Water quality monitoring and water quality index of the Tuikual River in the vicinity of Aizawl city, Mizoram

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The Tuikual River is a major source of potable water for the people of Aizawl city in the state of Mizoram. Domestic and municipal waste from Aizawl's western suburbs and biomedical effluents from the Civil and Ebenezer Hospitals are getting discharged into it. Agricultural run-off adds to the river's pollution. Here we examine the water quality of the Tuikual River over two years (October 2019 to September 2021) at four sampling stations selected along the river course both upstream and downstream of the city. The water quality index was computed as 287, 310, 162 and 135 at sites 1, 2, 3 and 4 respectively. The findings depict that the river water at all the sites is unfit for drinking because the weighted arithmetic water quality index exceeds 100 at all the stations.

Keywords: Biomedical effluents, contaminants, parameters, statistical analysis, water quality index.

SURFACE water bodies, especially rivers, are getting polluted due to agricultural run-off, mining, urbanization, industrialization and developmental processes. Having enough clean water for consumption is critical for human and animal health[1]. Consumption of polluted water can result in serious water-borne diseases[2]. Because water quality is directly related to human health, producing better and safer water for consumption is necessary. Surface water bodies – especially rivers and lakes – are the primary source of water for public consumption. Around 70% of the potable surface water in India has been contaminated by household sewage and industrial effluents[3].

Rivers, lakes, ponds and springs are the main sources of drinking water in Mizoram state. They receive the water from the southwest monsoon rainfall. Because it is a hilly terrain, the water holding capacity is poor, as the rainwater runs off swiftly, and most rivers/streams dry up during the summer months, resulting in water scarcity. Considering the water quality attributes, the water quality index (WQI), which expresses the overall quality as a single number at a given location, has been determined. This study presents the WQI of the Tuikual River water upstream and downstream of Aizawl city in Mizoram state of Northeast India.

Study areas and study sites

The capital of Mizoram state, Aizawl (lat. 23°30′N and long. 92°15′E), is situated in the northern part of Mizoram state at an altitude averaging 1132 m amsl. The Tuikual River is an important source of drinking water for the people of Aizawl city. Its water is getting polluted due to the discharge of domestic and municipal wastes from Aizawl's western suburbs, as well as by biomedical effluents from Civil Hospital and Ebenezer Hospital.

Four sampling sites have been selected upstream and downstream of Aizawl, considering the nature of pollutants released into river water (Figure 1). The stretch of the river is 9.45 km, and the catchment area is characterized by pockets of mountain forest. Siltation is common on gentle slopes. Site 1 is situated near the source of the Tuikual River. The river receives discharge from Aizawl Civil Hospital, the biggest hospital in the state located in this segment. Site 2 is located downstream of the confluence of Ebenezer and Tuikual streams. It is characterized by the discharge of domestic waste from settlements and discharges from Ebenezer Hospital. Site 3, located downstream of Aizawl, also receives runoff from sandstone quarries. Site 4 is situated further downstream, close to the where Tuikual merges with the Tlawng River.

Methodology

The water samples were collected from the selected sites at monthly intervals over two 2 years, from October 2019 to September 2021, in opaque plastic bottles. The pH, TDS and DO in the samples were determined at the sampling site. The water samples were brought to the laboratory to analyse the other water quality characteristics, adopting the methods outlined in 'The Standard Methods for Examination of Water and Wastewater' (APHA, 2005)[4]. The findings were compared with the standards established by the Bureau of Indian Standards (BIS)[5], the Indian Council of Medical Research (ICMR)[6] and the United States Public Health (USPH)[7].

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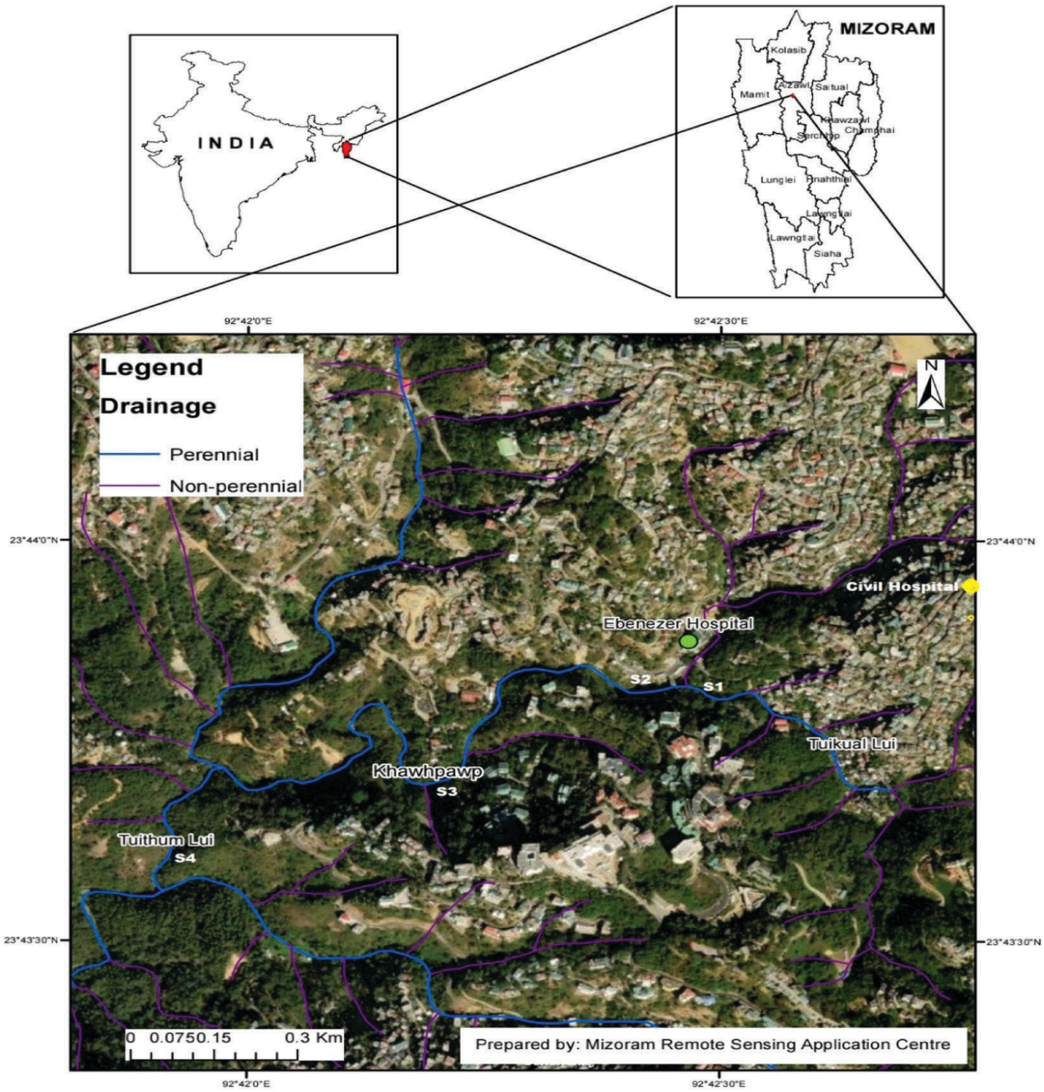

Figure 1. The sampling locations in the Tuikual River study area.

The WQI was calculated using equation[8]

$$\mathrm{WQI} = \sum_{n=1}^{n} q_n W_n \bigg/ \sum_{n=1}^{n} W_n ,$$

where q_n represents the quality rating for the nth water quality parameter and W_n represents the unit weight of the nth water quality parameter.

The quality rating, or q_n, is 100 $[(V_n - V_{\mathrm{id}})/(S_n - V_{\mathrm{id}})]$ where n is the water quality parameter, V_n the estimated value of the nth water quality parameter and V_{id} is the ideal value of the nth parameter in pure water which for all the studied parameters are 0 except for pH = 7 and dissolved oxygen (DO) = 14.6. S_n is the standard permissible value for the nth parameter.

The standard values, recommending organizations, and unit weight are shown in Table 1. $W_n = k/S_n$ where k is the proportionality constant.

To check the significance and validity of the data, SPSS-16.0 and Microsoft Excel were used.

Results and discussion

The descriptive statistics of water quality attributes for Tuikual River during the winter, summer and rainy seasons at various sampling sites are given in Table 2.

The findings indicate that the pH ranges from 6.5 to 7.7, 6.6 to 7.74, 7 to 8 and 7.2 to 8.2 at sites 1, 2, 3 and 4 respectively. The pH was lower during the rainy season and higher during the winter in both years (Figure 2 *a*). The lower pH levels during the rainy season could be due to excessive surface run-off containing organic matter releasing humic acid[9]. The total dissolved solids (TDS) are in the range 101 to 322 mg l^{-1}, 109 to 331 mg l^{-1}, 81 to 197 mg l^{-1} and 60 to 124 mg l^{-1} at sites 1, 2, 3 and 4 respectively. TDS was lower during the rainy season and higher during

Table 1. Water quality standards given by various scientific agencies and its unit weight (W_n)

Parameters	Standards	Recommending agencies	Unit weight (W_n)
pH	6.5–8.5	BIS/ICMR	0.011036
TDS (mg/l)	500	BIS/ICMR	0.000188
Nitrite-N (mg/l)	1	BIS	0.009381
Phosphate-P (mg/l)	0.1	USPH	0.938059
DO (mg/l)	5	BIS/ICMR	0.018761
BOD (mg/l)	5	ICMR	0.018761
Magnesium (mg/l)	30	BIS	0.003127
Total hardness (mg/l)	300	BIS/ICMR	0.000313
Chloride (mg/l)	250	ICMR	0.000375

BIS, Bureau of Indian Standards; ICMR, Indian Council of Medical Research; USPH, United States Public Health. TDS, Total dissolved solids; DO, Dissolved oxygen; BOD, Biological oxygen demand.

Table 2. Descriptive analysis of the Tuikual River's water quality (October 2019 to September 2021)

Parameter	Minimum	Maximum	Mean	Standard deviation	Standard error
pH	6.65	8.02	7.34	0.25	0.07
TDS (mg/l)	70.2	308.7	161.6	38.3	11.0
Nitrite-N (mg/l)	0.014	0.52	0.26	0.17	0.04
Phosphate-P (mg/l)	0.052	0.45	0.23	0.09	0.02
DO (mg/l)	3.56	7.9	5.7	0.56	0.16
BOD (mg/l)	0.6	3.4	2.09	0.40	0.11
Magnesium (mg/l)	42	146	89.4	21.5	6.20
Total hardness (mg/l)	78.7	182	123	28.9	8.36
Chloride (mg/l)	23.5	82	57.9	5.8	1.67

the summer in both years (Figure 2 *b*). Higher values during summer could be attributed to the low volume of water, resulting in the leachate of different pollutants and nutrients from underground water[10]. Nitrite-N concentrations range from 0.019 to 0.65 mg l^{-1}, 0.02 to 0.67 mg l^{-1}, 0.009 to 0.52 mg l^{-1} and 0.008 to 0.33 mg l^{-1} at sites 1, 2, 3 and 4 respectively. The lower values in the winter and higher values in the rainy season in both years (Figure 2 *c*) could be due to changes in phytoplankton tubular secretion, ammonia oxidation and nitrate reduction, as well as nitrogen recycling and microbial decomposition of planktonic detritus[11]. The phosphate-P ranges from 0.101 to 0.528 mg l^{-1}, 0.13 to 0.54 mg l^{-1}, 0.015 to 0.29 mg l^{-1} and 0.03 to 0.25 mg l^{-1} at sites 1, 2, 3 and 4 respectively. In both years, the phosphate-P was lower during the winter and higher during the rainy season (Figure 2 *d*). Higher values during the rainy season could be due to agricultural run-off containing phosphate fertilizers brought about by heavy rainfall and storm sewage inflow[12]. The phosphate-P values were higher than the USPH standard for potable water at the study sites in all the seasons. The critical limiting nutrient phosphate is thought to cause eutrophication in freshwater bodies, and when combined with nitrate-N, it causes algal blooms[13]. The DO content ranges from 3.6 to 6.2 mg l^{-1}, 3.4 to 5.8 mg l^{-1}, 6 to 7.9 mg l^{-1} and 6.1 to 8.1 mg l^{-1} at sites 1, 2, 3 and 4 respectively. Lower values were recorded during the rainy season, and higher values during the winter (Figure 2 *e*). Lower values during the rainy season may be due to the discharge of organic debris followed by microbial decomposition requiring oxygen, resulting in reduced DO content[14]. During the summer and rainy seasons, the DO content at sites 1 and 2 was lower than the BIS/ICMR limits for drinking water, leading to the death of fish. The biological oxygen demand (BOD) ranges from 1.7 to 3.5 mg l^{-1}, 1.9 to 3.7 mg l^{-1}, 0.4 to 2.4 mg l^{-1} and 0.3 to 1.7 mg l^{-1} at sites 1, 2, 3 and 4 respectively (Figure 2 *f*). Higher values during the rainy season may be due to increased organic matter through run-off containing organic matter and increased microbial decomposition[15]. The magnesium hardness ranges from 63 to 138.5 mg l^{-1}, 56 to 146 mg l^{-1}, 54.5 to 114 mg l^{-1} and 42 to 111 mg l^{-1} at sites 1, 2, 3 and 4 respectively. The values were lower during the rainy season and higher during the summer (Figure 2 *g*). The higher concentration of magnesium hardness during the summer could be attributed to the low volume of water and sewage inflow. The magnesium hardness exceeded the limit permitted by BIS at all the sites. According to reports, high magnesium levels (>100 mg/l) are linked to cardiovascular conditions and hypertension, both of which can be fatal[16]. The total hardness ranges from 86 to 189 mg l^{-1}, 85 to 198 mg l^{-1}, 75 to 169 mg l^{-1} and 62 to 150 mg l^{-1} at sites 1, 2, 3 and 4 respectively. In both years, lower values were recorded during the rainy season and higher values during summer (Figure 2 *h*). The higher values

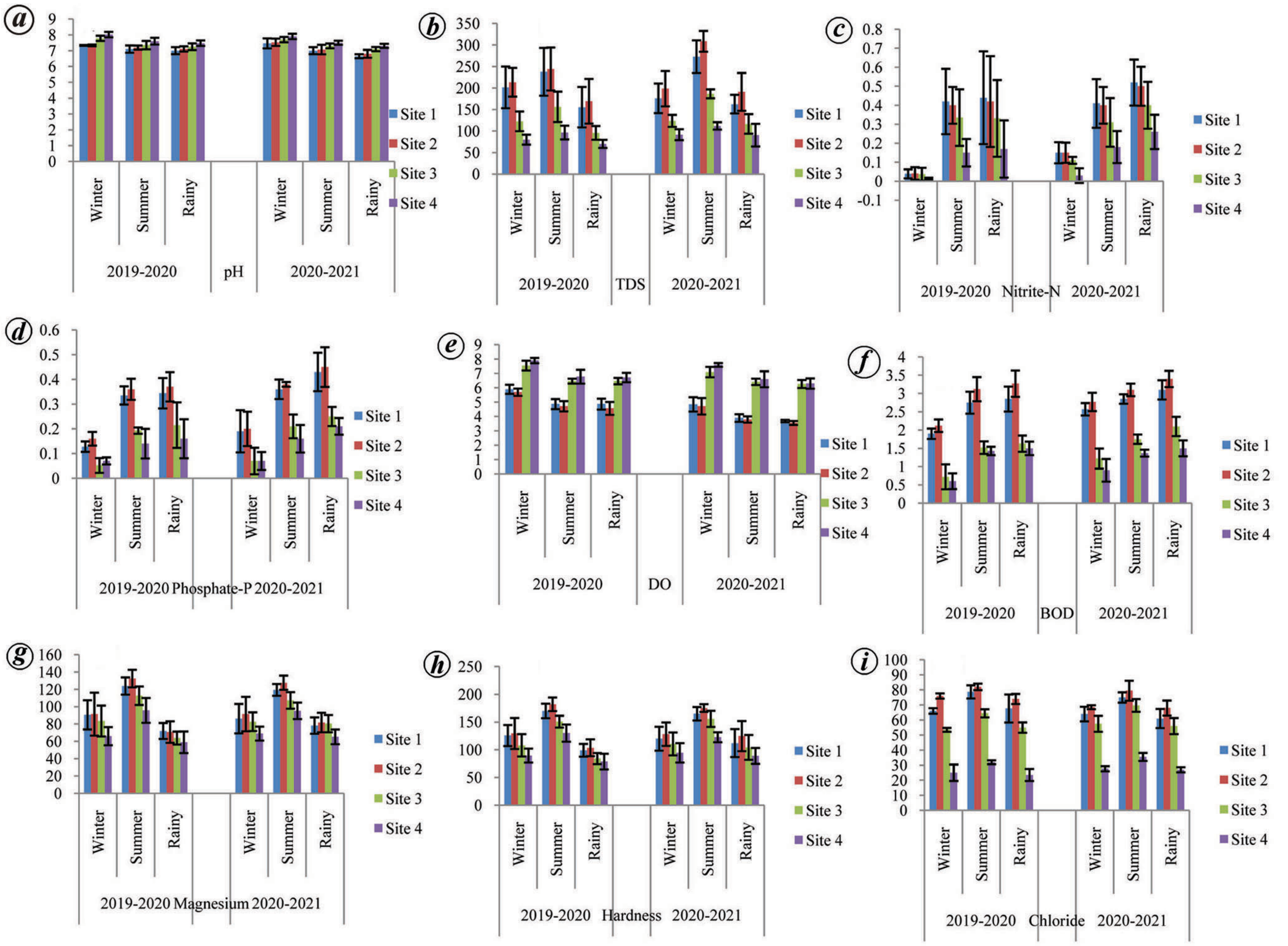

Figure 2. Seasonal variations in water (***a***) pH, (***b***) Total dissolved solids, (***c***) Nitrite-N, (***d***) Phosphate-P, (***e***) Dissolved oxygen, (***f***) BOD, (***g***) Magnesium hardness, (***h***) Total hardness and (***i***) Chloride at selected study sites.

Table 3. Pearson's linear correlation matrix (r) for water quality parameters of the study area

	pH	TDS	NO_2^-	PO_4^{3-}	DO	BOD	Mg^{2+}	TH	Cl^-
pH	1								
TDS	–0.11	1							
NO_2^-	–0.85*	0.19	1						
PO_4^{3-}	–0.92*	0.16	0.96*	1					
DO	0.88*	–0.12	–0.94*	–0.94*	1				
BOD	–0.93*	0.14	0.92*	0.97*	–0.96*	1			
Mg^{2+}	–0.11	0.95*	0.19	0.16	–0.15	0.11	1		
TH	–0.13	0.95*	0.22	0.19	–0.17	0.14	0.99*	1	
Cl^-	–0.26	0.91*	0.45	0.38	–0.41	0.36	0.92*	0.93*	1

*Correlation is significant at the 0.01 level.

could be attributed to cleaning activities in the reservoir[17,18]. The chloride content ranges from 53 to 85 mg l^{-1}, 64 to 88 mg l^{-1}, 50 to 75 mg l^{-1} and from 20 to 38 mg l^{-1} at sites 1, 2, 3 and 4 respectively. The chloride content is high during summer and less during the rainy seasons (Figure 2 *i*). The higher chloride values during the summer may be due to the low volume of water, resulting in a higher concentration of chlorides. The main source of chloride salts in river water is emissions from agro-industrial and municipal waste[19].

Correlation matrices show relationships between water quality attributes. The correlation coefficient (r) showed a

Table 4. Water quality index (WQI) and status of Tuikual river water quality

Grade	WQI	Water quality status	Tuikual river grade
A	0–25	Excellent	
B	26–50	Good	
C	51–75	Poor	
D	76–100	Very poor	
E	>100	Unfit for consumption	Sites 1, 2, 3 and 4

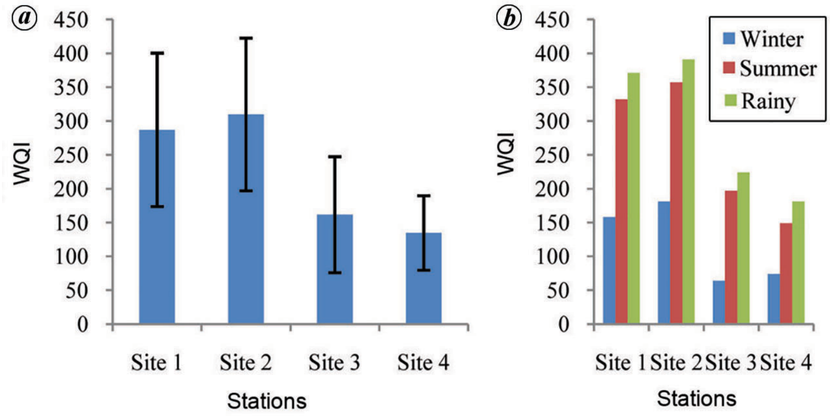

Figure 3. ***a***, The overall Tuikual river water quality index (WQI). ***b***, WQI site-specific variation during seasons.

positive and significant ($P < 0.01$) correlation between pH and DO ($r = 0.88$), TDS and magnesium hardness ($r = 0.95$), TDS and total hardness ($r = 0.95$), TDS and chloride ($r = 0.91$), nitrite-N and phosphate-P ($r = 0.96$), nitrite-N and BOD ($r = 0.92$), phosphate-P and BOD ($r = 0.97$), magnesium hardness and total hardness ($r = 0.99$), magnesium hardness and chloride ($r = 0.92$), total hardness and chloride ($r = 0.93$). On the contrary, a negative and significant ($P < 0.01$) correlation was established between pH and nitrite-N ($r = –0.85$), pH and phosphate-P ($r = –0.92$), pH and BOD ($r = –0.93$), nitrite-N and DO ($r = –0.94$), phosphate-P and DO ($r = –0.94$), DO and BOD ($r = –0.96$) (Table 3).

The WQI reveals that the quality of river water overall (Figure 3 *a*) is unfit for drinking because WQI values are 287, 310, 162 and 135 at sites 1, 2, 3 and 4 respectively (Table 4), as against the recommended maximum WQI value of 100 (Grade E) for drinking water. WQI values range from 64 to 181 in the winter, 149 to 357 in the summer and 181 to 391 in the rainy season (Figure 3 *b*). TDS, nitrite-N, phosphate-P, BOD, magnesium, total hardness and chloride are some of the contaminants introduced at each site, causing a significant impact on the Tuikual River's water quality. Since there is no effective sewage treatment infrastructure in the area, untreated residential waste continues to flow into the river. Three drains have been identified within the headwaters of the polluted Tuikual River, along with an automobile workshop, two hospitals and hotels in the vicinity of the river. Agricultural activities and intensive animal farming are also common in the catchment area.

Conclusion

The monitoring of water quality attributes indicates that the river water is polluted due to the direct discharge of waste of different origins and the lack of a proper drainage system. The high WQI values suggest the need for better drainage system management, sewer diversion to the sewage treatment plants, and proper river water treatment before supply for drinking purposes. Moreover, hospital discharge needs to be checked, as it has a severe health impact on people consuming river water.

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