ASSESSMENT OF THE TROPHIC STATUS AND WATER QUALITY IN THE HINH RIVER BASIN, CENTRAL VIETNAM

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Abstract

This study aims to evaluate the eutrophication status and ecological conditions of the Hinh River basin underhydrological conditions. The Hinh River basin is essential for agriculture, hydroelectric power, and water supplies. Evaluating the trophic status and water quality is a supply-based science that is essential for environmental preservation and sustainable water resource usage. Surface water samples were collected from twenty-two sites in 2024-2025 during dry and rainy seasons. The result shows the parameters TSS, DO, COD, TN, and TP vary seasonally and are influenced by rainfall. The river is nitrogen-rich (TN exceeds standards by 2.7–3.8 times) and phosphorus-limited (N:P ratio > 20). The trophic index (TRIX) indicates the dominance of eutrophic conditions (TRIX > 6). Positive correlations between TRIX and TN, TP, and chlorophyll-a reveal nutrient enrichment mainly from agricultural, domestic, and industrial wastewater.

Keywords: *Eutrophication, nutrients, Hinh River basin, trophic state index, ecological.*

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1. INTRODUCTION

Surface run off from basins with diverse land use types flows into rivers, serving as a pathway for transporting nutrients in dissolved and suspended forms from the soil to receiving water bodies, which may include rivers, lakes, or oceans [1]. River, stream, lake, and reservoir systems are important aquatic ecosystems both ecologically and economically because of their high biodiversity and productivity. Therefore, for countries in tropical regions, when considering the current state of dammed rivers and future development projects, there is significant concern about the ecological conditions, nutrient status, and water quality of these systems.

The increase in the fertility of water bodies is a natural part of the developmental process of all aquatic systems. However, the accelerated eutrophication of these water bodies is more broadly recognized as a result of human activities. Changes in the state and quality of surface water are determined not only by the external input of nutrients but also by internal processes occurring within aquatic ecosystems [2]. Human activities alter the biogeochemical cycles of nutrients through processes such as changes in land use and land cover, as well as runoff from residential and agricultural areas, leading to a significant increase in nutrient loads within aquatic ecosystems [3]. Increased nutrient levels can disrupt the balanced nitrogen-to-phosphorus (N:P) ratio required for primary productivity. Excess nutrients can lead to blooms of certain microalgal species that may release toxins, thereby reducing natural biodiversity, degrading water quality, and causing nutrient imbalances [4].

The Hinh River basin is located in southwestern Phu Yen Province in central Vietnam. This basin's landscape is highly important, providing essential environmental services to downstream areas [5]. Located in the transition zone between the lowland plains and the Central Highlands, in the upper and middle reaches of major rivers and streams flowing through the southern part of Phu Yen Province, the Hinh River Basin holds significant value for watershed protection, water resource storage, and ecological conservation. The area has abundant and relatively rich surface water resources, but experiences water scarcity during certain periods. This reality has led to the construction of reservoirs that store water for human use. However, there have been only a few environmental studies related to this area, such as the use of the Water Quality Index (WQI) to assess river basin water quality [6].

Eutrophication is the process of enriching water with nutrients, primarily nitrogen and phosphorus, leading to an increase in the primary productivity of algae (in terms of chlorophyll-a) [7]. To assess river water quality, Dodds et al. (1998) proposed the use of values of TN, TP, and Chl-a to classify trophic status. However, using a univariate scale may not be sufficient to describe the nutrient status of rivers[8]. Therefore, a multivariate approach is needed to evaluate river water quality by using a trophic index (TRIX) [9, 10]. This index is a mathematical equation that integrates information from the most important parameters of the dataset, enabling it to describe the overall condition and reflect changes in a representative manner [11]. It is one of the main tools supporting decision-making related to water resources, contributing to the development of environmental policies at the local, regional, and national levels.

Access to safe water is essential for sustaining human life, ecosystems, and socioeconomic development. The objective of this study was to apply the Trophic State Index (TRIX) to assess the trophic status and ecological conditions of the Hinh River basin under the impact of anthropogenic pressures. The water quality in this river basin plays an important role in the socioeconomic development of Phu Yen Province and the Central Highlands region. The highlight points of the paper are: 1). Evaluated the water quality and eutrophication status of the Hinh River basin; 2). Identified nitrogen as a major pollutant, with concentrations exceeding standards.3). Determined anthropogenic inputs drive eutrophication and impact water quality.

The trophic status of aquatic ecosystems reflects the degree of nutrient enrichment and biological productivity, which directly influence water quality and ecological balance. Based on nutrient levels (TN, TP) and algal biomass (Chl-a), aquatic systems are generally classified as mesotrophic, meso-eutrophic, or eutrophic. Mesotrophic waters have moderate nutrient concentrations and primary productivity, indicating a balanced ecosystem with limited algal growth. Meso-eutrophic conditions represent a transitional stage between mesotrophic and eutrophic states, where nutrient enrichment and algal biomass increase noticeably, and water transparency begins to decline. Eutrophic waters are characterized by high nutrient concentrations, excessive algal blooms, and oxygen depletion, often resulting from anthropogenic nutrient loading. Understanding these trophic levels helps evaluate ecological conditions, diagnose eutrophication risks, and guide sustainable management of river basins such as the Song Hinh [8, 9, 23, 24].

2. MATERIALS AND METHODS

2.1. Study area

The Hinh River is one of the three largest tributaries of the Ba River. It originates from the Chu H'Mu peak at an elevation of approximately 2,051 m and converges with the Da Rang River in Duc Binh Tay commune of Song Hinh district after a course of approximately 88 km (Fig. 1).

The total area of the Hinh River basin is approximately 1,021 km^2, and its annual flow volume is approximately 1.7 billion m^3 [12]. The climate of the Hinh River basin is a tropical monsoon climate, with an average annual temperature of 26°C, a minimum temperature of 22.1°C, and a maximum temperature of 28.7°C. The long-term average rainfall ranges from 2,200 to 2,400 mm, with an average of approximately 150–160 rainy days per year [5]. The main land use patterns in the basin include agricultural land and forestland, followed by water bodies and built-up areas. The main types of forests present in the area are evergreen broadleaf forests and plantation forests.

2.2. Sampling and analytical techniques

Surface water samples (n = 44) were collected in clean polyethylene bottles from twenty-two locations across the Hinh

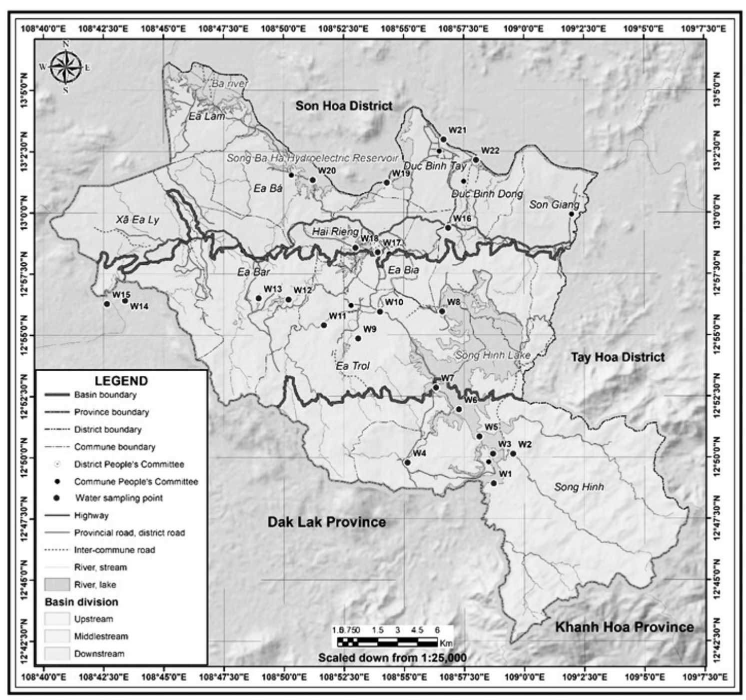

Figure 1. Study area diagram showing the sampling points in the Hinh River basin

River basin during the dry season (March 2024) and at the end of the rainy season (January 2025) (Figure 1). The sampling coordinates were determined via a Garmin 64S GPS device. All samples were collected to the standards TCVN 6663-1:2011, TCVN 6663-4:2020, and TCVN 6663-6:2018. After sampling, the water samples were pretreated and stored following TCVN 6663-3:2016 to prevent any changes in composition caused by chemical reactions, physical processes, or biological degradation. Water temperature (T), pH, and dissolved oxygen (DO) were measured directly in the field via a TOA WQC22A multiparameter meter. The samples were then transported in iceboxes to the laboratory. Analyses of total suspended solids (TSS), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), and chlorophyll-a (Chl-a) were carried out following the standard methods outlined in the Vietnamese Technical Regulation (QCVN 08:2023) (Figure 1).

The selection of twenty-two sampling sites was based on the hydrological, geomorphological, and land-use characteristics of the Hinh River basin to ensure spatial representativeness of the entire watershed. The sites were distributed along the river's main course and its tributaries, covering upstream, midstream, and downstream sections with distinct topographic and land-use features. Upstream stations (W1–W6) represent forested headwaters with limited human influence; midstream stations (W7–W15) correspond to mixed agricultural and residential zones with moderate anthropogenic activities; and downstream stations (W16–W22) are influenced by intensive agriculture, aquaculture, and mining activities. This spatial framework captures the gradients of nutrient input and water quality variations across hydrological and land-use zones, thereby ensuring the representativeness of sampling points for the entire Hinh River basin [5, 15, 16].

***2.3. Trophic status assessmen*t**

2.3.1. Nutrient stoichiometry (N:P)

The N:P mass ratio is considered an important factor for diagnosing trophic status and indicating nutrient limitation in aquatic systems [13]. An N:P ratio between 10 and 20 suggests balanced nutrient conditions in the water body, whereas a ratio below 10 indicates nitrogen limitation, and a ratio above 20 indicates phosphorus limitation [14]. The N:P ratio has been used to identify which nutrient has the greatest influence on primary productivity.

2.3.2. Trophic indices

In this study, the trophic status of the Hinh River basin was determined via the modified trophic index (TRIX) for river water, as proposed by Paula Filho et al. (2020) [10]. The multivariate TRIX index is calculated via Equation (1):

$$TRIX = [\log(Chl-a \times D\%O \times TN \times TP) - 3.7]/0.41 \quad (1)$$

Where TN, TP, and Chl-a are concentrations measured in µg/L, and D%O is the absolute deviation of dissolved oxygen from 100% oxygen saturation. The classification scale considers five trophic status categories as follows: TRIX < 2 (ultraoligotrophic/excellent); 2 < TRIX < 4 (oligotrophic/high); 4 ≤ TRIX < 5 (mesotrophic/good); 5 ≤ TRIX < 6 (mesotrophic to eutrophic/moderate); and TRIX > 6 (eutrophic/poor) [9].

2.4. Data analysis

Microsoft Excel 2016 and XLSTAT 2025 software were used for data processing. A t-test was applied to determine any statistically significant differences between the mean values of the hydrochemical variables ($p < 0.01$). Pearson correlation analysis was performed to identify linear relationships between variable pairs on the basis of correlation coefficient values ($p < 0.05$). Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were conducted to identify relationships among different physicochemical parameters and pollution sources. The correlation between the TRIX index and eutrophication parameters was analysed via a simple linear regression model. Maps were created viathe ArcGIS 9.0 software. The color distribution was implemented on the basis of values via a hierarchical color scheme. All maps were drawn via a geographic coordinate system with the WGS84 horizontal datum.

To demonstrate the effectiveness of Chl-a, TN, TP, and D%O parameters when applied to environmental research of the research area, the linear regression method was used to quantitatively test the relationship of the above environmental parameters.

3. RESULTS

3.1. Hydrochemical parameters and their variations

The data obtained from the analytical studies were subjected to descriptive statistics, including mean values and standard deviations. The water quality parameters and regulatory limits for the hydrochemical variables at the twenty-two sampling stations are summarized in Table 1. To assess the impact of anthropogenic activities within the basin, the water quality parameters were compared with the surface water quality standards for the best intended use (class A) set by Ministry of Agriculture and Environment (formerly Ministry of Natural Resources and Environment)-QCVN 08:2023/BTNMT. The t - test($p < 0.01$) revealed statistically significant differences in T, TSS, DO, COD, and TN between the dry and rainy season sampling periods. In contrast, pH, D%O, TP, and Chl-a were not significantly different. The Ave ± SD value represents the dispersion of the ambient values around the mean value (Table 1).

The pH measurements mostly fell within the regulatory range, with average recorded values of 7.5 (dry season) and 7.4 (rainy season). However, during the dry season, some pH measurement points are outside the level A threshold as prescribed in QCVN 08:2023, including points from 2 to 6. The TSS values were largely within the regulatory limits, ranging from 0.63 to 13.3 mg/L, with an average of 4.32 mg/L during the dry season, which was lower than the average during the rainy season (13.22 mg/L). In the rainy season, values exceeding the regulatory limit were observed at sites 17, 18, 20, and 21 (downstream area). Pearson's rank correlation test (Table 2) revealed a significant positive correlation between TSS and COD during the dry season ($r = 0.44$, $p < 0.05$). In terms of spatial distribution, the results indicated an increasing trend in the TSS values from the upstream to the downstream sections of the river in both seasons. The COD concentrations measured during the rainy season were higher than those measured during the dry season and exceeded regulatory limits, with an average of 30.0 mg/L (rainy season) compared with 13.82 mg/L (dry season). Like the TSS concentration, the COD concentration also tended to increase from the upstream area to the downstream area.

The DO concentration in the Hinh River basin ranged from 2.37 to 7.5 mg/L, with an average value of 5.9 mg/L (dry season). In the rainy season, the measured DO concentration was 1.1 times greater than that recorded in the dry season, with an average value of 6.66 mg/L. No significant positive correlations were found with the other studied water quality parameters, except for D%O ($r = 0.93$ and 0.97, $p < 0.05$). The negative correlation between DO and several other water quality parameters during the rainy season suggests the influence of rainfall patterns on water quality in the area, as well as the presence of organic pollution in the study region. This may be one of the main contributing factors to ecological and environmental degradation in the area.

According to Table 1, the SD values for the parameters TN, TP, COD, and Chl-aare relatively high. This is due to the unusually high actual measurements at sampling point W22, which is located at the intersection of Ba River and Hinh River. For example, during the dry season, the Chl-a level at point W22 is measured at 17.5 µg/L, which is over 8.5 times higher than the average value. The TP concentration at this location is 380 µg/L, approximately 7.5 times the average value. Similarly, both the TN and COD values at sampling point W22 are significantly higher than those recorded at other sampling locations. This area is characterised by a range of human activities, including agricultural cultivation and mineral extraction.

High TN concentrations dominated throughout the sampling period, ranging from 1120.0 to 5820.0 µg/L, with an average of 2275.45 (dry season), and from 670.0 to 2690.0 µg/L, with an average of 1395.45 µg/L in the rainy season. The values recorded during the rainy season were 1.6 times lower than those recorded during the dry season because of increased rainfall and water flow. However, all the sampling sites still had TN concentrations that exceeded the permissible limits. Strong positive correlations were detected between TN and Chl-a ($r = 0.81$ and 0.63, $p < 0.05$) and between TN and TP ($r = 0.83$ and 0.49, $p < 0.05$) in both seasons. The TP concentrations measured in different areas of the river basin were greater during the rainy season than during the dry season, with average values of 50.14 µg/L

Table 1. Changes in the water quality parameters of the Hinh River basin between the dry and rainy seasons

Parame-ters	Value	Dry season	Rainy season	P value	QCVN08:A
pH	Ave Min–Max	7.5 6.3 - 8.8	7.4 6.8 - 8.1	0.7093	6.5 - 8.5
TSS (mg/L)	Ave Min–Max	4.32 0.63 - 13.3	13.22 5.35 - 33.4	0.0000	≤ 25
DO (mg/L)	Ave Min–Max	5.9 2.37 - 7.5	6.66 4.8 - 7.4	0.009	≥ 6
T (oC)	Ave Min–Max	28.2 21.8 -32.8	23.1 21.1 - 25.2	0.0000	-
D%O	Ave Min–Max	76.75 30.6 - 106.4	78.57 56.5 - 86.9	0.6112	-
COD (mg/L)	Ave Min–Max	13.82 3.2 - 28.8	30.0 6.4 - 73.6	0.0001	≤ 10
TN (µg/L)	Ave Min–Max	2275.45 1120.0 - 5820.0	1395.45 670.0 - 2690.0	0.0007	≤ 600
TP (µg/L)	Ave Min–Max	48.18 10.0 - 380.0	50.14 19.0 - 91.0	0.9075	≤ 100
Chl-a (µg/L)	Ave Min–Max	2.03 0.11 - 17.50	1.79 0.28 - 4.53	0.7737	≤ 14

QCVN08:A = Vietnamese national technical regulation for surface water quality

Table 2. Correlation analysis of water quality parameters in the Hinh River basin between the dry and rainy seasons

	pH	TSS	DO	T	D%O	COD	TN	TP	Chl-a
Dry season									
pH	1								
TSS	0.10	1							
DO	**0.65**	0.18	1						
T(°C)	**-0.45**	-0.34	-0.19	1					
D%O	**0.49**	0.05	**0.93**	0.18	1				
COD	0.03	**0.44**	0.30	0.24	0.40	1			
TN	0.10	0.13	0.08	0.26	0.17	0.37	1		
TP	0.21	0.21	0.26	0.06	0.28	0.41	**0.83**	1	
Chl-a	0.34	0.29	0.29	-0.12	0.25	0.40	**0.81**	**0.93**	1
Rainy season									
pH	1								
TSS	0.35	1							
DO	0.11	-0.33	1						
T (°C)	-0.05	0.03	-0.08	1					
D%O	0.09	-0.32	**0.97**	0.15	1				
COD	-0.06	-0.03	-0.14	0.34	-0.06	1			
TN	0.41	0.43	-0.05	0.05	-0.04	0.03	1		
TP	0.36	0.42	-0.06	-0.04	-0.07	-0.17	**0.75**	1	
Chl-a	0.08	0.20	0.18	0.17	0.21	0.12	**0.63**	**0.49**	1

Coefficients in bold are significant at $P < 0.05$

and 48.18 μg/L, respectively. A strong positive correlation between TP and Chl-a was observed in both the dry and rainy seasons ($r = 0.93$ and 0.49, $p < 0.05$). The TP values tended to increase from the upstream areas to the downstream areas, and most values were within the regulatory limits, except for site 22 in the dry season, where the value was 3.8 times greater than the limit. The Chl-a concentration, an indicator of primary productivity, ranged from 0.11 to 17.50 μg/L (dry season) and from 0.28 to 4.53 μg/L (rainy season), with the highest concentration recorded at the downstream site (site 22) during the dry season. The spatial variation in the Chl-a concentration was similar to that observed for the other parameters, with higher average values recorded in the downstream section (Table 2).

Table 3. PCA of the environmental variables for the water quality data from the Hinh River basin

Parameters	Factor I	Factor II	Factor III	Factor IV	Factor V
pH	**0.521**	0.003	0.201	0.001	0.005
TSS	0.147	**0.285**	0.243	0.103	0.168
DO	0.241	**0.514**	0.213	0.000	0.009
T	0.123	**0.351**	0.300	0.000	0.204
D%O	0.145	**0.766**	0.077	0.000	0.003
COD	0.099	0.029	0.141	**0.705**	0.023
TN	**0.803**	0.035	0.084	0.027	0.002
TP	**0.737**	0.001	0.167	0.019	0.006
Chl-a	**0.814**	0.011	0.117	0.021	0.008
Eigenvalue	3.631	1.996	1.543	0.876	0.428
% Variance	40.35	22.18	17.14	9.73	4.75

Bold letter: The most significant factor loadings

3.2. Relationships among the ecological parameters of the Hinh River basin

Multivariate analysis techniques such as PCA and HCA have been proven to be highly important statistical tools for identifying the underlying relationships between various physicochemical parameters, detecting pollution sources, and grouping sites or parameters into similar clusters to gain a better understanding of water quality and the ecological status of the studied system [15]. In this study, PCA based on eigenvalues was used to determine the number of principal components needed to identify or confirm the key water quality variables (Table 3). Five principal components were extracted on the basis of the scree plot and eigenvalues. Factors I and II accounted for 62.53% of the total variance in the observed dataset for the Hinh River. The first factor mainly included pH, TN, TP, and Chl-a, indicating an increase in nutrients associated with eutrophication. The second factor suggested higher levels of suspended solids in the water body and a seasonal variation in the positive relationship between DO and temperature in the study area. Factor IV indicated that the COD levels in the surrounding watershed environment increased due to the presence of low-concentration industrial pollutants. These factors highlight the main variables affecting water quality in the study area, which include pH, TSS, DO, COD, and especially TN, TP, and Chl-a.

The dendrogram based on the HCA results reinforced the close relationships among the ecological parameters (Fig. 2) and supported the findings of the PCA. In Cluster I, TSS, pH, and DO were similar within a subcluster, indicating their collective influence on the system. Similarly, within the same cluster, TN, TP, and Chl-a also demonstrated a close association, suggesting an increase in anthropogenic activities in the watershed area and confirming

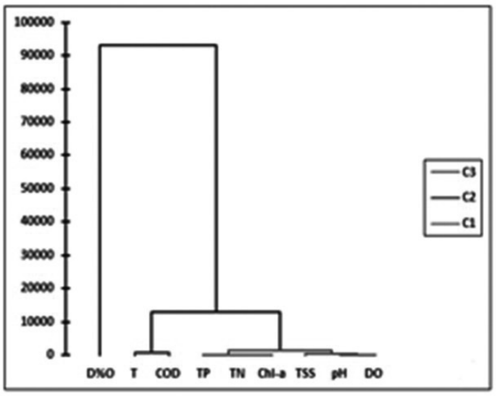

Figure 2. Dendrogram showing the cluster between the water quality ecological parameters of the Hinh River basin

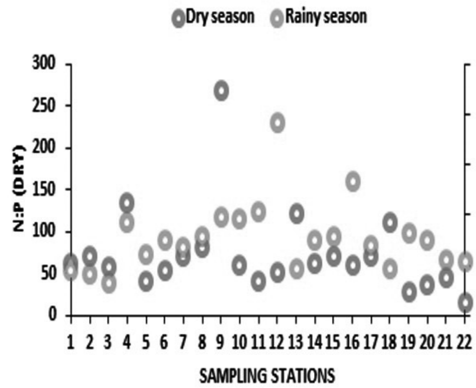

Figure 3. Spatial status of N:P ratio in surface water of the Hinh River basin in different hydrological periods

their importance as key variables in the TRIX index (Table 2). Temperature and COD were grouped into a separate cluster (Cluster II), indicating that COD may not be influenced by a single source but could result from anthropogenic, industrial, or agricultural origins.

3.3. Assessment of the trophic status of the Hinh River basin

The TN:TP ratio is closely related to land use activities that can directly impact the biological components of aquatic ecosystems[16]. In the Hinh River basin, the mass ratio of N:P (Fig. 3) during the dry season was greater (mean = 73.67) than the ratio recorded in the rainy season (mean = 30.98). In both seasons, we observed that the N:P ratio was greater in the midstream section than in the upstream and downstream areas. The results demonstrate that the Hinh River basin is a highly dynamic environment related to the availability of nutrients, as evidenced by seasonal changes in limiting nutrients. Although phosphorus is the limiting nutrient in both cases (N:P > 20), some river areas presented balanced ratios (10 < N:P < 20). This balanced ratio appeared in the dry season at site 22, where the Hinh River joins the Da Rang River, with TN and TP values recorded at 9.7 and 3.8 times above the permitted limits, respectively. During the rainy season, the upstream area (sampling sites 1–3), midstream area (site 13), and downstream area (site 18) were locations with balanced nutrient availability for primary productivity.

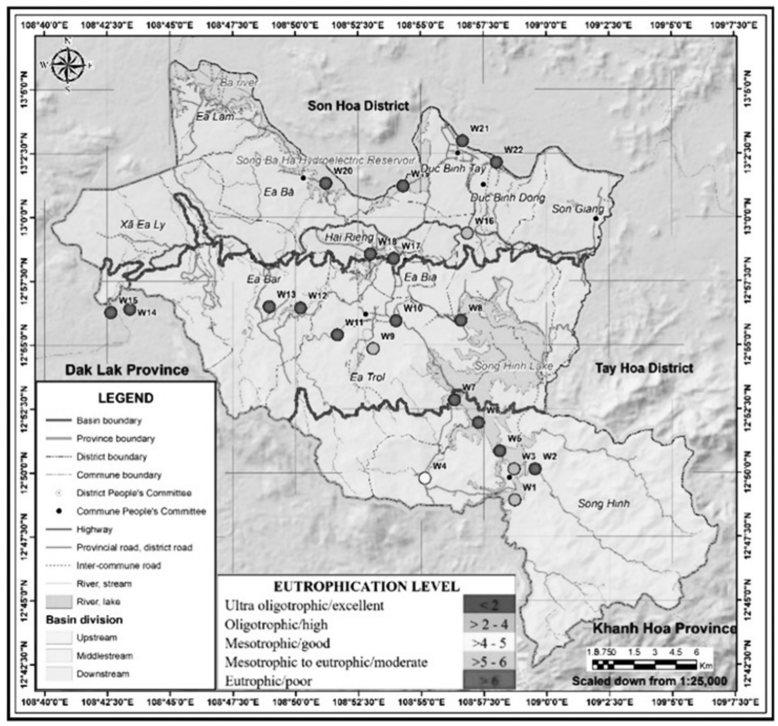

Figure 4. Spatial variation in the TRIX index along the sampling stations in the Hinh River basin in dry seasons

To determine the trophic status of the Hinh River basin, we used the TRIX index, which considers the sets of TN, TP, Chl-a, and D%O from two sampling campaigns. The average TRIX values were 7.31 and 7.5 for the dry and rainy seasons, respectively, indicating that eutrophic conditions prevailed in both seasons and across the spatial distribution of the river basin (Fig. 4). The results from the dry season revealed that 5% of the sampling sites were mesotrophic, 18% were meso-eutrophic, and 77% were eutrophic. During the rainy season, the proportion of mesotrophic conditions remained unchanged, whereas 13% were meso-eutrophic and 82% eutrophic (Figure 5,6).

This study revealed that the trophic status/water quality of the Hinh River basin is eutrophic/poor because of inputs from human activities, including agricultural, industrial, and domestic sources.

The correlations between the TRIX index and eutrophication-related parameters indicate a strong positive relationship between TRIX and the concentrations of TN, TP, and Chl-a (Fig. 5). In particular, the correlation was strongly demonstrated in the Chl-a and TP indices (R2 values were 0.7147 and 0.5736, respectively). These correlations clearly demonstrate that nutrient enrichment along the flow of the Hinh River significantly increases primary productivity (in terms of Chl-a) and eutrophication. Therefore, the TRIX index is highly sensitive in determining the trophic status of the Hinh River basin. The increase in eutrophication in parts of this river basin contributes to further nutrient enrichment, leading to more severe eutrophication in the downstream area of the Da Rang River before it flows into the sea.

The elevated TRIX values indicate eutrophic conditions mainly driven by human activities. Agricultural runoff is a major source of nutrients, as Phu Yen Province uses about 23,000–25,000 tons of chemical fertilizers annually, with urea and NPK accounting for over 80% of the total. Moreover, only ≈12% of rural and 40% of urban wastewater are treated before discharge. Combined with effluents from livestock and small industries, these sources increase nitrogen and phosphorus concentrations. The downstream rise in TRIX values thus reflects the cumulative effect of agricultural, domestic, and industrial inputs that accelerate eutrophication in the Hinh River basin [5, 16, 19, 22].

4. DISCUSSION

Assessment of the trophic status and water quality of river basins is of utmost importance for sustainable water resources management and ecosystem conservation[17, 18]. This study focused on the Hinh River basin, Phu Yen Province, an economically and ecologically significant area in Central Vietnam. The results showed that this river basin is significantly affected by human activities, leading to eutrophication, as shown by high TN concentrations and high TRIX index.

Figure 5. Spatial variation in the TRIX index along the sampling stations in the Hinh River basin in rainy seasons

Our results are consistent with previous studies showing that nutrient pollution is an increasing problem in river basins worldwide [19, 20]. Specifically, the high TN concentrations found in the Hinh River are similar to those in other rivers in Vietnam that are under pressure from agriculture and urbanisation[21, 22]. Eutrophication in the Hinh River can have negative impacts on aquatic ecosystems, including algal blooms, dissolved oxygen depletion, and biodiversity loss[23, 24]. These impacts can affect important ecosystem services provided by the Hinh River, such as water supply, aquaculture, and tourism.

The limited scope of the study, spanning only two seasons (dry and wet) over two years, presents a limitation. Therefore, the results may not be representative of long-term changes. In addition, this study focused on only a limited number of water quality parameters. Further research is needed to more fully assess the sources of pollution and their impacts on the ecosystem in the Hinh River basin.

Future studies should be conducted to accurately identify the specific sources of nutrient pollution in the Hinh River basin. This could include monitoring water quality at different points along the river and conducting surveys of farming, land use, and wastewater treatment practices in the area. In addition, we should evaluate the effectiveness of various management measures, such as best farming practices and upgrading wastewater treatment plants, in reducing nutrient pollution and improving water quality in the Hinh River basin.

Eutrophication in the Hinh River basin not only degrades aquatic ecosystems but also affects broader environmental and socioeconomic systems. Excessive nutrient loading promotes algal blooms, reduces water transparency, and causes oxygen depletion, threatening fishery resources and biodiversity. These impacts may reduce agricultural productivity in irrigated

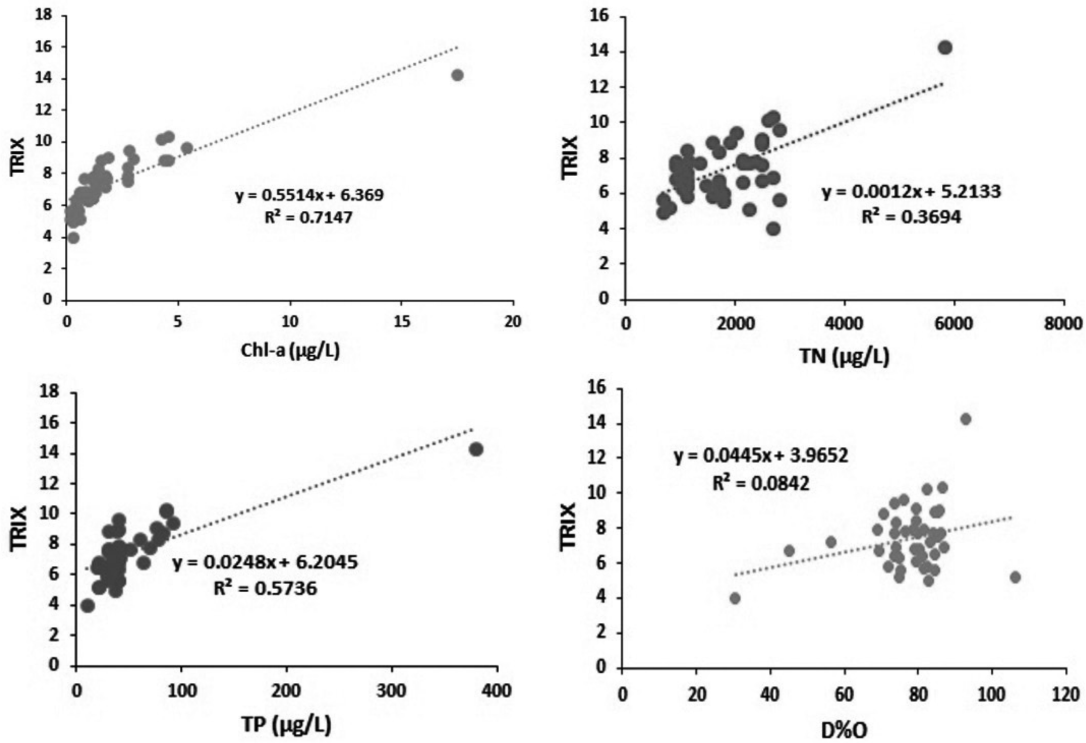

Figure 6. Correlations between TRIX and eutrophication parameters

areas, increase water treatment costs, and affect livelihoods dependent on river resources. To mitigate these effects, integrated river basin management is required, focusing on controlling nutrient inputs from agricultural and domestic sources. Priority actions should include expanding wastewater treatment coverage, promoting organic and low-emission agriculture, and strengthening riparian buffer zones to filter runoff. Implementing monitoring networks and community-based management would enhance long-term water quality control and support sustainable development in the Hinh River basin [17, 18, 19, 22].

5. CONCLUSION

In this study, hydrochemical and eutrophication parameters were identified to assess the water quality of the Hinh River basin. The results revealed that eutrophication-related parameters varied significantly across both space and time within the study area. High TN concentrations and seasonal increases in TP significantly enhanced primary productivity (in terms of Chl-a) and contributed to eutrophication. Accordingly, the water quality/trophic status of the Hinh River basin is classified as poor/eutrophic because of anthropogenic inputs from agricultural, industrial, and domestic discharges. The strong positive correlations between TRIX values and nutrient concentrations as well as Chl-a indicate that nutrient enrichment along the river's course contributes to increased eutrophication in the downstream section of the Da Rang River before it discharges into the sea. Therefore, measures are urgently needed to reduce the input of organic and inorganic substances into the Hinh River to sustainably manage eutrophication and ensure the ecological health of river systems in the region before they reach the marine environment.

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