

Zooplankton community structure and ecology of the Pit Lakes, Raniganj Coal Field, West Bengal, India

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ABSTRACT

*Man-made pit lakes are often formed as a result of mining activities, and they can significantly alter the local ecosystem. Understanding the zooplankton community in these lakes is crucial as zooplankton play a vital role in the aquatic food chain and are sensitive indicators of water quality. The primary aim of this study is to determine the zooplankton composition and wet land zooplankton index in some pit lakes of Raniganj Coal Field (RCF) area. For three years (2023-2025), monthly samples of surface water and zooplankton were collected from 11 pit lakes. Water quality parameters like temperature, Secchi depth, dissolved oxygen, pH, conductivity, and total dissolved solids were measured on-site. Analyses for nitrate, phosphate, total hardness, alkalinity, Turbidity and chloride were conducted using standard methods. Zooplankton were collected from the subsurface layer using a 50-liter bucket and a 50 µm plankton net. 52 zooplankton species, of which nine were Cladocera, six Copepoda and 37 Rotifera. The most abundant and diverse zooplankton species were rotifers, followed by copepods. The most abundant species were: *Brachionus falcatus*, *B. forficula*, *Keratella cochlearis*, *K. tropica*, *Tropocyclops* sp. and *Moina micrura*. Redundancy analysis highlighted that pH, chloride, phosphate, turbidity, nitrate and Secchi depth were the prevailing environmental parameters. The most prevalent species was *Brachionus forficula*. Overall, these findings contribute to a deeper understanding of zooplankton diversity, community structure, and their relationship with environmental factors in man-made pit lakes, providing valuable information for conservation and management efforts in these unique aquatic environments.*

Keywords: Pit lakes; Zooplankton; Redundancy analysis; Bio-indicator

Mathematics Subject Classification: 92B99, 92D40

Journal of Economic Literature (JEL) Classification: Q57

1. Introduction

Water quality can be assessed by biological and chemical approaches, but both have limitations. According to Singh and Kalamdhad (2016), organic matter and nutrients entering water bodies are either consumed by primary producers or accumulated in bottom sediments (Kowalczevska-Madura et al., 2019). As a result, only a fraction of the components is considered in the chemical analysis of water. In contrast to chemical analysis methods, biological assessments comprehensively assess the

water quality (Dembowska *et al.*, 2018). Since the architecture of natural communities develops in a complex of climatic and anthropogenic influences, biological assessment approaches are very revealing. Planktonic invertebrates are, on average, more numerous and smaller when nutrient loads are higher (Krupa *et al.*, 2019). Svensson *et al.* (2018) have demonstrated the feasibility of the biological approach based on aquatic invertebrates in environmental studies. The inability to precisely localize the causes of the negative ecological status of water bodies is a disadvantage of the bioindication method. Therefore, a combination of chemical and biological approaches is the most effective treatment for them. Pit lakes are common consequences for open pit mining and can lead to serious concerns while offering opportunities for beneficial end uses. Mine lake closure and management has become more difficult because how several mechanisms affect these is not fully understood yet. A notable example of this is the pit lakes near the Raniganj Coal Field (RCF) in West Bengal, India. These reservoirs were created by open cast coal mining. They serve primarily as huge water bodies and popular spots for recreational fishing.

The food webs connecting primary producers and consumers are strongly influenced by zooplankton in freshwater habitats (St-Gelais *et al.*, 2017). Zooplankton are widely used as a bioindicator of water quality due to their ubiquitous abundance, small size, high reproductive potential, and sensitivity to changes in environmental factors and organic pollution (Zhou *et al.*, 2018). Variations in zooplankton population can indicate alternation of ecosystem functioning and food web (Benedetti *et al.*, 2018). The ecological conditions of the pit lakes should be assessed using both bioindication techniques and chemical data. The solution to this application challenge can be found using statistical data mapping (Barinova *et al.*, 2016). This technique has proven beneficial for water monitoring studies (Krupa *et al.*, 2018; Krupa *et al.*, 2020). Pit lakes have occasionally been the subject of hydrochemical and hydrobiological studies, but a thorough assessment has not yet been carried out in the RCF area. This study fills in some of the gaps. The primary aim of this study is to determine the zooplankton composition and wet land zooplankton index in some pit lakes of RCF area.

2. Materials and Methods

2.1. Description of Study Area

Eleven abandoned pit lakes in the Raniganj, Andal and Pandabeswar Blocks within the RCF area of the Paschim Bardhaman District in West Bengal, India were sampled (Table 1). The RCF has a gently sloping surface and its elevation is typically between 65 and 75 meters above sea level. The Barakar and Raniganj formations are the main coal bearing horizons and the RCF corresponds to the Gondwana supergroup. The Raniganj formation, which contains vast seams of coal, carbonaceous shale and fine greyish sandstone, appears in the central and southern regions. The RCF has tropical weather with significant temperature fluctuations between winter and summer. In April and May, the highest temperature of the coal fields can reach around 40°C, while in December and January, it drops to 10-15°C. Eighty percent of annual precipitation falls during the monsoon season.

Table 1: Study area details.

Name of the pit lake with code	Area (acre)	Mean Depth (meter)	Location
Harabanga 1 (H1)	82.65	22.86	23°36'39.65"N; 87°3'49.18"E
Harabanga 2 (H2)	92.21	24.38	23°36'33.02"N; 87°3'57.78"E
Searsole (S)	15.87	31.50	23°37'35.38"N; 87°6'9.88"E
Dhanderdih 1 (D1)	34.71	30.48	23°37'26.58"N; 87°9'22.85"E
Dhanderdih 2 (D2)	17.19	25.91	23°37'41.14"N; 87°9'26.20"E
Dhandadih 3 (D3)	18.18	33.53	23°37'52.61"N; 87°9'21.83"E
Khadan kali (K)	36.67	13.72	23°35'48.7"N; 87°9'54.9"E
Belpahari (BIL)	3.31	14	23°42'15.71"N; 87°14'15.71"E
Dalurbandh (DALU)	36.36	22.86	23°42'48.68"N; 87°15'35.70"E
Joyalbhanga (JOYAL)	42.97	24.34	23°41'42.73"N; 87°16'59.55"E
Nagrakonda (NAG)	17.19	15.24	23°41'0.29"N; 87°17'19.59"E

2.2. Field Sampling and analysis

A monthly sample of surface water and zooplankton was collected from the 11 pit lakes over three years (2023 to 2025) at random sites during the day (6.00 am-8.00 am) throughout the study period in each alternate week. Due to the regional differences in bathymetry in the investigated mine lakes, sampling was limited to the surface layer (0.5 m). A water sample was taken in a pre-cleaned 500 ml plastic bottle (Tarsons) at a depth of approximately 0.5 m, which was then kept cold for subsequent analysis to determine water quality. Temperature, Secchi depth, dissolved oxygen (DO), pH, conductivity (COND) and total dissolved solids (TDS) of water were measured in situ. The Winkler titrimetric method was used to determine the DO of the water. Multi-probe tester was used to determine the surface water temperature and Secchi disks were used to assess the water transparency of each mine lake. A portable digital pH was used to measure pH. Nitrate (NO_3^-) and phosphate (PO_4^{3-}) were analyzed using the standard method (American Public Health Association [APHA] 2005). A portable TDS meter was used to test total dissolved solids (TDS) and conductivity (COND) was measured using a TDS/conductivity meter. Total hardness (TH), total alkalinity (TA) and chloride were estimated by standard method (APHA 2005). Turbidity was estimated using a turbidity meter.

2.2.1. Zooplankton sampling and analysis

Zooplankton were collected in the subsurface (0.5 m) using a 50 liter bucket and filtered using a 50 μm plankton net. The catch was immediately fixed with 4% buffered formaldehyde solution for subsequent analysis. Mean abundance of zooplankton was expressed in individuals per liter (ind/L) with the aid of the microscope (Olympus, Magnus: MS24). Identification of zooplankton species were performed using standard literature (Edmondson, 1959; Kotov *et al.*, 2013; Sharma *et al.*, 2017; Walter and Boxshall, 2015).

2.2.2. Determination of Wetland Zooplankton Index (WZI)

General formula of Loughheed and Chow-Fraser (2002) was used to calculate the WZI (equation 1). The index varies from 1 (low quality wetlands) to 5 (high-quality wetlands).

$$WZI = \frac{\sum_{i=1}^n Y_i T_i U_i}{\sum_{i=1}^n Y_i T_i} \quad \text{Eq. (1)}$$

Where Y_i is the species abundance, T_i indicates tolerance (1–3), and U_i indicates optimum (1–5). U -value for that species was calculated using the centroid's location along Canonical correspondence analysis (CCA) axis 1. Centroids were sorted and classified into five groups, with an equal number of species in each category. Each group was then assigned a score between 1 and 5. A U -value of 1 was given to species with high positive centroids (far right of CCA axis 1), while a U -value of 5 was given to species with high negative centroids (far left of axis 1). All centroids between these two extremes used intermediate values based on where they were along the first axis. It is helpful to think of U -value as an indication of the species' sensitivity to poor water quality, with a value of 1 denoting the species' greatest sensitivity and a value of 5 denoting its lowest tolerance. The standard deviation of the species scores from the CCA output was used to calculate T -value, measured the niche width for each species. Species with a broad niche (large standard deviation) received a T -score of 1, while species with a narrow niche (small standard deviation) received a score of 3. To do this, the standard deviations of the species values were first sorted in descending order (similar to the assignment of U -values). Relative abundance (%) (Walag and Canencia, 2016) was calculated using standard formula. Engelmann's scale of dominance (Engelmann, 1978) is actually the relative abundance of the zooplankton species. <1="subrecedent", 1.1 to 3.1="recedent", 3.2 to 10="subdominant", 10.1 to 31.6="dominant" and >31.7% = "eudominant" (Engelmann, 1978).

To determine how the zooplankton composition and water quality variables are related, a redundancy analysis (RDA) was carried out. Various ecological diversity indicators such as Margalef richness (Margalef, 1967), Shannon diversity (Shannon, 1948) and Pielou evenness (Pielou, 1966) were calculated using PAST software. The identification of possible zooplankton indicator species in each mine lake was based on indicator analyzes (Dufrene and Legendre, 1997). Using the PAST software, SIMPER analysis was conducted (Hammer *et al.*, 2001). A cluster analysis was performed using the XLSTAT program to examine the associations between mine lake frequency and water quality. In the cluster analysis, Euclidean dissimilarity metrics and Ward's merging rule were used. The major differences between the pit lakes in terms of all biotic and abiotic factors were done by one-way analysis of variance (ANOVA).

3. Result

3.1. Zooplankton composition

Fifty-one zooplankton species were documented by analyzing 66 samples collected from 11 pit lakes over a three-year period. Rotifera was represented by 36 species from 32 genera belonging to 19 families. Thirteen species were found of the genus *Brachionus* (Table 2). The average zooplankton abundance ranged from 548.75 ± 7.42 ind/l to 171.375 ± 2.84 ind/l and was significantly different across the lakes ($p=0.0324$). Dhandardihi 2 Pit Lake had the highest zooplankton abundance

(548.75±7.42); however, the lowest value was documented at Nagrakonda Pit Lake (171.38±2.84) (Table 3 and Fig. 1). Based on the Engelman's scale (Engelmann, 1978), in some pit lakes certain zooplankton species were found as eudominant. Those were *Sida* sp. in Khadankali, Dalurbandh, Joyalbhanga and Nagrakonda Pit Lakes; *Moina micrura* in Dhandardihi 3 and Belpahari Pit Lakes; *Paracyclops* sp. in Khadankali, Belpahari, Dalurbandh, Joyalbhanga and Nagrakonda Pit Lakes; *Tropocyclops* sp. in all the studied pit lakes; *Brachionus forficula* in Dhandardihi 1, Dhandardihi 2 and Joyalbhanga Pit Lakes. Fig. 2 shows the spatial variations of different diversity indices. We calculated different diversity indices for rotifers, copepods and cladocerans separately. The highest rotifer diversity ($H'=2.327$) was found at Harabhanga 2 Pit Lake and the lowest ($H'=0.8975$) at Dhandardihi 2 Pit Lake. The highest copepod diversity ($H'=1.559$) was found at Harabhanga 1 Pit Lake and the lowest ($H'=1.188$) at Nagrakonda Pit Lake. The highest Cladoceran diversity ($H'=2.137$) was found at Harabhanga 1 Pit Lake and the lowest ($H'=1.368$) at Joyalbhanga Pit Lake. Evenness was varied from 0.179 to 0.709 for rotifers, 0.655 to 0.793 for copepods, and 0.6546 to 0.9419 for cladocerans. The richness values were ranged from 1.617 to 3.263 for rotifers, 0.8649 to 1.111 for copepods, 1.278 to 1.69 for cladocerans.

3.2. Spatial variation of hydrological parameters

Physicochemical parameters like pH, temperature, TDS, electrical conductivity, DO, PO_4^{3-} , NO_3^- , Cl⁻, Secchi depth and turbidity exhibited variations. With the exception of NO_3^- , other water quality parameters showed significant spatial variations (ANOVA, $p \leq 0.05$) (Table 3). The surface water temperature (mean value) ranged between $28.0 \pm 0.78^\circ\text{C}$ and $31.5 \pm 0.85^\circ\text{C}$. pH varied between 9.22 ± 0.01 and 8.17 ± 0.35 . The highest pH value (9.22) was recorded at Dhandardihi 2 Pit Lake and the lowest value (7.40) at Harabhanga 2 Pit Lake. The TDS of surface water varied from 192.5 ± 12.02 mg/l to 382.5 ± 53.03 mg/l. The transparency was varied from 0.78 ± 0.09 m to 2.17 ± 0.10 m. The mean electrical conductivity was recorded at a maximum (780 ± 91.92 mg/l) at Searsole Pit Lake and minimum (384 ± 22.63 mg/l) at Khadankali Pit Lake. The chloride value was higher (77.12 ± 1.58 mg/l) in Searsole Pit Lake and lower (40.37 ± 7.42 mg/l) in Joyalbhanga Pit Lake. The DO was varied from 4.10 ± 0.28 mg/l to 5.7 ± 0.14 mg/l. The average value of NO_3^- varied between 0.25 ± 0.11 mg/l and 1.16 ± 0.24 mg/l. The average PO_4^{3-} concentrations were recorded from 0.73 ± 0.21 mg/l to 1.23 ± 0.15 mg/l.

The cluster analysis classified pit lakes into three different groups: Group 1 (Belpahari, Dhandardihi 2 and Khadankali Pit Lakes), Group 2 (Dhandardihi 3 and Nagrakonda Pit Lakes) and Group 3 (Searsole, Harabhanga 1, Harabhanga 2, Dhandardihi 1, Dalurbandh and Joyalbhanga Pit Lakes) (Fig. 3). The closeness of the distribution of the site clusters suggests that biological factors and physicochemical traits are consistent in describing aquatic ecosystem health.

3.3. Relationship between zooplankton and water quality parameters

This study showed distinct variations in the zooplankton population between the several pit lakes. In order to identify taxonomic prevalence across environmental gradients, redundancy analysis (RDA) was used (Fig. 4). The variance (89.01%) in the correlation between zooplankton and water quality parameters was explained by the first two axes. The first axis had correlations with pH, TDS, COND,

PO_4^{3-} , Cl^- , and TUR, whereas the second one with temperature, DO, NO_3^- , and SD. *Filinia openalis*, *Brachionus falcatus*, *B. forficula*, *Ceriodaphnia* sp., *Diaptomus* sp., *Paracyclops* sp., *Anuraeopsis* sp., *Eurycercus* sp., *Diaphanosoma* sp., *Moina micrura*, *Gastropus* sp., *Ascomorpha* sp., *Alona* sp., *Notholca* sp., and *Pompholyx* sp. were mainly associated with pH, Cl^- and PO_4^{3-} and were negatively associated with TDS, COND and TEMP. *Keratella cochlearis*, *Keratella tropica*, *Brachionus caudatus personatus* and *Brachionus caudatus aculeatus* were positively associated with DO, NO_3^- and SD and were negatively associated with TUR. In contrast, *Filinia longiseta* showed strong positive relationship with TDS, COND and TEMP but was negatively associated with pH, Cl^- and PO_4^{3-} , whereas *Sida* sp., *Brachionus calyciflorus*, *B. diversicornis*, *Testudinella* sp., *Tropocyclops* sp., *Mesocyclops* sp., *Lecane* (*Monostyla*) *bulla*, *Microcyclops varicans*, *Microcyclops rubellus*, *Diaphanosoma* sp., *Moina micrura*, and *Rotaria* sp. showed a positive association with TUR and negative relationship with DO, NO_3^- and SD.

Table 2: Species of zooplankton observed in the pit lakes examined.

Family Brachionidae		
<i>Brachionus angularis</i>	<i>K. lenzi</i>	<i>B. diversicornis</i>
<i>B. calyciflorus</i>	<i>Anuraeopsis</i> sp.	<i>B. caudatus personatus</i>
<i>B. falcatus</i>	<i>Notholca</i> sp.	<i>B. caudatus aculeatus</i>
<i>B. forficula</i>	<i>Platylas quadricornis</i>	<i>B. quadridentatus</i>
<i>B. rubens</i>	<i>B. kostei</i>	<i>Keratella tropica</i>
<i>B. patulus</i>	<i>K. cochlearis</i>	<i>K. procurva</i>
<i>B. bidentata</i>	<i>B. mirabilis</i>	<i>Platylas quadricornis</i>
<i>Lecane</i> (<i>Monostyla</i>) <i>bulla</i>	<i>L. unguate</i> (Lecanidae)	<i>L. quadridentata</i> (Lecanidae)
<i>Filinia longiseta</i> (Filiniidae)	<i>F. opoliensis</i> (Filiniidae)	<i>Asplanchna brightwelli</i> (Asplanchnidae)
<i>Gastropus</i> sp. (Gastropidae)	<i>Ascomorpha</i> sp. (Gastropidae)	<i>Lepadella</i> sp. (Lepadellidae)
<i>Testudinella</i> sp. (Testudinellidae)	<i>Pompholyx</i> sp. (Testudinellidae)	<i>Cephalodella</i> sp. (Notommatidae)
<i>Polyarthra</i> sp. (Synchaetidae)	<i>Trichocerca similis</i> (Trichocercidae)	<i>Mytilina</i> sp. (Mytilinidae)
<i>Rotaria</i> sp. (Philodinidae)	<i>Paracyclops</i> sp. (Cyclopidae)	<i>Microcyclops rubellus</i> (Cyclopidae)
<i>M. varicans</i> (Cyclopidae)	<i>Mesocyclops</i> sp. (Cyclopidae)	<i>Tropocyclops</i> sp. (Cyclopidae)
<i>Diaptomus</i> sp. (Diaptomidae)	<i>Scapholebris</i> sp. (Daphnidae)	<i>Daphnia</i> sp. (Daphnidae)
<i>Ceriodaphnia</i> sp. (Daphnidae)	<i>Moina micrura</i> (Moinidae)	<i>Eurycercus</i> sp. (Chydoridae)
<i>Alona</i> sp. (Chydoridae)	<i>Sida</i> sp. (Sididae)	<i>Diaphanosoma</i> sp. (Sididae)

Table 3: Water quality metrics measured were given mean values and standard deviations (SD).

Pit Lakes	pH	TEMP (°C)	TDS (mg/l)	COND (μS/cm)	DO (mg/l)	PO_4^{3-} (mg/l)	NO_3^- (mg/l)	Cl^- (mg/l)	SD (metre)	TUR (NTU)
H1	8.22±0.14	29.1±2.40	200±19.80	406.5±34.65	5.7±0.14	1.07±0.15	1.12±0.03	69.52±1.98	0.78±0.09	14±5.66 0.008
H2	8.17±0.35	29.0±1.63	193.5±14.85	391.5±23.33	5.45±0.07	0.99±0.17	0.38±0.04	65.06±1.33	0.87±0.12	11±1.41
S	8.36±0.22	28.7±1.48	382.5±53.03	780±(91.92)	4.85±(0.49)	1.17±0.24	0.43±1.13	77.12±1.58	1.2±10.3	12.5±7.78

D1	8.51±0.14	28.6±0.14	308±72.12	646.5±101.12	5.15±0.35	1.3±0.10	0.69±0.21	67.62±19.6	1.22±0.35	8±5.66
D2	9.22±0.01	28.3±1.84	205±15.56	404±41.01	4.1±0.28	1.23±0.15	0.25±0.11	62.12±12.45	0.98±0.34	31±1.41
D3	8.43±0.27	28.0±0.78	319.5±28.99	646±48.08	4.55±0.21	1.20±0.36	0.56±0.09	61.06±5.93	2.17±0.10	13±4.24
K	8.48±0.06	29.4±1.63	192.5±12.02	384±22.63	4.8±0.14	1.13±0.35	0.87±0.02	61.58±13.22	1.83±0.44	6±1.41
BIL	8.19±0.09	28.9±0.28	260±1.41	533.5±2.12	5±0.28	0.73±0.21	0.65±0.31	40.37±7.42	1.96±0.09	9±2.83
DALU	8.78±0.06	31.5±0.85	207±4.24	427.5±2.12	5.2±0.85	1.1±0.26	1.16±0.24	48.98±3.27	0.94±0.01	10±1.41
JOYAL	8.24±0.42	34.1±0.57	243.5±2.12	498±4.24	5.45±0.21	0.9±0.2	0.4±0.05	56.81±16.13	.65±0.15	17±2.83
NAG	8.13±0.03	31.9±0.14	263±2.83	565±2.83	4.9±0.35	0.87±0.20	0.62±0.13	59.38±5.78	1.35±0.2	8.5±0.71
ANOVA (P)	0.008*	0.011*	0.001*	0.003*	0.039*	0.001*	1.355	0.045*	0.001*	0.003*
Total zooplankton abundance (ANOVA P value: 0.0324*)										
H1	H2	S	D1	D2	D3	K	BIL	DALU	JOYAL	NAG
495.75±8.77	281.13±3.50	312.13±2.17	320.75±1.50	548.75±7.42	172.25±5.36	426.13±4.89	325.75±5.45	300.75±10.88	213±2.68	171.38±2.84

TDS – Total dissolved solids, COND – Conductivity, PO_4^{3-} – Phosphate, NO_3^- – Nitrate, DO – Dissolved oxygen, Cl^- – Chloride, SD – Secchi disc, TUR – Turbidity

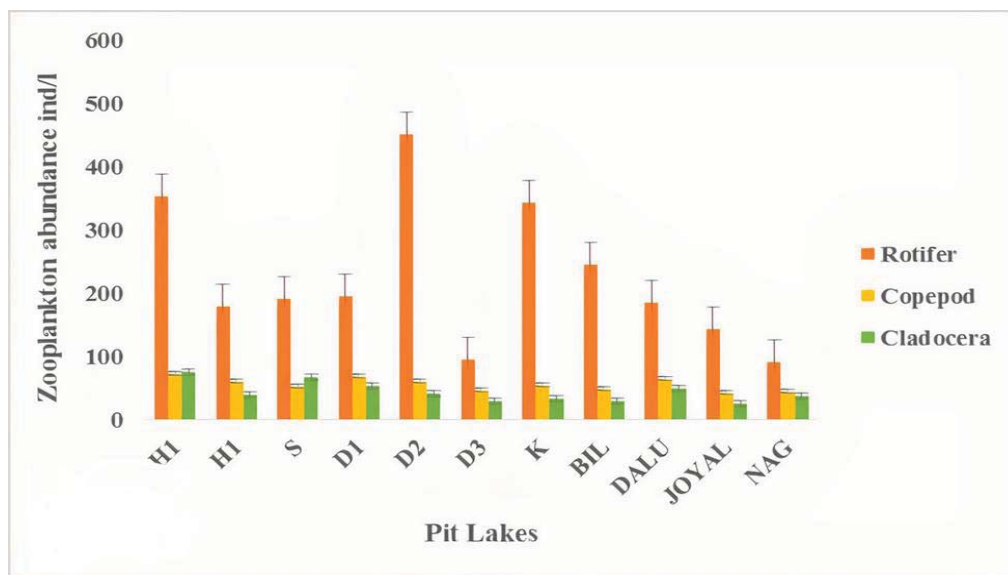


Figure 1. Spatial variation of total zooplankton abundance.

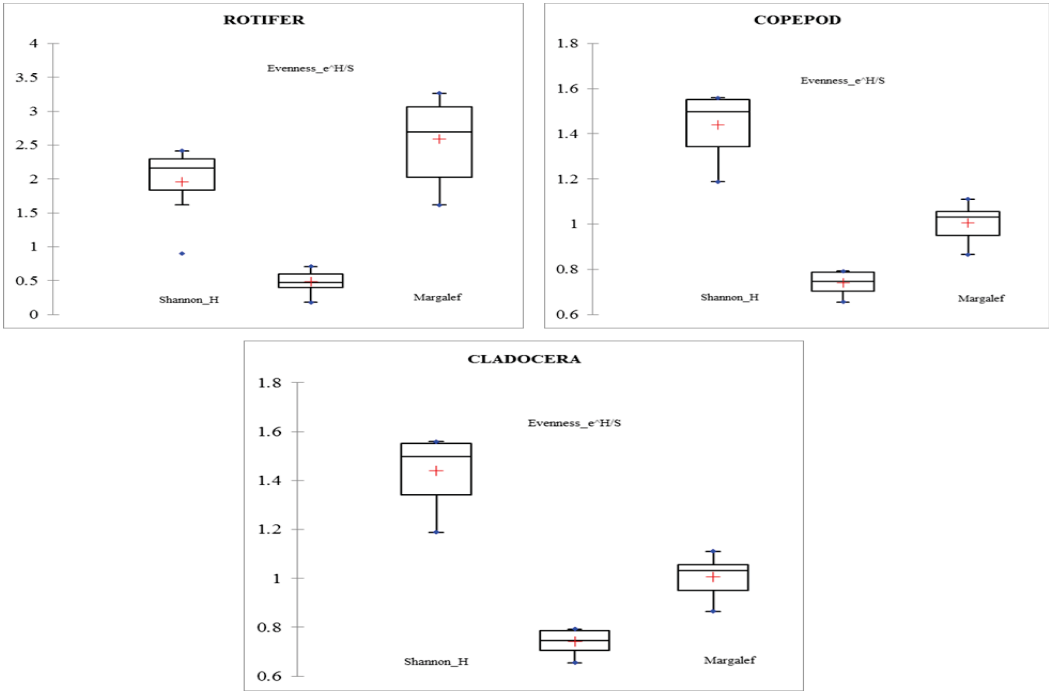


Figure 2. Variation of different diversity indices for three different groups of zooplankton.

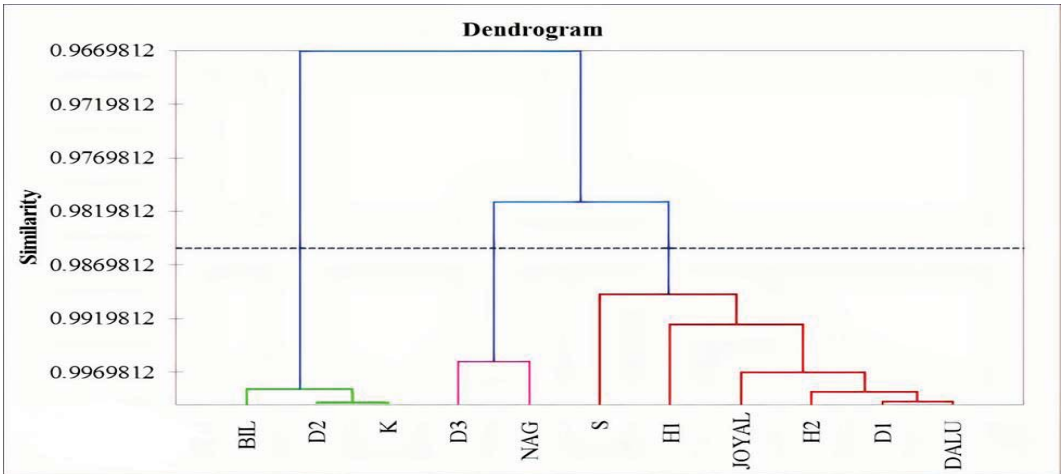


Figure 3. Dendrogram plot based on total zooplankton abundance and water quality.

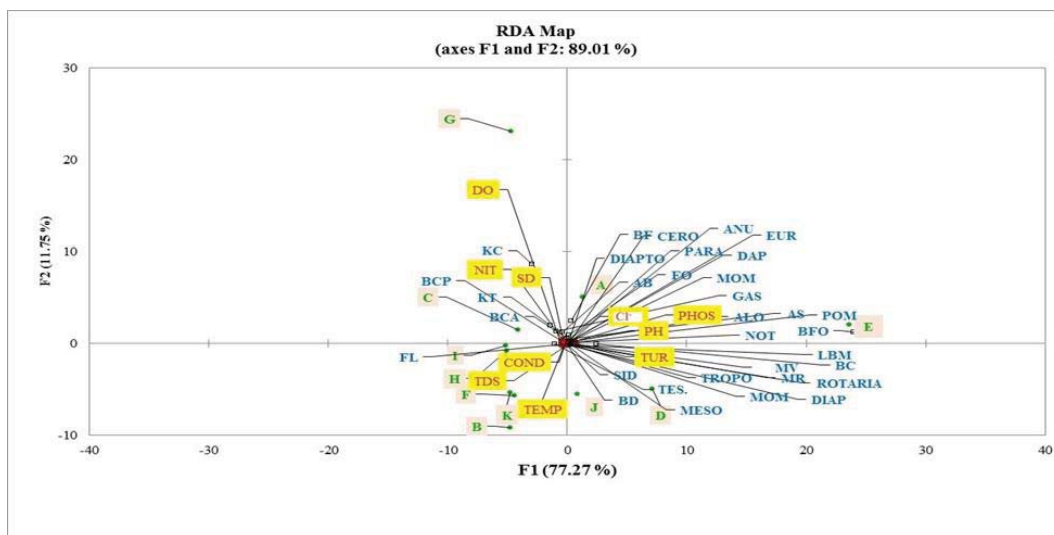


Figure 4. RDA plot between the limnological variables and abundance of individual zooplankton species of the studied pit Lakes. *Filinia openalis* (FO), *Brachionus falcatus* (BF), *Cerodaphnia* sp. (CERO), *Diaptomous* sp. (DIAPTO), *Paracyclops* sp. (PARA), *Anuraeopsis* sp. (ANU), *Eurycercus* sp. (EUR), *Diaphanosoma* sp. (DIAP), *Moina micrura* (MOM), *Gastropus* sp. (GAS), *Ascomorpha* sp. (AS), *Alona* sp. (ALO), *Notholca* sp. (NOT), *Brachionus forficula* (BFO) and *Pompholyx* sp. (POM), *Keratella cochlearis* (KC), *Keratella tropica* (KT), *Brachionus caudatus personatus* (BCP) and *Brachionus caudatus aculeatus* (BCA), *Filinia longiseta* (FL), *Sida* sp., *Brachionus diversicornis* (BD), *Testudinella* sp. (TES), *Tropocyclops* sp. (TROPO), *Mesocyclops* sp. (MESO), *Brachionus calyciflorus* (BC), *Lecane Bula Monostyla* (LBM), *Microcyclops varicans* (MV), *Microcyclops rubellus* (MR), *Diaphanosoma* sp. (DIAP), *Moina micrura* (MOM), and *Rotaria* sp. (ROT), DO – Dissolved oxygen, NO₃⁻ – Nitrate, PO₄³⁻ – Phosphate, CHL – Chloride, TEMP – Temperature, TDS – Total dissolved solids, COND – Conductivity, SD – Secchi Depth, TUR – Turbidity. A – H1 Pit Lake, B – H2 Pit Lake, C – Searsole Pit Lake, D – Dhandardihi 1 Pit Lake, E – Dhandardihi 2 Pit Lake, F – Dhandardihi 3 Pit Lake, G – Khadankali Pit Lake, H – Belpaharai Pit Lake, I – Dalurbandh Pit Lake, J – Joyalbhangra Pit Lake, K – Nagrakonda Pit Lake.

3.4. Wetland Zooplankton Index (WZI)

The WZI scores ranged from 3.66 to 3.92. WZI scores showed moderate water quality in all pit lakes examined (Fig. 5). Wherever practical, it is recommended that WZI should be used as supplement to data based on water quality parameters, rather than as the primary indicator for the quality assessment of wetland. Further investigation would be done to compare the WZI's effectiveness to other indices such as the Biotic Integrity Index, which draws on fish, benthos and macrophytes, to provide the most accurate and affordable combination of approaches for routine wetland assessment quality (Burton *et al.*, 1999; Karr, 1991; Minns *et al.*, 1994).

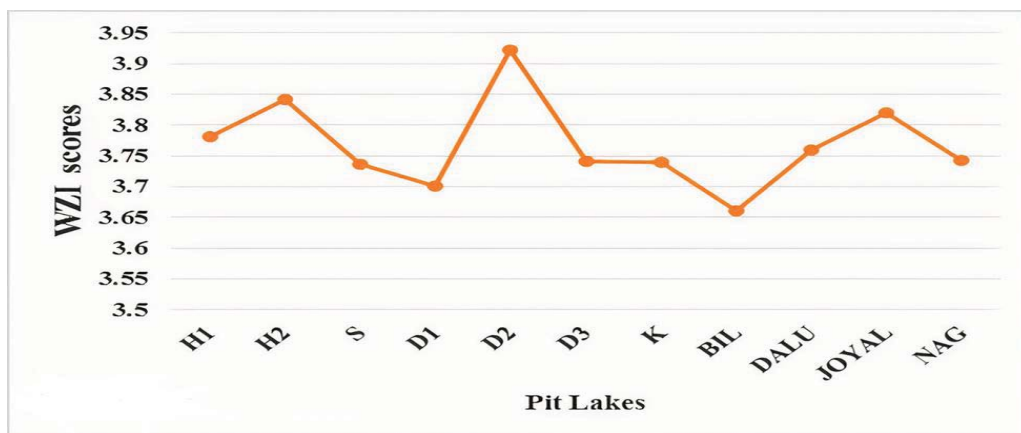


Figure 5. Wetland zooplankton index in the studied pit lakes.

3.5. Bio-indicator species

The discriminator species that predominantly accounts for the assemblage differences was revealed via SIMPER analysis based on community estimates at different pit lakes. According to SIMPER analysis, *Brachionus forficula* contributed the most important one to make differences between the pit lakes under study (26.66%).

4. Discussion

In the pit lake ecosystem, physicochemical variables were subject to significant regional variations. In tropical countries, monsoon rain influences the biogeochemical properties of different water bodies (Kumar and Perumal 2011). With the exception of NO_3^- all hydrographic metrics in the current survey showed remarkable spatial variability. pH was between 8.13 and 9.22 which indicate the alkaline nature of the studied pit lakes. It is well known that the concentration of nutrients has a significant impact on productivity and geographic differences in nutrient concentration can significantly affect trophic dynamics, community structure and the competitive process in water bodies (Gaonkar *et al.*, 2010). All TDS values were within the acceptable range as per Bureau of Indian standards. It was found that TDS at Searsole Pit Lake was higher than other pit lakes may be due to anthropogenic activity like bathing and washing of domestic animals. Turbidity measures the presence of suspended organic and mineral particles (Shigut *et al.*, 2017). All of the water samples were taken with turbidity values that exceeded the one nephelometric turbidity unit (NTU) drinking water requirements (Bureau of Indian Standard [BIS], 2015). One of the key indicators of water quality is chloride, which is abundant in earth as salt of different elements. Chloride levels in water are influenced by various natural and human-made variables, leaching from rocks, domestic and irrigation discharges (Barakat *et al.*, 2018). The results indicated that all chloride levels were within acceptable limits as per Bureau of Indian standards. NO_3^- is another crucial factor for water quality. NO_3^- is a substance, linked to several diseases neonatal diseases and congenital disabilities (Shigut *et al.*, 2017). The DO content was met with the surface water criterion as per Bureau of Indian standards.

4.1. Zooplankton community structure and abundance

The current study shows how zooplankton structure varies in pit lakes in RCF. There were differences in nutrient content, zooplankton diversity, and species uniformity between lakes. The abundance of zooplankton also varied significantly between lakes. Rotifers were dominant throughout the investigated pit lakes. Nutrient and water turbidity levels in the pit lakes have been increased by the organic and inorganic waste discharged into the lakes by anthropogenic activities. Visibility of planktivorous species is limited by high turbidity levels due to increased suspended matter, which can lead to a decrease in foraging activity, increasing zooplankton community survival and consequently zooplankton density (Wetzel 2001). The presence of macrophytes may be a factor in the high diversity of zooplankton in the Dhandardihi 2 Pit Lakes. During field sampling, this water body was qualitatively seen with a high submerged macrophyte cover. Several investigations in various temporary and permanent ponds, including storm water retention systems, have shown a significant positive correlation between zooplankton and macrophyte abundance (Sun *et al.*, 2019). Ecological gradients such as food availability and poor predator visibility are two potential macrophyte influences that could drive zooplankton abundance (Mimouni *et al.*, 2018). Rotifers were the most biodiversed zooplankton group (37 species) in this study. Our results were comparable to those of Manickam *et al.* (2018), who surveyed Lake Ukkadam in India and identified nine species of rotifers, and Wen *et al.* (2017) who studied two urban lakes in China and found 47 species of rotifers.

Previous research suggests that trophic status often influences the distribution of certain rotifers (Wen *et al.*, 2011). *Brachionus* dominated the rotifer aggregations in this study and seems to be abundant in the eutrophic lakes (Tasevska *et al.*, 2012). *Brachionus* is also a good trophic indicator, according to Ismail and Adnan (2016), as it is less affected by algal blooms. According to the SIMPER study, *B. forficula* contributed significantly to the mine lakes studied. Similar results were made by Mola (2011) who discovered that *B. angularis* was the dominant species in eutrophic Lake El-Manzalah. *Brachionus* sp., *Keratella* sp. and *Trichocerca* sp. were the most dominant genera in the hyper-eutrophic Sembrong reservoir (Umi *et al.*, 2018). Two other species which are also prevalent in eutrophic lakes are *Brachionus* sp. and *Keratella cochlearis* (Ejsmont-Karabin, 2012). Cyclopoid copepods, especially *Tropocyclops* sp. dominated among the zooplankton fauna. This is consistent with the reports of several other authors who claimed that copepods were prevalent in tropical and subtropical region (Wondie and Mengistou, 2006). *Polyarthra* spp., which are the markers of mesosaprobic water (Ermolaeva and Dvurechenskaya, 2013), have been found in Harabhanga 1, Belpahari, Dalurbandh and Joyalbhangha Pit Lakes. However, they are reported in different trophic types (Jekatierynczuk-Rudczyk *et al.*, 2014). According to Kolkowitz *et al.* (1909), *Asplanchna* sp., an oligotrophic species, also favored water bodies with higher nitrite nitrogen or phosphate concentrations. The Khadankali Pit Lake is dominated by *Keratella cochlearis*. Although *K. cochlearis* is a species thought to be mesosaprobic (Kolkowitz *et al.*, 1909), it is abundant in eutrophic lakes. *Mesocyclops* sp., a cyclopean copepod, was positively affected by phosphorus. It is a mesosaprobic species living in eutrophic water (Kolkowitz *et al.*, 1909). The most abundant zooplankton species identified during the study were Rotifer species, consistent with several studies previously performed on different freshwater bodies (Akindele and Adeniyi, 2013) and information on mine-affected water

(Ekpo, 2013). The dominance of rotifers over other zooplankton species may be due to their resilience to various stresses, allowing them to adapt to various environmental situations (Abioye, 2015). With a total of 15 species, copepods and cladocerans come next to the rotifers in this study. Certain rotifer species have been identified that have eutrophic communities. *Anuraeopsis fissa*, *Keratella tropica*, *Filinia* sp., *Brachionus angularis*, *B. calyciflorus*, *Trichocerca* sp. and *Polyarthra* sp. were some of them.

4.2. Zooplankton as a pertinent bio-indicator

Zooplankton is regarded as a viable bio-indicator for researching and documenting environmental effects in any water system because to its brief life span, migratory propensity, and rapid sensitivity to changes in aquatic ecosystems (Drira *et al.*, 2018). The dominant zooplankton species in tropical water typically control community structure and the flow of materials and energy into the environment. Community structure will change when a dominant group disappears, and the natural environment will also change (Wang *et al.*, 2014). In our study, the presence of specific zooplankton species with noticeable geographic variation suggests that the changing environmental conditions in the water have an impact on the emergence or local extinction of some species. When compared between the examined pit lakes, there was a substantial (ANOSIM, $p = 0.0001$) difference in abundance of various indicator zooplankton species. In our study, *Keratella tropica*, *Brachionus caudatus personatus*, *Asplanchna brightwelli*, *B. patulus*, *Filinia longiseta*, *Gastropus* sp., *Mytilina* sp., *B. angularis*, *B. rubens*, *B. calyciflorus*, *B. diversicornis* showed highest indicator value in the studied pit lakes.

4.3. Zooplankton response to environmental changes

The hydrological properties, climate variability, and anthropogenic effects in the nearby aquatic ecosystems have significant impact on the diversity and dispersion of zooplankton (Xiong *et al.*, 2017). Changes in the physicochemical properties of water affect the diversity and abundance of aquatic life. For zooplankton to grow and be abundant, a variety of environmental parameters must be considered. In the work described here, this type of zooplankton clustering tendency in response to a specific environmental parameter. In contrast to pH, PO_4^{3-} , and Cl^- , *Filinia longiseta* demonstrated a positive association with temperature. In our investigation, some zooplankton species negatively correlated with water temperature. Variation of water temperature can result in adverse effect on several zooplankton species (Andrulewicz *et al.*, 2008; Chen, 2020). Zooplankton stay away from the water surface at extremely high temperatures to prevent hypoxia (Roman *et al.*, 2019). Other authors have shown that temperature affects zooplankton species diversity and abundance (Sebastian *et al.*, 2012). Most aquatic life loses abundance and diversity when pH decreases (Andrulewicz *et al.*, 2008). However, high pH and optimal temperature favor the growth and survival of zooplankton (Mustapha, 2009). Since most species in this study showed a good association with pH, RDA showed that pH significantly affects zooplankton populations. The composition and abundance of zooplankton is influenced by the availability of nutrients (Kudari and Kanamadi, 2008). Eutrophication is inevitable due to anthropogenic activities that increase the concentration of PO_4^{3-} and NO_3^- in the water (Andong *et al.*, 2019). There are several conflicting assumptions about the influence of temperature and nutrients on aquatic invertebrates (Birk *et al.*, 2020). In this work, both temperature and nutrients have

a crucial impact on zooplankton abundance. Zooplankton abundance was substantially correlated with PO_4^{3-} and NO_3^- . Several zooplankton species have also been associated with turbidity, DO and SD. Srichandan et al. (2015) also reported similar observation. Decreased zooplankton abundance and increased copepod mortality could also be caused by anoxia and excessive turbidity associated with organic enrichment (Dira *et al.*, 2018). The RDA analysis revealed that several environmental factors have a significant effect on the overall composition of zooplankton in the mine lake ecosystem and could be the reason for the spatial variation of zooplankton. Most of the spatial changes in zooplankton population dynamics have been explained by the environmental variables pH, TDS, COND, PO_4^{3-} , Cl^- , and TUR. In addition, all zooplankton species have a negative relationship with COND. Predation and salinity might have influenced zooplankton abundance in pit lakes; however, it was not examined in this investigation (Roman *et al.*, 2019; Yuan *et al.*, 2020). Future research may be extended for longer study periods and more modern trapping methods to collect a larger sample of zooplankton to ensure proper assessment of the influence of physicochemical factors on zooplankton density.

5. Conclusion

A total of 51 species of zooplankton were found belonging to Rotifera, with genus *Brachionus* was the dominant. The pit lakes exhibited notable variations in zooplankton diversity, abundance, and community structure, indicating strong spatial variability influenced by regional environmental factors. Redundancy and cluster analyses indicate that the primary physicochemical characteristics influencing zooplankton dispersal were pH, DO, COND, TDS, nutrients, turbidity and water clarity. All pit lakes were categorized as having a moderate ecological state by the Wetland Zooplankton Index (WZI), and the primary indicator species responsible for the community differences amongst lakes was *Brachionus forficula*. As a result, zooplankton assemblages have been demonstrated to be sensitive ecological status indicators and helpful instruments for evaluating the state of the environment. So, a strong framework for pit lake monitoring and management is provided by the integration of biological indices with physicochemical investigations, which also yields important baseline data for pit lake conservation and sustainable use.

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