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Hirakud Reservoir-The Longest Earthen Dam in Asia: An Assessment on Physicochemical Parameters and Macrobenthic Community Assemblage

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Abstract

The current study evaluated the ecohydrological interactions of macrobenthic community and the trophic state of the Hirakud Reservoir. According to the computed values of weighted arithmetic water quality index (WAWQI), the reservoir represented a mesotrophic state with "*good to excellent*" water quality, particularly during the monsoon and post-monsoon seasons. However, during the monsoon, the water fell into the "*poor to very poor*" category. Seasonal heterogeneity was noted in the macrobenthos characteristics, with the monsoon season (848 ind.m^{-2}) showing the highest quantitative spectrum. Ecological functional groups – SC/SH (46%) were the major contributors to the total macrobenthic population. A total of 25 taxa of macrobenthos were recorded with Gastropoda was the chief contributor. Species *Melanoides tuberculata, Filopaludina bengalensis, Tarebia granifera* and *T. lineata* were consistently present throughout the seasons suggested that these species were highly tolerant of seasonality and other environmental disturbances. The ordination analysis stated that sediment variables such as water depth, clay (%), available-N, available – P and sediment organic carbon were the major influencing variables for abundance and distribution of macrobenthos in the Hirakud reservoir. Because of the constant inflow of water from the main river, Mahanadi, which inhibits the settling of finer particles at the bottom, the reservoir's sediment was primarily sandy (44–82%). The baseline data from the current study on Hirakud Reservoir will be useful in developing management recommendations for fisheries and water quality monitoring.

Keywords: Aquatic Biodiversity: Ecological Balance; Plants

Introduction

Aquatic biodiversity in reservoir ecosystems is vital for maintaining ecological balance, supporting human livelihoods and enhancing the overall health of the system. A variety of species, including plants, fish, and invertebrates, create complex habitats that provide shelter and breeding grounds for numerous organisms and this complexity supports a wide range of life forms in an aquatic ecosystem [1]. The ecology of the reservoir plays very important role in the habitability and abundance of its biotic community including the flora and fauna. The abundance of different organisms is greatly influenced by the interaction of the physical and chemical properties of the water and sediment and also on the interaction between individuals of the biotic community. The properties of the abiotic component of the reservoir are again depends upon the basin properties, the climatic condition, etc [2]. The longitudinal continuum within the reservoir *i.e.* zonation in space and seasonality both are the major factors governing the reservoir ecology. The changes in ecological parameters lead to physiological and behavioural alterations of the organisms. In addition, depending on the tolerance limits of these organisms, the stimulus often triggers in decline in the population of certain organisms [3]. Therefore, changes in the population and abundance of one organism directly or indirectly affect other groups of organisms, becoming a chain process that reflects up to the organisms in the higher trophic level, mainly fishes in the case of reservoirs [4].

Hirakud reservoir plays vital role in fish production in the Odisha state. Fish production in the reservoir was 8200 t during 2018–19 with catfish dominating and total annual catfish landings accounting for more than 50% of the total fish production. The major carps and minor carps contributed around 40% of total fish catch. The miscellaneous group (others) contributed only 7% of the total fish landing [5]. The multipurpose reservoir provides water for irrigation, power generation, industry, flood control, tourism and – above all - potability to the nearby cities, including Sambalpur.

The physicochemical changes in water—such as alterations in temperature, pH, dissolved oxygen, turbidity, and the presence of pollutants—can have significant impacts on aquatic organisms [6]. These changes affect the physiological processes, behavior, and survival of organisms, sometimes leading to ecosystem imbalances. Therefore, maintaining aquatic diversity in reservoir ecosystems is essential for ecological health, economic sustainability, and cultural integrity. In order to preserve and enhance the reservoir ecosystem's biodiversity, the current study set out to evaluate the ecological health status of the Hirakud Reservoir by analyzing physicochemical and biotic variables such as macrobenthos.

Materials and Methods

Study Area

Built across the Mahanadi River, just below its confluence with its tributary Ibb, Hirakud is India's first major multipurpose river valley project. It was put into service on January 13, 1957, and is the largest irrigation reservoir in Asia and the second largest in the world. Situated within the geographical ordinates of 21º30" and 21º60" N and 83º30" and 84º05" E, the reservoir has a water spread area is 74,592 ha (Jhingran, 1983). The reservoir expanse of the Hirakud dam is situated across three districts namely, Sambalpur, Jharsuguda and Bargarh in the state of Odisha. The present study was carried out across 5 (five) representative sites *namely* Tamdei (Lat. 21°44'10.48" Long. 83°34'45.55"), Birenbandh (Lat. 21°36'45.20" Long. 83°45'14.23"), Mahammadpur (Lat. 21°33'16.66" Long. 83°53'54.04"), Zeropoint (Lat. 21°29'78.83" Long. 83°47'25.58") and Kurla (Lat. 1°56'91.09" Long. 83°98'58.35"), and herein after the stations are referred as S1, S2, S3, S4 and S5, respectively. Recently, Hirakud reservoir was designated as Ramsar site [7] (Figure 1). The present study was conducted from June 2022 to May 2023.

The seasons were referred as monsoon from July to October, the post-monsoon (November–February) and the pre-monsoon (March – June) according to Indian Meteorological Department (IMD).

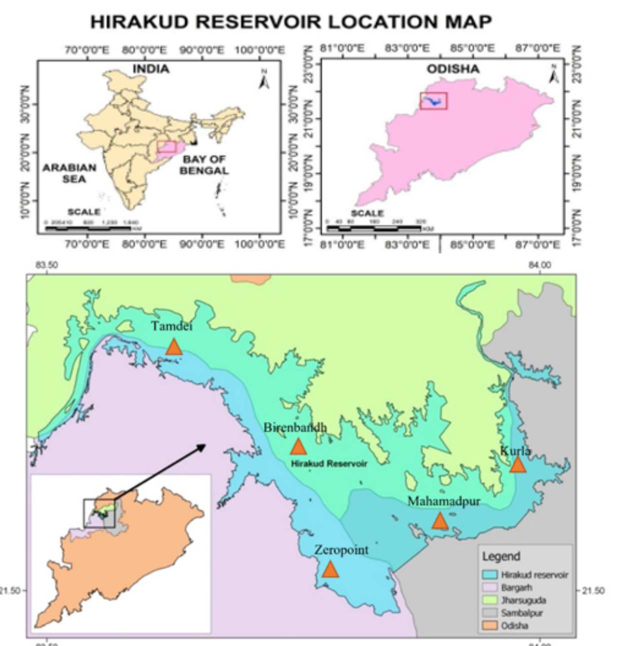

Figure 1: Study area map and sampling locations in Hirakud reservoir, Odisha.

Sampling Procedure

Using a standard water sampler based on the "Ruttner water sampler" design, water samples were taken seasonally from the subsurface water column (0.5 m) and stored in 1 L pre-rinsed polyethylene bottles. Water characteristics, including water temperature (Temp.), pH, transparency (SD), dissolved oxygen (DO), electrical conductivity (EC) and total alkalinity (TA) were measured in the field. The standard titrimetric methods were used for estimating DO and TA [8]. A Secchi disc was used to measure transparency, and a commercial probe (PCSTestr 35, multiparameter probe) was used to measure water temperature, pH, TDS, and EC. The stored water samples were brought to the laboratory and analyzed nutrients (NO_3–N, PO_4–P, SiO_4–Si) following standard methods of APHA [8]. For estimating Chlorophyll (Chl *a*), one liter water samples were collected by amber bottles and were estimated by acetone extraction method according to APHA [8]. The sediment samples were collected using Petersen grab sediment sampler. Samples were collected from sub-surface layer of the selected sites. By suspending the sediment in distilled water (1:2.5), the pH-EC meter was used to measure the sediment's pH and EC [9].

Sediment organic carbon (OC) was determined following Walkley–Black method [10]. Available nitrogen and available phosphorous in the sediments were estimated following methods of Jackson ML [11]. In addition, sediment grain texture, sediments were analysed by Laser Diffraction Particle Size Analyzer (Beckman Coulter, USA, LS). Percentage of finer fraction like clay (< 2 μm) and silt (2 – 63 μm) as well as coarser fraction like sand (> 63 μm) were calculated.

For macrobenthic community structure, seasonal sampling was carried out at the respective sites of the reservoir, using a Peterson Grab (23.5 cm x 23.5 cm^2) sampler. After completion of the sieving procedure (500 μm and 300 μm mesh sized sieve) of the grab sediment, samples were preserved in 4 % buffered formalin for the soft bodied animals. The taxonomic evaluation was done with the help of stereo zoom microscope following published taxonomic keys [12-15] up to genus or species level wherever possible both in the field and in the laboratory.

The abundance of microbenthic organisms was expressed as nos. m^{-2}. The macrobenthic organisms that are encountered are categorized based on their functional groups [16].

Data Treatment

Summary statistics of water and sediment variables were performed in MS excel 2010. Pearson's correlation analysis was used to comprehend the intra and interrelationships of water variables and Chl *a*. Additionally, the significant difference of water variables between stations and seasons were tested using the ANOVA post hoc (Duncan) test.

An ordination analysis (Canonical Correspondence Analysis) was performed to examine the interactions between macrobenthic ecological functional groups and the sediment properties.

The Weighted Arithmetic Water Quality Index (WAWQI) was used to calculate the Water Quality Index (WAWQI) [17]. The degree of purity or potability of the water variables was specified by the Bureau of Indian Standards [18]. According to the WAWQI, the water quality rating was followed as 0 – 25: Excellent; 26 – 50: Good; 51 – 75: Poor; 76 – 100: Very poor and >100: unfit for consumption. In addition, Carlson Trophic State Index (CTSI) [19-20] was followed for estimating trophic state of the reservoir.

Results and Discussion

Water Quality Parameters

The spatio-temporal variations in water quality parameters are depicted in Table 1. One way-ANOVA revealed that the majority of the measured water variables (Temp., pH, TA, EC, TDS, TH, NO_3–N, PO_4–P, SiO_4–Si, Chl *a*) displayed notable seasonal differences ($p<0.05$). Across sampling locations, the reservoir's water temperature fluctuated seasonally between 24.10±3.82°C and 28.5±3.94°C, with lowest in S1. The inverse relationship between water temperature and DO in the present study is typical with many studies in the reservoir environment [21,22].

The pH range of the reservoir was moderately alkaline 7.2-8.3 indicating that the reservoir is productive in nature. The pre-monsoon season had the highest seasonal pH values (8.24±0.20), while the monsoon season had the lowest (7.65±0.25). Dissolved oxygen triggers a number of biochemical alterations and serves as indicator of the ecological health of water resources [23,24]. The annual average DO of the reservoir was recorded to be 7.5 mg l^{-1} which indicates a well oxygenated environment and conducive for fisheries. Seasonally, the DO values ranged from 6.64±0.29 to 7.52±0.39 mg l^{-1} with the highest being recorded in post-monsoon (7.52±0.39 mg l^{-1}) and lowest in pre-monsoon (6.64±0.29 mg l^{-1}).

Moderate range of total alkalinity was recorded with peak during the post-monsoon season 83.8±8.77 mg l^{-1}.

The measured value of TA was slightly higher than the earlier study by Sugunan, et al. [25] and comparable with Pathak, et al. [26]. Electrical conductivity and TDS showed similar trend with EC ranged between 126.4±19.89 μS cm^{-1} (monsoon) to 184.8±25.75 μS cm^{-1} (pre-monsoon) indicating low dissolved ionic concentrations during the monsoon. The monitoring of waterbody resulted that water quality parameters (pH, DO, TA, EC, TDS and TH) were within the permissible limit of BIS [18] and WHO [27].

Water variables	S1	S2	S3	S4	S5	PRM	MON	POM
Temp. (^{0}C)	24.10±3.82	26.46±3.77	28.27±3.73	28.5±3.94	28.5±3.80	30.32±0.53	28.74±4.08	22.44±0.84
pH	7.72±0.32	7.84±0.56	8.13±0.12	8.07±0.21	7.86±0.28	8.24±0.20	7.65±0.25	7.88±0.34
DO (mg l^{-1})	7.03±0.78	7.17±0.61	7.45±0.38	7.3±0.14	6.64±0.29	6.68±0.47	7.16±0.51	7.52±0.39
TA (mg l^{-1})	77±22.38	79±9.27	61.67±11.61	66.67±13.60	75.67±15.80	77±15.35	55.2±8.26	83.8±8.77
EC (µS cm^{-1})	195±24.10	213±48.15	204.67±19.48	207.34±24.57	189.47±25.15	240.8±21.29	179.68±12.22	185.2±6.14
TDS (mg l^{-1})	149.33±40.20	155.67±48.40	154.34±15.08	145±24.86	139±19.44	184.8±25.75	126.4±19.89	134.8±13.06
TH (mg l-1)	83±18.71	83±9.90	66.34±11.67	72.34±13.07	83.67±18.73	83.4±13.95	61±6.26	88.6±12.22
NO_3-N (mg l^{-1})	0.013±0.01	0.012±0.003	0.02±0.002	0.02±0.004	0.01±0.01	0.008±0.004	0.019±0.002	0.013±0.001
TN (mg l^{-1})	0.031±0.003	0.030±0.002	0.025±0.025	0.028±0.005	0.028±0.013	0.022±0.006	0.034±0.006	0.027±0.004
PO_4-P (mg l^{-1})	0.021±0.01	0.023±0.002	0.018±0.01	0.013±0.003	0.024±0.01	0.0271±0.01	0.013±0.00	0.016±0.01
TP (mg l^{-1})	0.039±0.016	0.038±0.017	0.045±0.046	0.041±0.042	0.042±0.045	0.039±0.020	0.018±0.003	0.069±0.024
SiO_4-Si (mg l^{-1})	14.44±3.26	11.763±3.08	13.80±4.56	12.74±4.51	12.25±4.77	10.566±2.51	18.448±1.38	9.986±0.38
SO_4- (mg l^{-1})	0.055±0.02	0.033±0.01	0.037±0.01	0.043±0.02	0.053±0.03	0.064±0.02	0.0387±0.01	0.029±0.01
Chl a (mg m^{-3})	4.499±2.60	5.574±1.05	4.830±2.14	4.631±1.56	4.243±1.43	2.800±0.90	5.4128±1.54	6.054±1.28

Table 1: Spatio-temporal variations of water variables at the sampling locations of Hirakud reservoir (mean values ±SD).

The nutrient parameters are varied substantially in seasons. Nitrate–N plays a very important role in influencing the primary producers of the water, *i.e.,* the phytoplankton and algae absorbs the nitrate-N in water for their metabolism. The NO_3–N concentrations varied from 0.008 – 0.019 mg l^{-1} shows medium productive reservoir. Phosphate–P promotes the growth of phytoplankton and other aquatic plants, which in turn provides natural food for the fishes inhabiting in the waterbody. The PO_4–P concentration ranged from 0.013±0.003 mg l^{-1} to 0.023±0.002 mg l^{-1}. Sulphate concentrations were minimal, ranging from 0.029±0.01 mg l^{-1} (post-monsoon) to 0.064±0.02 mg l^{-1} (pre-monsoon), however, Silicate – Si concentrations showed a wide range across sampling stations and estimated to be ranged between 9.68 and 20.25 mg l^{-1} with maximum during the monsoon season (18.448±1.38 mg l^{-1}).

Earlier studies by Sugunan, et al. [25] in Hirakud reservoir stated that the bay sector had a relatively higher NO_3–N concentration, while the lentic sector had PO_4–P concentration with mean values of 0.06 mgl^{-1} and 0.04 mgl^{-1}, respectively. When comparing these nutrient values with the former study, it was estimated that slightly lower value in NO_3–N and PO_4–P concentrations. However, silicate-Si concentrations were significantly elevated. The pronounced water level fluctuations and large amount of surface runoff could be correlated to the significant changes of nutrients in the reservoir [25] coupled with feeder rivers inputs (Mahanadi and its tributary *Ibb*). The reservoir's productivity is also determined by its Chl *a* concentration. According to the seasonal and spatial analyses, the Hirakud reservoir's productivity was moderate, with values ranging from 1.561 to 7.88 mg m^{-3}.

Seasonally, the Chl *a* concentration was recorded maximum during the post-monsoon season (6.054±1.287 mg m^{-3}). The values of Chl *a* indicating relatively good with mesotrophic environment. ANOVA post-hoc test (Duncan) suggests that there was no significant difference in Chl *a* between sites, but showed its value during pre-monsoon was significantly differed ($p<0.05$) from monsoon and post-monsoon season. Water temperature was positively correlated with WQI and CTSI but negatively correlated with Chl *a*.

Sediment Characteristics

The pH of sediment varied between 6.24 – 7.23 with maximum during pre-monsoon. Similarly, specific conductivity also showed ranging from 0.268 ± 0.311 (S1) to 0.895 ± 0.23 $mScm^{-1}$ (S2), and post-monsoon values (0.765 ± 0.30 $mScm^{-1}$) were relatively high compared to the pre-monsoon and monsoon season. The sediment was predominantly sandy in all three zones of the reservoir where sand content varied from 44 to 82 %. According to Saha, et al. [9], the Krishnagiri reservoir in Tamil Nadu had a higher pH (8.23–8.91) than the Hirakud reservoir, but a comparatively lesser amount of sand and clay. Riverine influx, which inhibits the settlement of finer particles and supports outflow from the reservoir, may be the cause of the higher sand fractions in the sediment samples under study [28]. Silt fractions observed to be similar trend across stations. The sediment organic carbon of the reservoir across the different zones ranged from 1.36 – 4.1% and comparatively higher in the intermediate and lentic zones. Most stations recorded more than 1.5% of sediment organic carbon suggests that the reservoir sediment was productive in nature in context of fisheries. The available nitrogen concentration in the sediment ranged from 9.8 to 18.4 mg/100 g, with the higher values recorded at the lentic zones of the reservoir. Similar trends were also shown by the available phosphorous, which peaked in availability during the post-monsoon season (Table 2).

Sediment variables	S1	S2	S3	S4	S5	PRM	MON	POM
pH	6.4±0.36	6.96±0.44	6.43±0.47	6.6±0.65	6.71±0.33	7.23±0.23	6.39±0.24	6.24±0.30
Specific Conductivity ($mScm^{-1}$)	0.268±0.311	0.895±0.23	0.576±0.32	0.698±0.29	0.760±0.37	0.399±0.11	0.754±0.41	0.765±0.30
Organic Carbon (%)	2.72±0.99	3.02±0.92	2.51±0.42	2.88±0.66	2.96±0.75	1.87±0.29	3.15±0.08	3.43±0.65
Available- N (mg/100g)	11.96±0.54	11.92±1.58	13.9±2.12	14.82±2.58	13.43±1.56	12.26±1.57	12.22±1.02	15.14±2.12
Available - P (mg/100g)	2.34±0.95	2.12±1.07	3.57±2.9	3.84±2.9	1.37±0.33	0.74±0.21	2.66±0.54	4.54±2.52
Sand (%)	53±8.83	57±9.93	56.33±9.67	57±11.31	61±14.85	72.2±5.56	49.8±0.74	48.6±2.41
Silt (%)	25.33±10.96	25.66±8.26	25±12.96	27±11.57	25±12.02	10±2.44	31.8±0.74	35±2.44
Clay (%)	21.66±2.49	17.33±1.69	18.66±3.68	16±2.44	14±2.82	17.8±5.49	18.4±1.2	16.4±2.87

Table 2: Spatial and temporal variations in sediment characteristics.

Benthic Community Dynamics

Four functional groups of macro benthic invertebrates *namely,* Scrappers/Shredders (SC/SH), Filter collectors (FC), Collector gathers (GC), Detrital Shredders (DSH) and Predators (P) were recorded comprising 25 taxa (Figure 2). Functional groups SC/SH accounted maximum (46%), followed by GC (28%), DSH (20%), FC (4%) and P (2%) of the total benthic assemblage (Figure 3a).

Seasonal changes of macrobenthic community were pronounced in the reservoir and mean abundance of macrobenthos was maximum during the monsoon season (848 $nos.m^{-2}$) followed by pre-monsoon and monsoon (Figure 3b). The seasonality scenario in terms of abundance and distribution was typical with the results of Khan, et al. [29] with peak abundance during the monsoon (12,427 $ind.m^{-2}$) and lowest in the pre-monsoon season (8,686 $ind.m^{-2}$). Gastropods, *Melanoides tuberculata* (22%) showed notable presence during the pre-monsoon, followed by *Filopaludina bengalensis* (11%), *Tarebia granifera* (8.9%) and *T. lineata* (7%). Oligochaeta (*Tubifex tubifex* and *Limnodrilus* sp.) also, a major contributor during the pre-monsoon. However, a changing association pattern was observed during the monsoon, with chironomid larvae (28%) and oligochaeta (*Tubifex tubifex*; 14%) dominating over the former taxonomic group.

The dominance of *Tubifex tubifex*, which accounts for 47–25% of all annelid species from Ottu reservoir in Haryana, was also reported by Sunder, et al. [30]. Khan, et al. [29] reported in total 43 macrobenthic species belonging to 3 Phyla from Kolar reservoir, MP, where species richness was found to be comparatively higher than the present study.

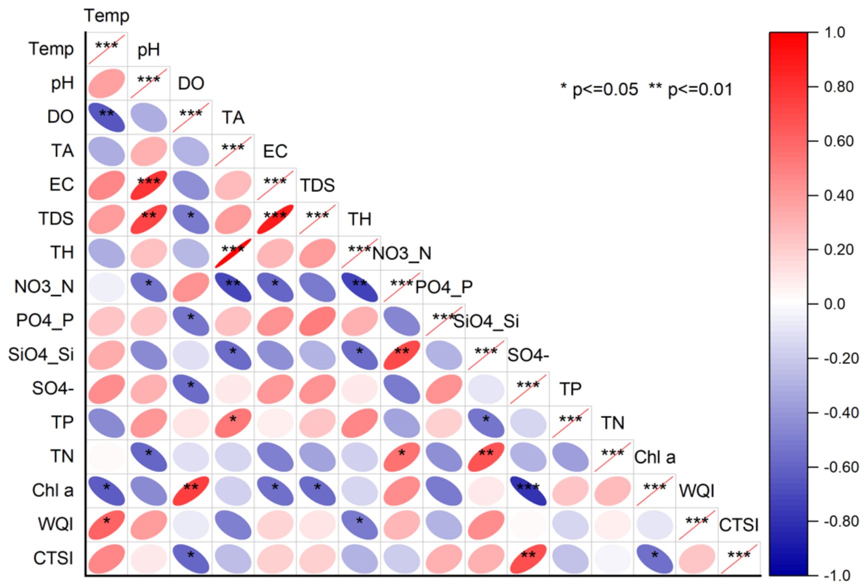

Figure 2: Correlation plot showing the intra and interrelationship of water variables and indices.

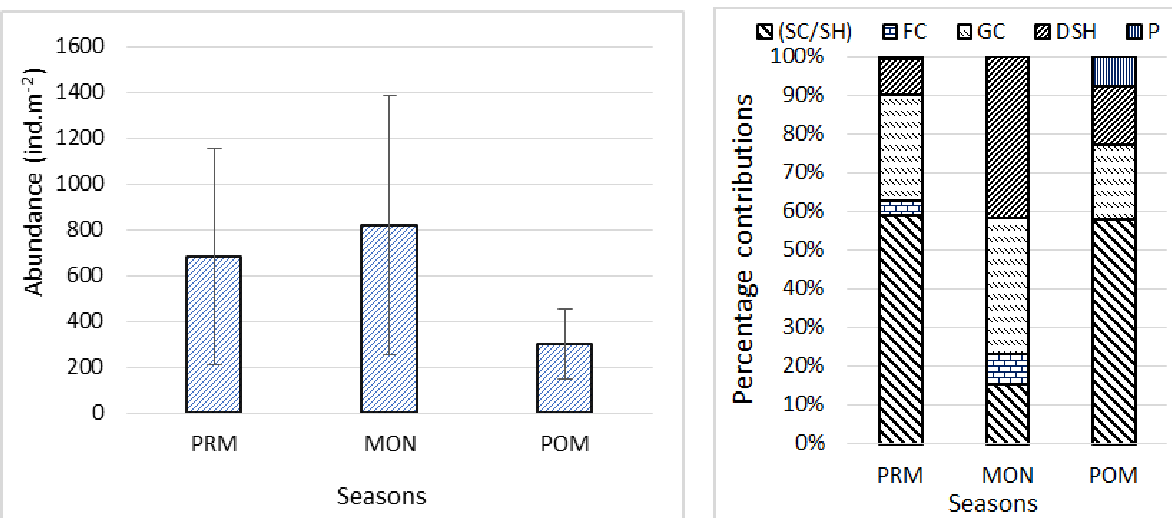

Figure 3: a & b Seasonal abundance (left – a) of macrobenthos and relative contributions of feeding guilds (right – b) in Hirakud reservoir.

The community structure during the post-monsoon was similar to the pre-monsoon season with maximum contributions of *Tarebia granifera* (16.7 %), *Melanoides tuberculata* (13.3 %) and *Filopaludina bengalensis* (13.3) %), respectively. The abundance (144±5 ind.m^{-2}) of bivalve (Viviparidae) was comparatively low across seasons. The quantitative spectrum of macrobenthos ranged from 133 – 1,866 ind.m^{-2} during the study period. WISA CDA [31] reported 35 species of macrobenthos with dominated by Gastropda and Bivalvia in the different stretches of river Mahanadi, which is corroborated to our findings. Furthermore, a wide range of abundance, from 6 to 2,217 ind.m^{-2} with a mean abundance of 390 ind.m^{-2}, which was consistent with the current findings. Similar results also reported by Wala, et al. [32] from Dilawara Reservoir, MP and Fule, et al. [33] from Sarangpuri Lake, Wardha, India. Earlier study by Indumathi, et al. [34] recorded the dominance of Oligochaeta followed by other groups (oligochaeta > ostracoda > gastropoda

> diptera) in Krishnagiri reservoir, Tamil Nadu which contrasted with the present findings. The authors recorded 36 benthic taxa belonged to 8 groups in the reservoir. Several other studies also reported the rich contributions of Phylum Arthropoda, Mollusca and Annelida in the total macrobenthic population in the reservoir ecosystem of India [29,32].

Association of Macrobenthic Functional Groups and Sediment Variables

The association between macrobenthos ecological guilds (functional groups) and sediment variables was assessed using ordination analysis (Canonical Correspondence Analysis). Sand, silt and clay (%) are positively associated with the benthic functional groups. Scrappers/Shredders (SC/SH) had a strong association with clay (%), specific conductivity and water depth. Likewise, detrital shredders (DSH) exhibited a strong positive gradient with organic carbon (%) and pH. The other two functional groups such as collector gathers (GC) and predators (P) are more inclined towards sand (%) and available – N. However, Filter collectors (FC) were negatively correlated with available – P (Figure 4). Meena, et al. [35] correlated the macro-zoobenthos with water variables in their study. The authors found a positive influence of pH, DO, TA, hardness and EC on the distribution and abundance of macro-zoobenthos in the wetland ecosystem. Another study by Sharani, et al. [36] also reported that the available nitrogen, silt and clay are the major influencing factors for abundance and distribution of macrobenthic community. The authors reported that nitrogen in the sediment is one of the primary requirements including the sedimentary substrate for growth and reproductive success of macrobenthic organisms.

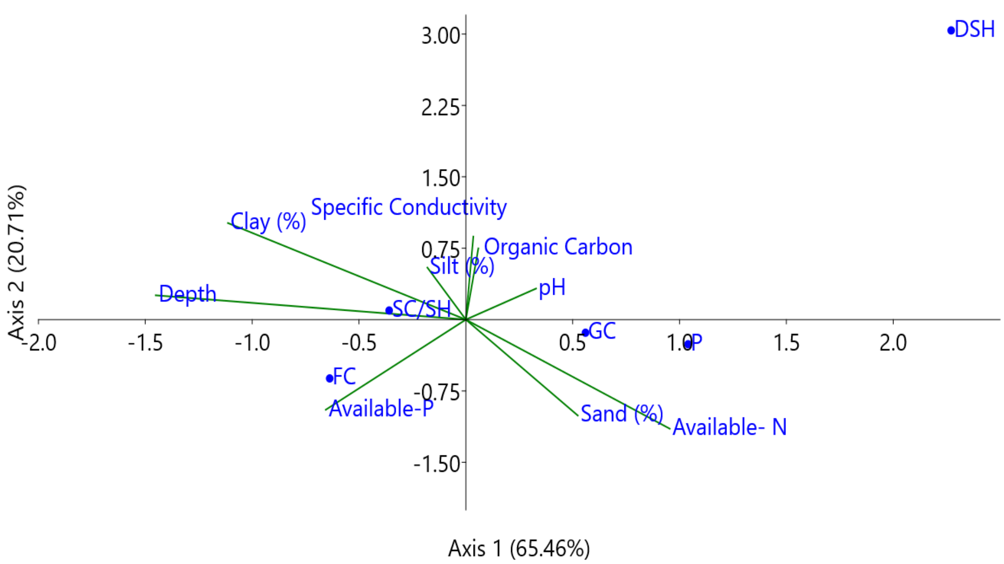

Figure 4: Ordination plot showing the association of macrobenthos ecological guilds and sediment variables.

State of Reservoir: Water Quality Index and Trophic State

Water Quality Index has been used by a number of authors to evaluate the water quality in reservoirs in India and overseas [9,37-42]. In the present assessment, WQI was calculated based on the 11 measured water quality parameters, *namely* Temp., pH, DO, TA, EC, turbidity, TH, TDS, NO_3–N, PO_4– P and SO_4^{2-} from the respective sampling locations for suitability assessment of potability of reservoir water. Based on the calculated values of WAWQI the reservoir water classified as "*good to excellent*" category during the pre-monsoon and post-monsoon season. During this period the WAWQI values varied between 16.42 and 32.58 (Figure 5a). However, the reservoir water reached a level of "*poor to very poor*"—unsuitable for drinking—and reached a WAWQI value >100 when considering the values of "turbidity" during the monsoon for a specific period. Thus, it determines that 'turbidity' was the single potent factor for deviating WQI during the monsoon, and directly responsible for inferior water quality in the reservoir. Accounting all the seasons, the WQI value was maximum during the monsoon (= 31.30 – excluding water turbidity) and the lowest during the post-monsoon season (23.37). Spatially, the WQI value did not show any significant ($p<0.05$) variations but showed a significant variation between seasons ($p<0.05$). Further, post hoc test showed insignificant variations (p>0.05) of WAWQI value between pre-monsoon and post-monsoon season. WQI had a positive correlation with water temperature (r = 0.61, p<0.05), pH (r = 0.39), EC (r = 0.26) and TDS (r = 0.21) and significant negative correlation with TH (r = – 0.52; p<0.05).

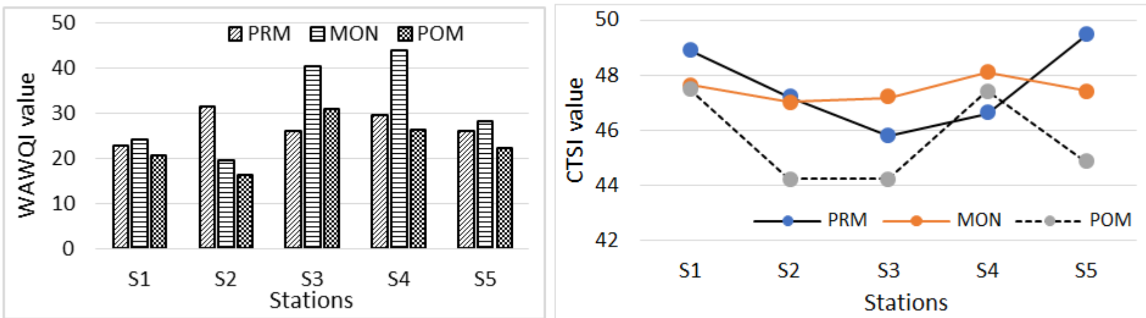

Figure 5: a & b Seasonal variation in water quality index (WAWQI) excluding water turbidity values (left panel - a) and CTSI values (right panel - b).

Trophic state distribution is a target for restoration projects, a reference point for managing and documenting human impacts, and a standard for evaluating biotic integrity [43]. Based on the calculated CTSI value, the reservoir was found to be 'mesotrophic' throughout the seasons and ranged from 44.21 – 49.46 (Figure 5b). No significant spatial variations of CTSI value were seen (F = 1.139; p = 0.393), however recorded a significant difference between seasons (F = 3.340; p = 0.027). Seasonally, CTSI value was maximum during pre-monsoon (= 48.11) and the lowest in the post-monsoon (= 45.64) season with a significant variation between both the seasons. The CTSI value was comparatively higher at Tamdei and Kurla and the lowest at Mahammadpur (Figure 5b). Several studies undertook by ICAR-Central Inland Fisheries Research Institute for assessing trophic status in various wetlands and reservoirs in India found that majority of the wetlands are mesotrophic to eutrophic, and reservoirs are oligotrophic to mesotrophic [44]. Our results were consistent with those of Pathak, et al. [26], who described a mesotrophic to eutrophic condition in the upper stretch of river Mahandi. According to a compilation report, the Patratu and Chandil reservoirs in Jharkhand, the Panchet reservoir in West Bengal, and the Maithon reservoir in West Bengal are all oligotrophic.

Likewise, Derjang in Odisha and Palair reservoir in Telengana recorded to be mesotrophic state [42] that supports our current assessment. Sahu, et al. [38] recorded a slightly higher level of CTSI in Hirakud reservoir (47.36 – 49.34) that may be due to variations in samples and sampling locations. We observed Secchi disc transparency and Chl *a* were the major factors for deviating trophic state (CTSI) value than the total phosphate concentration in the reservoir. Thus, it exists a higher algal biomass in the reservoir water and gradually turns into eutrophic in nature. CTSI showed positive correlation with temperature (r = 0.46), phosphate (r = 0.31), silicate (r = 0.30) and sulphate (r = 0.68; p<0.01). However, a negative correlation was seen with DO (r = – 0.59; p<0.05) and Chl *a* (r = – 0.54; p<0.05) (Figure 2).

Measures of Diversity Characteristics

Diversity metrics are commonly regarded as markers of ecological systems' health [45] and high value of diversity index indicated a healthy ecosystem [46]. Based on the calculated mean value of Shannon diversity index (*H'*) found to have 2.02±0.23 indicates that the reservoir environment is good [47] and moderate macrobenthic diversity. However, the Margalef's richness index (*d'*) found to be comparatively low (1.68±0.16) in the system which may be due to existence of species-specific dominance in the sites. This contrasts with the findings of Khan, et al. [29] where authors portrayed a higher richness index value across seasons in Kolar reservoir. The lowest *H'* index value during the pre-monsoon season might be due to low water level, little rainfall including exposures of large shallower areas of the reservoir. The value of evenness index (*J'*) was low during pre-monsoon (0.64±0.14), and it was gradually increased towards the post-monsoon and monsoon season. The evenness index (*J'*) indicated moderately uniform patter of macrobenthic distribution in the reservoir system. The maximum Shannon diversity during the monsoon season in the studied reservoir is typical with the findings of Khan, et al. [29] in their study from Kolar reservoir, MP, India.

Conclusion

Using multimetric indices such as WAWQI and CTSI as well as physicochemical parameters, the current study investigated the health of the Hirakud Reservoir, Odisha, India. In the reservoir, mesotrophic conditions predominated throughout the seasons. According to the WAWQI calculation, the reservoir water was found to have "*excellent to good*" water quality, particularly during the pre-monsoon and post-monsoon seasons. However, considering the water turbidity during monsoon season the reservoir water tuned in to '*poor to very poor*' quality for a certain period. There were notable variations in the macrobenthic community and water variables between seasons. A total of 25 taxa of macrobenthos were recorded with Gastropoda were the apex contributor. The functional groups SC/SH accounted for 46% of the total macrobenthic population. Measures of diversity indices (*H'* – 2.02±0.23) indicated moderate macrobenthic diversity in the system. Further, the distribution of macrobenthos in the reservoir were closely related to environmental factors (*viz.,* depth, clay (%), available-N, available – P and sediment organic carbon), as evident from CCA.

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