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Multivariate Analysis of Macroinvertebrate Diversity and Water Quality in the Suchindram Theroor Wetland Complex

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Authors' contributions

This work was carried out in collaboration among all authors. Author TMAP contributed to the design, collected the data, and statistical analysis and conceived the study. Author TP corrected the manuscript, did data curation and prepared initial draft of the manuscript. Author JBL did data analysis. All authors read and approved the final manuscript.

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ABSTRACT

The Suchindram Theroor wetland complex in Tamil Nadu is part of the ecologically significant wetlands, serving as a vital biodiversity hotspot and supporting diverse aquatic and terrestrial species. Despite its importance, this wetland faces severe ecological stress due to extensive

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anthropogenic pressures, including mining activities, agricultural runoff, and urbanization. This study investigates the wetland's ecological health through analysis of aquatic macroinvertebrate diversity and water quality. Macroinvertebrates were sampled using the kick-net method across three selected stations in September 2024. A total of 372 individuals were identified, encompassing 21 taxa, 17 families, and 10 orders, primarily representing the phyla Arthropoda, Mollusca, and Annelida. Arthropods, particularly *Diploneoceus sp*. dominated the community structure. Simpson, Shannon and Evenness indices revealed moderate biodiversity, indicating environmental stress and habitat disturbance. The integration of multivariate techniques, including Correspondence Analysis (CA), revealed significant correlations between macroinvertebrate diversity and water quality parameters such as dissolved oxygen, turbidity, pH and nutrient concentrations. Elevated levels of pollutants and habitat alterations were identified as key drivers influencing community composition. These findings underscore the wetland's ecological deterioration and highlight the critical need for effective conservation measures and sustainable management practices. By linking biological indicators with water quality assessments, this study provides valuable insights into the long-term impacts of anthropogenic disturbances on wetland ecosystems, contributing to the global discourse on wetland conservation and restoration.

Keywords: Aquatic macroinvertebrates; bio indicators; water quality; correspondences analysis; suchindram theroor wetland complex.

1. INTRODUCTION

Aquatic macroinvertebrates, are effective bio-indicator a diverse range of taxa, are integral to freshwater ecosystems due to their functional roles as primary consumers, decomposers, and a key food source for higher trophic levels. These organisms span multiple phyla, including Arthropoda (e.g., crustaceans and insects such as Coleoptera, Diptera, and Odonata) Mollusca (e.g., gastropods and bivalves), and Annelida (e.g., oligochaetes and leeches). Their ecological roles in biogeochemical cycling, organic matter decomposition, and energy transfer underscore their importance in maintaining ecosystem stability and productivity (Barbour et al., 1999; Klemm et al., 2023).The macroinvertebrates' special sensitivity to environmental changes makes them exceptional bioindicators. Unlike instantaneous chemical analyses, which provide a snapshot of water quality, macroinvertebrate assemblages reflect cumulative and integrated responses to abiotic and biotic stressors over time. Such as Shannon Wiener diversity index, Simpson diversity index, taxa richness, and evenness index assessments offer insights into ecosystem dynamics and anthropogenic pressures, including eutrophication, pollution, and habitat fragmentation (Hussain et al., 2022; Orozco-González & Ocasio-Torres, 2023). Moreover, multivariate approaches such as Correspondence Analysis (CA) enable the identification of specific environmental drivers affecting community composition, providing a robust framework for ecosystem assessment (Arimoro & Ikomi, 2020).

Wetlands are among the most productive ecosystems globally but are increasingly vulnerable to anthropogenic stressors. The Suchindram Theroor wetland complex in Tamil Nadu, a part of the Ramsar-designated Vembanad-Kol wetlands, represents a critical biodiversity hotspot and resource hub for local livelihoods. However, its ecological integrity faces severe threats from mining activities, agricultural runoff, and urban encroachment. These stressors result in sedimentation, habitat alteration, and water quality degradation, which have cascading effects on aquatic biota (Pandey et al., 2020; Sharma et al., 2021). Mining, in particular, contributes to the release of heavy metals and other pollutants, leading to bioaccumulation and toxicity in aquatic system (Dube et al., 2020).Despite the recognized ecological significance of this wetland, studies assessing its biodiversity, particularly macroinvertebrates, remain sparse. Previous research has highlighted the importance of wetland conservation and the role of macroinvertebrates in monitoring ecological health, but the Suchindram Theroor wetland remains underexplored (Kumar et al., 2023). This study seeks to address this gap by evaluating macroinvertebrates diversity and water quality parameter across the wetland. Using multivariate techniques, it aims to unravel the interactions between water quality parameters and macroinvertebrate assemblages. The findings are expected to provide yield criticalinsights into the effectsof anthropogenic disturbances and to inform the formulation of strategies for the sustainable management of wetland.

2. MATERIALS AND METHODS

2.1 Study Area

The Suchindram Theroor wetland complex is situated in Tamil Nadu, forming a vital part of the Theroor-Manakudi Conservation Reserve, recognized as a Ramsar site in April 2022 (Site No: 2492). This wetland is located near the terminus of the Central Asian Flyway, providing critical habitat for various migratory bird species. The region also supports local communities through agriculture and aquaculture. The study area was divided into three sampling stations strategically chosen to represent varying degrees of anthropogenic impact, such as proximity to mining activities, agricultural runoff, and relatively undisturbed areas. These stations were geo-referenced and mapped using GPS coordinates (Table 1, Fig. 1).

Table 1. Sampling stations corresponding to different anthropogenic uses at the Suchindram Theroor wetland

Location	Latitude	Longitude
Station 1 (S1)	77.45293	8.14231
Station 2 (S2)	77.45167	8.15875
Station 3 (S3)	77.45549	8.15528

2.2 Physico-chemical Parameters

Water samples were taken from each sampling Stations using a sterile plastic bottle. The sample were transported in ice boxes to the laboratory for analysis. The water temperature, Aerial temperature, Total dissolved oxygen (TDS), and pH were in situ using the Divinext Digital meter in addition transparency by using a Secchi disc this is field calculated. To determine the laboratory procedures were used; electrical conductivity (EC), total hardens ($CaCo_3$), total alkalinity, calcium (Ca), magnesium (Mg), chloride (Cl), phosphate (PO_4), nitrate(NO_3), nitrite (NO_2) and ammonia (NH_3)(APHA, 2002) Method. These parameters were selected based on their relevance to assessing water quality and their potential impact on aquatic macroinvertebrates.

2.3 Macroinvertebrate Sampling

Aquatic macroinvertebrates collected using the kick net sampling with standard pond net (230× 225mm frame with 500 µm mesh size a widely accepted technique for Aquatic macroinvertebrates in shallow waters approaching a semi- quantitative two minutes kick sampling is collected from each station, sample was collected by disturbing the substrate within a one minutes hand search carried out to located macroinvertebrates that reaming connected to the underside of the cobbles. The collected specimens were transferred to labelled containers, preserved in 10% formalin, and then transported to the laboratory for further shorting and identification using a stereo Microscope and taxonomic keys, specimens were identified to the lowest taxonomic level (often genus or species) possible (Winterbourn et al., 2000; Dickensand Graham 2002).

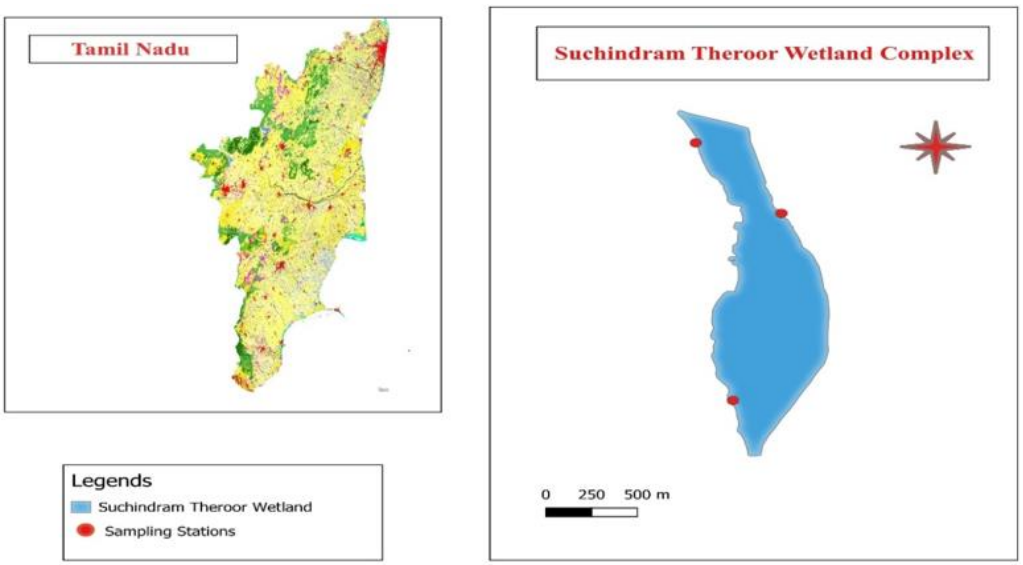

Fig. 1. Map showing the study area in Suchindram Theroor wetland complex

2.4 Diversity Indices and Statistical Analysis

Macroinvertebrate diversity was assessed using standard ecological indices:

Shannon- Wiener diversity index (H') was used to evaluate species richness and evenness, while Simpson's Index (1-D) assessed dominance.The Evenness Index (J') was used to determine community evenness.All calculations were performed using Microsoft Excel. To examine the relationships between macroinvertebrate assemblages and physico-chemical parameters, Correspondence Analysis (CA) was applied using PAST (Paleontological Statistics) software. This multivariate technique helps visualize patterns of association between taxa and environmental variables.

3. RESULTS

3.1 Macroinvertebrates Community and Composition

A total of 372 individual macro invertebrate from 21 taxa were identified, distributed across three major phyla: Arthropoda (47%), Mollusca (26%), and Annelida (13%). Arthropods were the most diverse, dominated by *Diploneoceus* sp. contributing significantly to overall abundance (Table 2). Stations 1 and 2 exhibited moderate diversity, as indicated by Shannon-Wiener index (H') of 2.4 and 2.1, respectively, reflecting relatively ecosystem signifies a habitat which is sustainable. In contrast, Station 3 exhibited unstable diversity (H' = 1.6) and a dominance of pollution-tolerant species, suggesting significant ecological stress (Table 3). The distribution of wetland species relativeabundancewas sampled using three stations. In the wetland, 327 individuals from 21 taxa were gathered from all location, as shown in (Fig. 2).

3.2 Physico-chemical Parameters Analysis

The Physico-chemical analysis of the Suchindram Theroor wetland revealed significant spatial variability in water quality across three stations. The temperature remained relatively stable, ranging between 27°C and 27.8°C, consistent with the tropical climatic conditions of the region. Neutral to slightly alkaline pH values (6.9 to 7.2) were observed, indicating conditions favourable for macroinvertebrate communities.

Table 2. Macroinvertebrates community in different stations

Phylum	Order	Family	*Genus / Species*	S 1	S 2	S 3
Arthropoda	Decapoda	Palaemonidae	*Palaemonetes sp.*	3	7	-
Annelida	Hirudinea	Glossiphoniidae	*Alboglossiphonia sp.*	4	-	9
	Tubificida	Naididae	*Bathydrilus sp.*	7	12	-
Mollusca	Basommatophora	Planorbidae	*Gryalus sp.*	5	-	-
			Indoplanorbis exustus (Deshayes, 1834)	29	8	11
		Viviparidae	*Idiopoma dissimilis* (O. F. Müller, 1774)	-	22	20
Arthropoda	Odonata	Coenagrionidae	*Ischnura sp.*	12	8	-
		Aeshnidae	*Anax indicus*	-	2	-
	Coleoptera	Hydrophilidae	*Hydrobiomorpha sp.*	5	-	-
			Regimbartia attenuata (Fabricius, 1801)	-	3	-
		Haliplidae	*Haliplas sp.*	23	-	-
		Gyrinidae	*Dineutus spinosus* (Fabricius, 1781)	-	7	-
		Noteridae	*Canthydrus luctuosus* (Aube, 1838)	-	1	-
	Hemiptera	Pleidae	*Praiaplea sp.*	8	-	-
		Belostomatidae	*Diploneoceus sp.*	41	8	27
		Gerridae	*Aquarius adelaidis* (Dohrn, 1860)	-	10	-
	Diptera	Chironomidae	*Chironomus sp.*	20	-	10
			Procaldius sp.	9	-	-

Phylum	Order	Family	*Genus / Species*	S 1	S 2	S 3
	Ephemeroptera	Baetidae	*Cloeon sp.*	4	-	-
	Trichoptera	Limnephilidae	*Limnephilinae sp.*	28		7
			Pseudostenophylax sp.	-	2	-
Total				198	90	84
Grand Total					372	

Table 3. Biodiversity Indices of macroinvertebrates in different station

Diversity Index	S1	S2	S 3
Taxa S	14	12	6
Individuals	198	90	84
Simpson 1-D	0.881	0.8721	0.7902
Shannon H'	2.331	2.232	1.672
Evenness e^H/S	0.7347	0.7769	0.8875

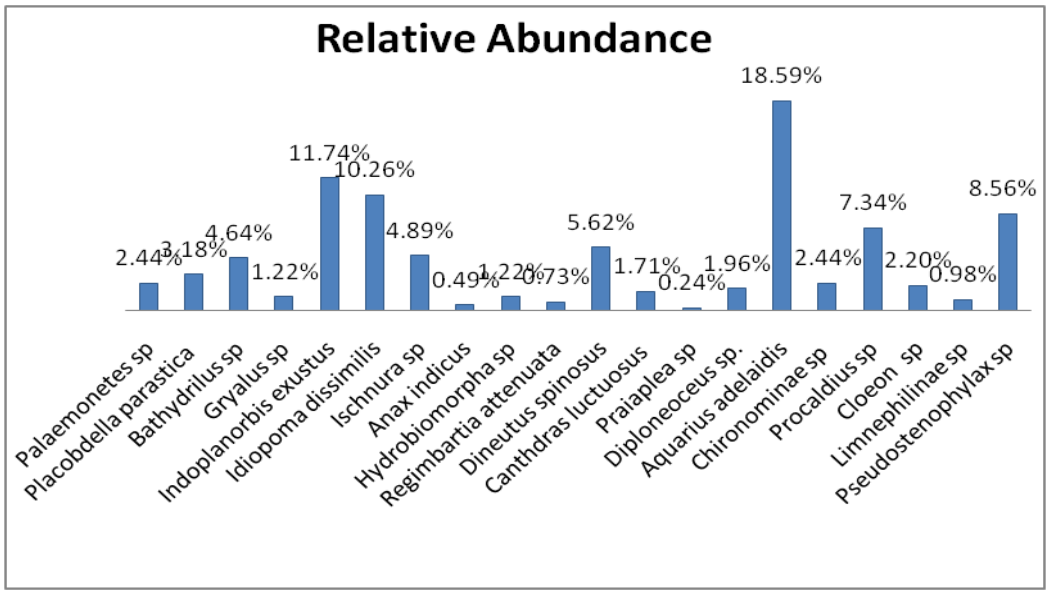

Fig. 2. Species abundance at different species of wetland

Table 4. Mean and standard deviation of physico-chemical parameters in Suchindram Theroor wetland

Parameters	Stations
Aerial temperature (^{0}C)	35.6± 1.15
Water temperature (^{0}C)	27.3±0.41
pH	7.03 ±0.15
Electrical Conductivity (µs/cm)	0.6±0.08
Turbidity (NTU)	82±2.64
Dissolved Oxygen(mg/L)	164±3.46
Hardness (mg/L)	83.3±14.43
Total Alkalinity (mg /L)	75± 0
Calcium (mg/L)	50± 0
Magnesium (mg/L)	125± 0
Chloride (mg/L)	41.3±10.23
Phosphate (mg/L)	1.5±0
Nitrate (mg/L)	20±8.66
Nitrite (mg/L)	0.2 ± 0.03
Ammonia (mg /L)	2.4± 0

Table 5. Association between macroinvertebrates communities and psysico- chemical parameters based on correspondences analysis

Axis	Eigenvalue	% of total	Cumulative
1	0.088462	74.104	74.104
2	0.0309131	25.896	100

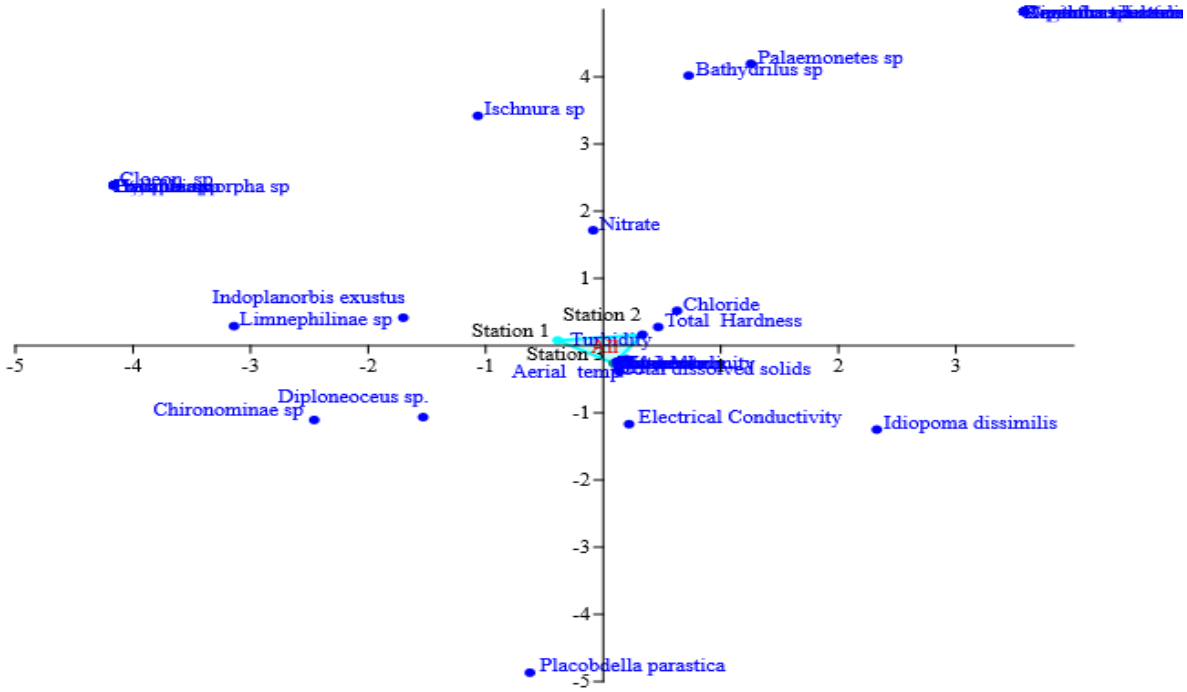

Fig. 3. Correspondences analysis of the physicochemical variable and macroinvertebrates community at the sampling stations

However, increased turbidity (28–54 NTU) at station 3 suggested sediment input from mining and agricultural runoff. Nutrient concentrations, particularly nitrates (1.8–3.2 mg/L) and phosphates (0.9–1.5 mg/L), were higherat station 3, indicative of eutrophication resulting from anthropogenic activities (Table 4).

3.3 Correspondence Analysis (CA)

The CA results illustrated strong associations between macroinvertebrate assemblages and environmental parameters. High nitrate and phosphate levels were positively correlated with the abundance of pollution-tolerant taxa like *Diploneoceus* sp., whereas sensitive taxa such as *Baetis sp.* were associated with lower nutrient levels and better water quality at Station 1 and 2. Turbidity emerged as a significant variable influencing the distribution of Mollusca, particularly gastropods, which were more prevalent in areas with reduced sedimentation (Fig. 3). The information in the variation is contorlled by the system of axis 1 and 2 at 74 % (Table 5). Greater effects on the distribution of macroinvertebrates are impacted by temperature, pH, turbidity, TDS and conductivity.

4. DISCUSSION

The dominance of *Diploneoceus sp*. and other pollution tolerance taxa at station 3 exhibits the impact of nutrient enchainment and habitat degradation on macroinvertebrates community. These findings align with studies by Kaaya et al., (2015), which observed similar patterns that shifts towards dominance by tolerant taxa in eutrophic wetlands. The absence of sensitive taxa such as *Baetis sp.*at Station 3 reflects the deteriorating water quality, likely influenced by mining and agricultural runoff (Heinoand Peckarsky, 2014; Bakerand Greenfield, 2019).The elevated nitrate and phosphate levels at Station 3 highlight the role of anthropogenic nutrient inputs, altering the ecological balance of wetlands. Nutrient enrichment promotes algal

blooms and subsequent oxygen depletion, which disproportionately affect sensitive macroinvertebrate taxa. Turbidity, caused by sedimentation from mining activities, further exacerbates habitat degradation by smothering benthic substrates and reducing primary productivity (Marchant et al., 2000; Braccia et al., 2007). Similar trends of declining macroinvertebrate diversity due to eutrophication and sedimentation have been reported in wetlands such as Keoladeo and Chilika (Arimoro & Ikomi, 2020). These findings highlight the urgent need for targeted conservation efforts to mitigate anthropogenic impacts and preserve biodiversity.

The study presentsthe critical role of macroinvertebrates as bio indicators of wetland health. Regular monitoring using macro-invertebrate-based assessments provide insights on health of aquatic systemindicating such as ecological degradation, enabling timely interventions. Conservation strategies such as implementing buffer zones, reducing agricultural runoff, and regulating mining activity are essential for restoring the ecological integrity of the Suchindram Theroor Wetland.

5. CONCLUSION

This study is provide insights into the ecological status of the Suchindram Theroor wetland, emphasizing the detrimental effects of anthropogenic activities on its biodiversity and water quality. The findings demonstrate that nutrient enrichment and sedimentation are the primary drivers of ecological stress, as indicated by the dominance of pollution-tolerant macroinvertebrates and declining diversity indices. The integration of physico-chemical analysis with macroinvertebrate bioassessment underscores the potential of multivariate approaches for wetland monitoring and management.To ensure the sustainable management of the Suchindram Theroor wetland, it is imperative to implement conservation measures that address nutrient and sediment inputs, promote habitat restoration, and enhance community awareness. This research adds up to growing literature on wetland ecology and serves as a foundation for developing evidence-based conservation policies.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

DATA AVAILABILITY STATEMENT

The paper including the original contributing that were made throughout the investigation and additional question can be sent to the relevant author.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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