winter	842	Unsuitable
Chite	Spring	962	Unsuitable
Chite	Summer	371	Unsuitable
Chite	Autumn	329	Unsuitable
Lawibual	Winter	735	Unsuitable
Lawibual	Spring	194	Poor
Lawibual	Summer	64	Good
Lawibual	Autumn	195	Poor
Tuikual	Winter	1304	Unsuitable
Tuikual	Spring	1414	Unsuitable
Tuikual	Summer	172	Poor
Tuikual	Autumn	37	Excellent

Chite stream consistently showed high WQI values in all seasons, stating the stream water was not fit for drinking. This can be due to high concentrations of nutrient parameters, like phosphate and ammonia-N, as well as high ionic content. These are the characteristic of streams receiving continuous input of domestic effluent, where pollutant exceeds the natural assimilative capacity of the river. Studies reported in river systems affected by untreated wastewater, where sustained nutrient enrichment leads to consistently poor water quality [2], [14].

The Lawibual stream exhibit seasonal fluctuations, ranging between good to unsuitable classification. Summer season had better water quality, this could be due to increased water flow and subsequent dilution. Conversely, poor quality of water observed in other seasons implies gradual accumulation of pollutants. Other study also

found this seasonal variation, in which hydrological conditions influenced on pollutant concentration and water flowing intensity [13]. Furthermore, Tuikual stream showed the most variations during winter and spring seasons, and autumn showed a clear improvement. This pattern indicates a significant seasonal impact, where pollutant build up when the flow is low, and dilution and flushing occurred when the flow is high. This seasonal recovery findings have also been observed, in which the water quality was affected by urban drainage and domestic wastewater [12].

IV. CONCLUSION

The present study shows that the quality of water in the selected streams of Mizoram is significantly affected by the discharge of domestic wastewater, with spatial and seasonal variability. The descriptive analysis revealed that physicochemical parameters, especially turbidity, ionic constituents, and nutrients, indicating the combined influence of natural processes and anthropogenic activities. Principal component analysis identified three primary dominant factors influencing water quality- ionic enrichment, nutrient loading, and hydrochemical–biogeochemical interactions. Of these, nutrient-related parameters were the most critical contributors, highlighting the strong impact of domestic wastewater inputs. The Water Quality Index further confirmed these results by showing consistent poor water quality in the Chite stream, while seasonal variation in Lawibual and Tuikual streams changes from excellent to unsuitable. PCA and WQI results align with each other, validating the reliability of the study and confirms that nutrient enrichment from domestic effluent is the main reason for deterioration of water quality. Seasonal improvements in specific streams show the effects of hydrological processes, particularly dilution and flushing. However, these effects are not strong enough to stop the continuous pollutant inputs. The integrated approach provides a valuable structure for evaluating water quality and additionally can facilitate informed decision-making for water resource sustainable management.

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