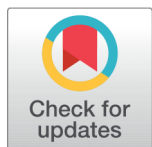


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* Corresponding author.

lallawmkimievs@gmail.com

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Multivariate Discriminant Analysis of Oxygen Saturation Level, Organic Pollution, Thermal Profile, and Chloride Variances between Tlawng and Tuirial River Systems in Aizawl, India

B Lalthlengliana¹, Lallawmkimi^{1*}, Lalnunthari Ngente¹, Hilda Lalrinpuii¹

¹ Department of Environmental Science, Pachhunga University College, 796005, Aizawl, Mizoram, India

Abstract

Objectives: The present study was intended to compare the water quality of two rivers, Tlawng and Tuirial as per their dissolved oxygen, biological oxygen demand, chloride and water temperature and to find out the variables which best discriminated the two river systems and seasons among the evaluated parameters by discriminant analysis. **Method:** Water samples were collected on a monthly basis from the selected monitoring sites from January 2023 to December 2023. Discriminant analysis was done with two different analytical dimensions: temporal (seasonal) and spatial (river system) discriminant analysis, which were performed under four active water quality parameters: dissolved oxygen, biological oxygen demand, chloride and water temperature. **Findings:** A temporal discriminant analysis produced two canonical discriminant functions (F_1 and F_2) that explained the total variance in the temporal data set (Wilks' Lambda = 0.451, $F = 13.957$, $p < 0.001$). Function 1 was dominated by dissolved oxygen (1.329), while Function 2 showed an inverse relationship with temperature (-0.947) and biological oxygen demand (0.931). For spatial discriminant analysis, a single discriminant function (F_1) accounted for 100% of the spatial variance (Wilks' Lambda = 0.668, $F = 14.318$, $p < 0.001$), where dissolved oxygen (1.234) was found to be a strong contributor to the discriminant function (1.234) while the remaining parameters showed a low contribution to the discriminant function. **Novelty:** Comparative data on hydrochemical properties of Tlawng and Tuirial rivers remains scarce; this study provides the first multivariate discriminant analysis of oxygen saturation level, organic pollution, thermal profile, and chloride variances between Tlawng and Tuirial river systems in Aizawl to identify the variables that discriminate between these systems and minimize spatial-temporal noise within the complex monitoring matrix of Aizawl district.

Keywords: Discriminant analysis; Dissolved oxygen; Tlawng; Tuirial; Aizawl

1 Introduction

Ensuring water quality has become a major concern for public authorities across the world⁽¹⁾. To promote a more sustainable and resilient global future, the United Nations (UN) introduced the 2030 Agenda in 2015, with Goal 6 of the Sustainable Development Goals (SDGs) focusing specifically on securing the availability and sustainable management of water and sanitation for all⁽²⁾. The quality of surface water is a key factor in human health, economic activities and the maintenance of ecosystem and biodiversity⁽³⁾. Due to population growth, climatic change and human activities, one of the greatest challenges faced by modern regions is the management of freshwater resources⁽⁴⁾. Rivers are highly susceptible to these challenges and pressures, which can significantly affect their quality⁽⁵⁾. Therefore, understanding the condition and changes in river water quality is an essential first step toward developing effective and sustainable management policies⁽⁶⁾.

In the context of Aizawl district, which is the capital of Mizoram, rapid urbanization and localized anthropogenic activities have also increased pressures on these rivers, the Tlawng river located on the west and the Tuirial on the east side of the district⁽⁷⁾. These rivers are the largest and most important freshwater systems in the district that provide water for domestic supply, agriculture and other livelihood activities^{(8), (9)}.

Previous studies have highlighted water quality issues in both systems. A study on the Tlawng river reported that the dissolved oxygen (DO) and biological oxygen demand (BOD) parameters exceeded permissible limits due to high organic decomposition during the monsoon season⁽¹⁰⁾. Similarly, a water quality assessment of the Tuirial river revealed that the magnitude of pollutants increased from upstream to downstream mainly because of human activities⁽¹¹⁾.

Although recent hydrogeochemical studies have reported localised water quality within each respective river in Aizawl, it is still unclear whether the two rivers follow similar seasonal water quality trends or differ in their response to anthropogenic and natural influences. Comparative information on the hydrochemical properties between the Tlawng and Tuirial rivers remains scarce. Furthermore, no previous studies have applied multivariate discriminant analysis.

Recent surface water quality investigations have increasingly moved away from using indexal methods for monitoring to multivariate statistical methods⁽¹²⁾. Multivariate statistical techniques have been utilised by many researchers for the interpretation of complex information structures to enhance understanding of the quality of water⁽¹³⁾. Discriminant analysis is one such technique that is very useful in the identification of the parameters that best separate the groups to identify the key spatial and temporal discriminators between these two rivers⁽¹⁴⁾.

To address this gap, the present study was conducted to assess the variations in core water quality parameters along the Tlawng and Tuirial river systems and to identify the primary spatial and temporal discriminating variables in both the river systems. In doing so, this study aimed to provide a baseline chemometric evidence to support tailored, differential catchment management strategies across Aizawl district.

2 Methodology

2.1 Study area

The Tlawng river lies to the west and the Tuirial river to the east of Aizawl city, the capital of Mizoram. The study was conducted within Aizawl district and consisted of ten (10) monitoring sites, five (5) sites per river system (Figure 1).

2.2 Sampling protocols and laboratory analysis

Water samples were collected on a monthly basis from the selected monitoring sites from January 2023 to December 2023. The months of January to April were grouped as pre-monsoon season, May to August as monsoon season and September to December as post-monsoon season (N = 120). Analysis of the water quality parameters (temperature, dissolved oxygen, biological oxygen demand and chloride) followed the standard protocols established in *Standard Methods for the Examination of Water and Wastewater*⁽¹⁵⁾. Temperature was measured on the spot and recorded, while the remaining parameters were measured in the laboratory using appropriate procedures.

2.3 Multivariate statistical analysis and model validation

Discriminant analysis (DA) was used to systematically investigate the factors influencing spatial and temporal water quality variation in two different analytical spaces: temporal (seasonal) and spatial (river system). Four water quality parameters namely dissolved oxygen (DO), biological oxygen demand (BOD), chloride and water temperature were tested. Dissolved oxygen (DO), biological oxygen demand (BOD), thermal profiles and chloride concentrations are highly sensitive diagnostic parameters for organic loading, stream metabolism, and dilution of sewage. The chosen method, discriminant analysis, is one that includes

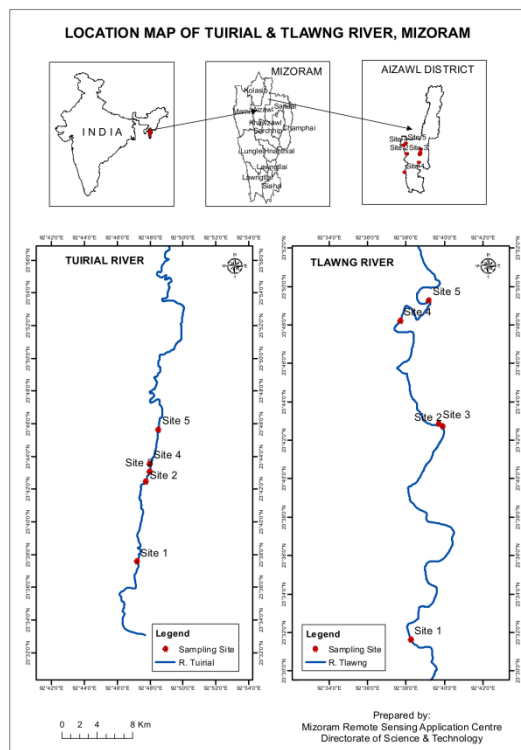


Fig 1. Map of Tlawng river and Tuirial river

pre-defined group labels (river systems and seasonal regimes). This supervised method will have the highest between-group difference and the lowest within-group difference, which helps to minimize spatiotemporal noise throughout the monitoring matrix. Model validity and global statistical significance were done based on Wilks' Lambda, the observed F -statistic (observed F – value) and cross-validation classification matrices. Wilks' Lambda was used to calculate the amount of variance not accounted for by the model and the F -statistic was used to examine whether the group centroids were significantly different at the alpha (α) priori significance level 0.05. Cross-validation was also used to show the model's predictive performance, with the spatial discriminant model showing a classification accuracy of 99.17% and the temporal model 98.33% for the three seasonal groups. The multivariate operations, extractions of eigenvalues, standardization of the data and the canonical scatter plot mapping the individual observation scores and their group centroids were performed directly in XLSTAT software of Microsoft Excel.

2.4 Temporal (seasonal) discriminant analysis

The three different seasons of pre-monsoon, monsoon and post-monsoon were considered to be the three different operational groups for the temporal model. Canonical discriminant functions were extracted as linear combinations of the variables:

$$F_i = \sum_{j=1}^n w_j X_j$$

where,

F_i represents the discriminant score of function i .

w_j represents the standardized canonical discriminant coefficient for parameter j .

n represented total number of monitored water quality parameters ($n = 4$)

X_j represents the monitored pool concentration of variable j .

The standardized canonical coefficients were obtained to evaluate the relative load weights of individual environmental parameters on the different functional axes. Mathematical dominance of each extracted function was measured using eigenvalues, canonical correlation values and percentage of variance metrics.

2.5 Spatial (river system) discriminant analysis

A secondary spatial discriminant analysis was also performed to test the null hypothesis that the two baseline water quality profiles have the same spatial matrix. In this model, two groups were predefined: the Tlawng river and the Tuirial river. Given this particular setup, the spatial classification engine generates one canonical discriminant function ($F1$) to account for 100% of the spatial variance, as it is dealing with only two independent streams.

2.6 Data availability statement

The raw hydrochemical dataset and multivariate XLSTAT statistical processing sheets generated during the current study are available from the corresponding author upon reasonable request.

3 Results and Discussion

3.1 Hydrochemical dynamics and seasonal variations

The background water quality parameters of the Tlawng and Tuirial river systems were found to be distinctly seasonal and were also spatially variable depending on the monsoonal rainfall and the local catchment conditions. The lowest mean water temperature of both systems was during the post-monsoon season (Tlawng: $18.70 \pm 1.98^\circ\text{C}$; Tuirial: $18.75 \pm 2.83^\circ\text{C}$), which was the winter season. On the other hand, thermal peaks were experienced in the pre-monsoon season which could be caused by increased solar intensity and decreased baseflow⁽¹⁶⁾ (Figure 2). The dissolved oxygen (DO) dynamics was one of the main indexes of the health of the river⁽¹⁷⁾, and showed an inverse relationship between water temperature and organic loads. The highest mean dissolved oxygen values were consistently observed in post-monsoon which ranged from $6.20 \pm 0.43 \text{ mgL}^{-1}$ in Tlawng river and a notable mean of $7.00 \pm 0.43 \text{ mgL}^{-1}$ in Tuirial river (Figure 3). This optimal oxygenation could be due to the lower water temperature, which maximizes water capacity to accommodate oxygen, and post-rain stabilization, which reduces suspended solids⁽¹⁸⁾. On the other hand, during the monsoon period, dissolved oxygen levels dropped significantly, reaching their lowest mean value of $4.97 \pm 0.46 \text{ mgL}^{-1}$ in the Tlawng system. This could be due to a large amount of surface runoff and soil erosion from organic matter that was washed into the river channels during heavy rains, which greatly increased the oxygen demand of the river for microbial breakdown of the organic matter. The trend of biological oxygen demand (BOD) also showed the increased in organic pollution during the monsoon (Figure 4). Peak mean biological oxygen demand concentration in the Tlawng river was observed during the monsoon ($2.45 \pm 0.75 \text{ mgL}^{-1}$) which coincided with the period of least dissolved oxygen availability⁽¹⁹⁾. Similar monsoonal deoxygenation pattern caused by urban runoff were also reported by Koley *et al.*⁽²⁰⁾ in the Yamuna river basin⁽²¹⁾. The Tlawng river had a higher mean biological oxygen demand concentrations across all seasons (1.96 to 2.45 mgL^{-1}) than the Tuirial river (1.75 to 1.99 mgL^{-1}). A consistent difference was observed in the Tlawng catchment which may be caused by the discharge of domestic wastewater and agricultural runoff from nearby settlements⁽²⁰⁾. The highest mean concentration of chloride in the two river systems were observed in the pre-monsoon phase (Tlawng: $25.85 \pm 18.04 \text{ mgL}^{-1}$, Tuirial: $24.87 \pm 17.84 \text{ mgL}^{-1}$). These low flows during this time period could cause an extreme concentration effects on the hydrology of the area, causing more noticeable impacts from domestic and municipal chemical effluents⁽²²⁾. The chloride concentration decreases significantly with the onset of the monsoon season with a minimal mean concentration of $18.70 \pm 13.62 \text{ mgL}^{-1}$ in Tuirial river. As the monsoon season begins, the flow of rain water dilutes chloride levels to a significant extent (reaching a minimum mean of $18.70 \pm 13.62 \text{ mgL}^{-1}$ in the Tuirial river) overriding localized chemical concentration effects⁽²³⁾ (Figure 5).

3.2 Multivariate discrimination of temporal variations

Table 1. Discriminant function coefficients and Wilks' Lambda for temporal variations in water parameters (N = 120).

Func- tion	Standardized canonical discriminant function coefficients Eigenvalues Wilks' Lambda								F-value (Observation)	df	Sig. (p)
	Temp.	DO	BOD	Chlo- ride	Eigen- value	% of variance	Cumula- tive %	Canonical Correlation			
1	0.245	1.329	0.409	0.359	1.070	93.677	93.677	0.719	13.957	8	<0.001
2	-0.947	0.352	0.931	- 0.702	0.072	6.323	100.00	0.260			

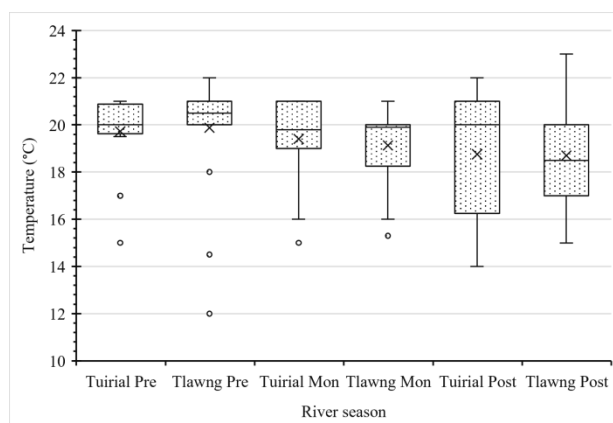


Fig 2. Temperature (°C) variations across river and season, (pre = pre-monsoon, mon = monsoon, post = post-monsoon).

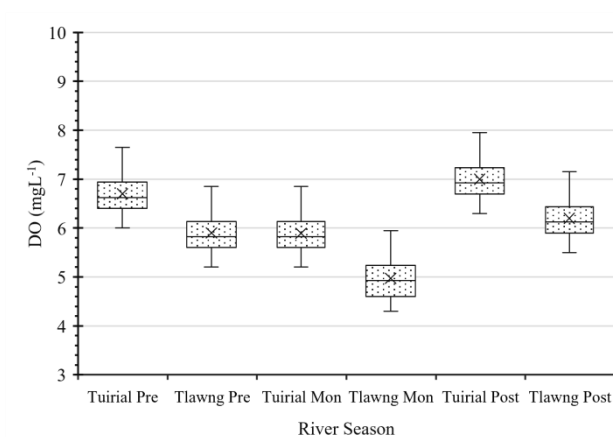


Fig 3. DO (mgL⁻¹) variations across river season, (pre = pre-monsoon, mon = monsoon, post = post-monsoon).

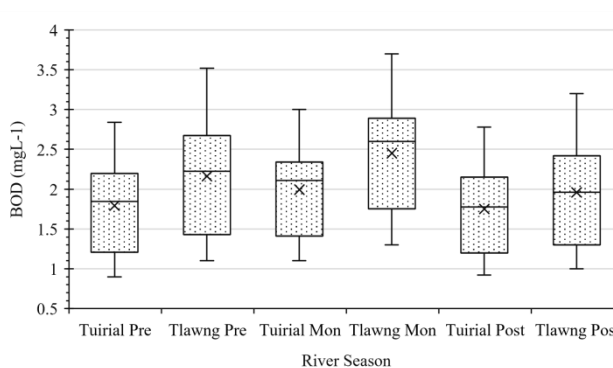


Fig 4. BOD (mgL⁻¹) variations across river season, (pre = pre-monsoon, mon = monsoon, post = post-monsoon).

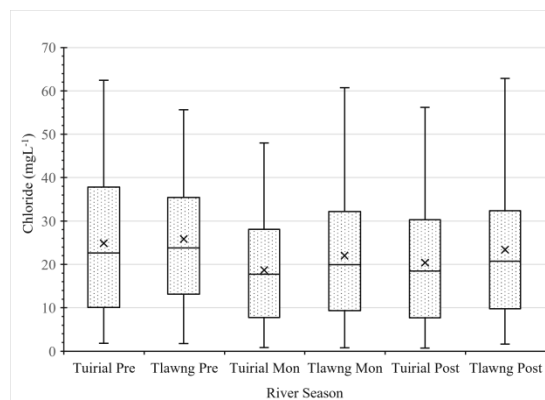


Fig 5. Chloride (mgL^{-1}) variations across river season, (pre = pre-monsoon, mon = monsoon, post = post-monsoon).

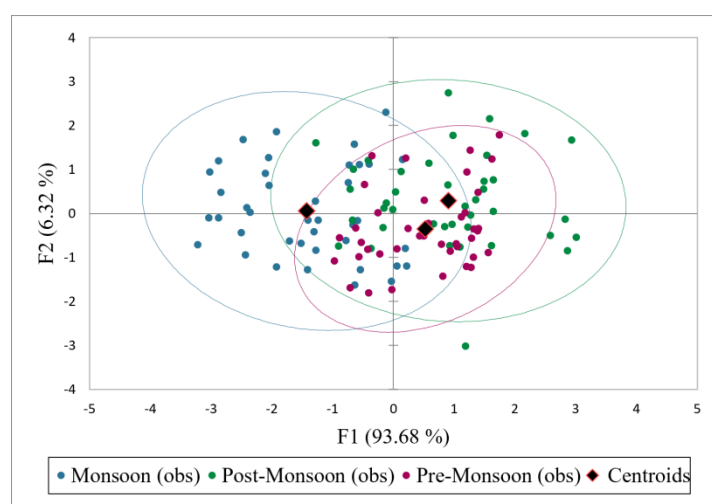


Fig 6. Canonical Discriminant Analysis observation plot mapping individual observation scores across F1 and F2 along with seasonal group centroids for pre-monsoon, monsoon and post-monsoon, (obs = observation).

A temporal discriminant analysis (DA) was employed to find out the parameters that were responsible for the changes in the water quality in the three seasonal groups (pre-monsoon, monsoon, post-monsoon). The analysis produced two canonical discriminant functions (F_1 and F_2) that explained the total variance in the temporal data set. Wilks' Lambda value (0.451) and F -value (13.957) supported a significant difference between the seasonal groups ($p < 0.001$). Function 1 (F_1) accounted for 93.677% of the total variance between the three sampling seasons with a high canonical correlation (0.719). Among the evaluated parameters, dissolved oxygen proved to be a strong contributor in discriminating the three seasons (1.329) while the other parameters showed a low contribution to the discriminant function. Function 2 (F_2) accounted for 6.323% of variance that was governed by an inverted contribution from temperature (-0.947) and chloride (-0.702) against biological oxygen demand (0.931). Table 1 showed the relative contributions of the studied parameters.

The canonical observations plot shown in Figure 6 visually supported this mathematical analysis. The monsoon group was on the negative side of the horizontal axis (F_1) and was extremely separated from the other seasonal groups. This could be related to the low dissolved oxygen and high organic loading during the wet season⁽¹⁹⁾. This outcome corroborates findings by Das in the Baitarani river basin⁽²⁴⁾ and Bramhanker *et al.* in the Nag river⁽²⁵⁾, where organic pollution and aeration indices dominated spatial canonical axes. The pre-monsoon and post-monsoon dry periods were in the positive domain of F_1 on the other hand. They were further separated by the vertical axis (F_2) which resulted in the pre-monsoon cluster in the negative quadrant (higher temperature and localized chloride concentrations). The post-monsoon cluster was seen in the positive quadrant (low water temperature). The separation of the group centroids provided a distinct separation of the basins which further showed the dominant influence of seasonality on the hydrochemical matrix of these basins.

3.3 Discrimination between river systems

Table 2. Discriminant function coefficients and Wilks' Lambda for variations between river systems (N = 120).

Function	Standardized canonical discriminant function coefficients							Eigenvalues		Wilks' Lambda		F-value (Observation)	df	Sig. (p)
	Temp.	DO	BOD	Chloride	Eigenvalue	% of variance	Cumulative %	Canonical Correlation	Wilks' Lambda					
1	0.260	1.234	0.361	0.004	0.498	100.00	100.00	0.577	0.668			14.318	4	<0.001
													,115	

A secondary spatial discriminant analysis was used to find out whether the Tlawng and Tuirial river systems were actually different hydrochemical environments in the absence of a seasonal noise. Table 2 showed the relative contributions of the evaluated parameters. The spatial analysis consisted of a single discriminant function F_1 , which accounted for 100% of the spatial variance and had a canonical correlation of 0.577, as this analysis only examined two different groups (Tlawng versus Tuirial). The spatial model was found to be statistically significant with a Wilks' Lambda of 0.668 and an observed F -value of 14.318 ($p < 0.001$), which meant that the null hypothesis (the water profiles for the two rivers were identical) was rejected.

From the standardized canonical coefficient of the spatial function, it was observed that among the evaluated parameters, dissolved oxygen (1.234) was a strong contributor and the most important spatial discriminator between Tlawng and Tuirial rivers, while the remaining parameters showed a low contribution to the discriminant function. The dissolved oxygen coefficient was heavily loaded (1.234), suggesting a better aeration capacity and lower organic loading signature for the Tuirial river system⁽¹⁸⁾ than the more anthropogenic stressed Tlawng river, as indicated by higher mean dissolved oxygen values in the Tuirial river throughout all parallel seasons.

4 Conclusion

This study provides the first comparative multivariate assessment of the Tlawng and Tuirial river systems in Mizoram using discriminant analysis (DA) to uncouple seasonal dynamics from spatial pollution profiles. The temporal discriminant analysis model effectively segregated seasonal regimes (Wilks' Lambda = 0.451, $p < 0.001$) with 98.33% classification accuracy, driven primarily by monsoonal deoxygenation and runoff dilution. Spatial DA demonstrated that both river systems possess distinctly different hydrochemical signatures (Wilks' Lambda = 0.668, $p < 0.001$) with 99.17% cross-validation accuracy. Dissolved oxygen (1.234) served as the primary spatial discriminator, confirming that the Tuirial River maintains higher reaeration capacity, whereas the Tlawng River suffers greater anthropogenic organic stress. These findings prove that uniform regional monitoring is insufficient, highlighting an urgent need for targeted municipal wastewater mitigation in the Tlawng catchment.

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