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Assessment of Water Quality and reservoir water level in relation to Phytoplankton Abundance and Diversity: A Study in Magalla Reservoir in the North Western Province of Sri Lanka

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Abstract: This study examines the relationship between water quality and the abundance and diversity of phytoplankton in the Magalla reservoir in Sri Lanka. The study was conducted from May to December 2023 in four sampling sites. Site 1 was influenced by anthropogenic domestic waste, including biodegradable material, polythene, and plastics. Site 2 a bathing area associated with inputs of soap, detergents, and paper waste. Site 3 received urban waste, such as leachates from hotels, along with food, paper, and plastic waste. Site 4, serving as the reference site, was minimally disturbed and was isolated from human activities. Standard methods were used for all in situ water quality parameters. Six replicates were taken for each parameter. The water quality parameters across sites 1, 2, and 3 significantly differed from the reference site (Kruskal-Wallis, Mann-Whitney U, $P < 0.05$). According to principal component analysis (PCA), the reference site clustered separately due to higher transparency, indicating minimal anthropogenic impact. pH and dissolved oxygen concentration were high in site 2. Water temperature, total dissolved solids, and electrical conductivity were high in sites 1 and 3. The highest abundance and diversity of phytoplankton were recorded in the reference site, and the lowest in site 3. Twenty-nine phytoplankton species, representing 7 distinct classes, were identified. One species from *Trebouxiophyceae*, and *Euglenophyceae*, two species from *Chrysophyceae*, and *Zygnematophyceae*, four species from *Cyanophyceae*, seven species from *Bacillariophyceae*, and twelve species from *Chlorophyceae* were observed during the study period. *Melosira granulata* constituted 69.4%, and *Fragilaria capucina* constituted 3.78% of the observed phytoplankton population, indicating their dominance in the reservoir. According to ANOVA, Tukey's method, Shannon Wiener Diversity Index (SWDI) of phytoplankton in site 3 significantly differed ($P < 0.05$) due to different water quality conditions, and phytoplankton abundance and Pielou's Evenness Index of phytoplankton at all three sites were not significantly different ($P > 0.05$) from the reference site. Abundance and SWDI of phytoplankton did not show a significant correlation (Pearson correlation analysis) with the reservoir water level.

Keywords: Abundance, Diversity, Freshwater, Phytoplankton, Water quality

INTRODUCTION

Sri Lanka is a tropical island situated in the southeast of the Bay of Bengal, in the Indian Ocean (Siriwardana *et al*., 2019). Sri Lanka does not face a shortage of water, as it receives an average annual rainfall of approximately 1900 mm, with a total annual precipitation of 132 billion m^3 and total surface runoff of 50 billion m^3. Sri Lanka experiences a tropical climate with wet and dry seasons and two monsoon periods (Fan, 2015). There are three climate zones in Sri Lanka: the wet zone, the dry zone, and the intermediate zone, which vary according to precipitation patterns and evaporation rates (Yatigammana and Cumming, 2016). Sri Lanka consists of more than 12,000 reservoirs, which collectively cover about 300,000 ha of the country's land area (Amarasinghe *et al*., 2009; Chandrasoma *et al.,* 2015). Reservoirs are mainly distributed in the dry zone, where many low-income communities reside, and they provide an important source of income through reservoir fisheries. The sustainable use of aquatic resources can ensure maximum long-term benefits

(Dematawewa *et al.*, 2008; Chandrasoma *et al.*, 2015). Reservoirs provide both ecological and economic benefits and constitute an important component of infrastructure that improves the living standards and quality of life of nearby communities (Siriwardana *et al.*, 2019). . These reservoirs are primarily used for irrigation, while inland fisheries constitute a secondary use. These freshwater ecosystems help sustain human lives by providing water for drinking, sanitation, agricultural activities, and aquatic organisms with protein-rich food sources (Siriwardana *et al*., 2019). Reservoirs also provide important ecosystem services such as recreational activities, flood control, industrial use, cooling of power plants, transportation, and hydropower generation (Znachor *et al*., 2020). These freshwater ecosystems are highly sensitive to disturbances resulting from the increasing impacts of climate change and anthropogenic activities (Znachor *et al*., 2020). Anthropogenic activities, such as the discharge of chemicals, fertilisers, and domestic waste into water bodies, are increasingly contributing to water pollution. Pollution, nutrient enrichment, and eutrophication resulting from the discharge of waste into water bodies are major threats to many aquatic ecosystems in Sri Lanka (Siriwardana *et al.*, 2019). Uncontrolled urbanisation and industrialization have led to the direct discharge of domestic sewage and untreated industrial effluents into water bodies, as well as indirect contamination through runoff and floods (Oliver *et al.*, 2019). Climatic changes, such as rising global warming and anthropogenic activities, adversely affect the stability of the structure of aquatic ecosystems (Liu *et al*., 2023). The quality of water can be changed due to different chemical, physical, and biological pollutants added to water by different pollutant sources (Matta *et al*., 2015; El-Azim *et al*., 2017). Assessing the physicochemical characteristics of water is an essential step in evaluating water quality. Colour, temperature, hardness, total suspended solids, pH, alkalinity, dissolved oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), heavy metal concentration (Lead, Mercury, Cadmium, Chromium) are examples of physicochemical parameters of water (Patil *et al*., 2012). Physicochemical parameters of water play an important role in determining the aquatic species diversity, density, and yield of aquatic communities. Maintaining water quality at desirable levels can determine the quality and status of aquatic organisms in freshwater aquatic environments (El-Azim *et al*., 2017). Plankton consist of two main groups: phytoplankton and zooplankton (Liu *et al*., 2023). Plankton contribute to the ecological balance of aquatic ecosystems and can indicate the presence of eutrophication and pollution (Katsiapi *et al.,* 2016; Liu *et al*., 2023). Phytoplankton are photosynthetic microorganisms that prefer to live partly or continuously in aquatic environments (Reynolds, 2006). It is a polyphyletic group and varies in size, colour, shape, metabolism, type, and traits of life history (Borics *et al*., 2021). Phytoplankton form the foundation of aquatic food webs (Webber *et al.*, 2005; Eiler *et al.,* 2013; Gorde and Jadhav, 2013) and serve as the primary producers in these ecosystems. They regulate the flow of energy and the cycling of nutrients (Liu *et al*., 2023), and their abundance and diversity directly influence fish productivity. Thus, phytoplankton are essential for maintaining both ecological balance and biogeochemical processes in aquatic environments. Phytoplankton can monitor the status of aquatic ecosystems and help predict and understand environmental conditions, such as nutrient input increases, climate change, and modifications in flow regimes (Eiler *et al*., 2013). However, the excessive growth of phytoplankton can lead to toxic algal blooms, posing significant threats to the biodiversity and functioning of the ecosystem (Eiler *et al*., 2013). For the succession of phytoplankton communities in freshwater, abiotic factors such as temperature, nutrients, transparency, light, pH, dissolved oxygen, metal concentrations, salinity, conductivity, wind speed, and water level should be maintained at favourable levels (Ariyadej *et al*., 2004; Patil *et al*., 2012; El-Azim *et al*., 2017; Baruah, 2013; Liu *et al*., 2023). Eutrophication is a major problem that causes a high degree of threats to phytoplankton blooms in reservoirs. The bloom-forming taxa that cause the worst threats to trophic structure and aquatic ecosystems are cyanobacteria. These harmful cyanobacteria blooms enhance the resource-use efficiency of phytoplankton in freshwater ecosystems. Additionally, cyanobacterial blooms disrupt phytoplankton grazing by producing cyanotoxins, forming colonies and large filaments, and reducing the nutritional quality of phytoplankton (Amorim and Moura, 2021). Magalla is a man-made reservoir located in the Deduru Oya basin in Sri Lanka. It is situated in

Nikaweratiya, North Western Province (Buddhimal *et al*., 2017). The Magalla reservoir is situated in the intermediate climatic zone. The rainfall range for this zone is 1750 mm – 2500 mm. Moreover, this area experiences short and less pronounced dry seasons (Alahacoon and Edirisinghe, 2021). The capacity of the reservoir is 9 million cubic meters, and the basin area is 32 Km^2. Three irrigation canals—the Right Bank Canal, the Left Bank Canal, and the Centre Canal—distribute water to the downstream irrigable areas. The reservoir receives in flow from an ancient canal called Ridi Bendi Ela (Sampath *et al*., 2018). During the dry season, the reservoir's surface level gradually decreases, and the littoral zone becomes covered with terrestrial plants and grasses, providing feeding grounds for free-range cattle in the area. The reservoir primarily supports small-scale fishing, provides a domestic water supply to surrounding communities, and supplies water for agricultural activities. The study tested two hypotheses: first, that water quality affects phytoplankton abundance and diversity across the four sampling sites, and second, that reservoir water level influences these parameters at the same sites. . The research aimed to examine how phytoplankton abundance and diversity vary with water quality and to investigate their relationship with reservoir water levels across the in four sampling sites.

MATERIALS AND METHODOLOGY

Study area

Figure 1 represents the location of the Magalla reservoir in Sri Lanka, and the location of the study areas selected in the reservoir, and Table 1 represents the characteristics of the sampling areas.

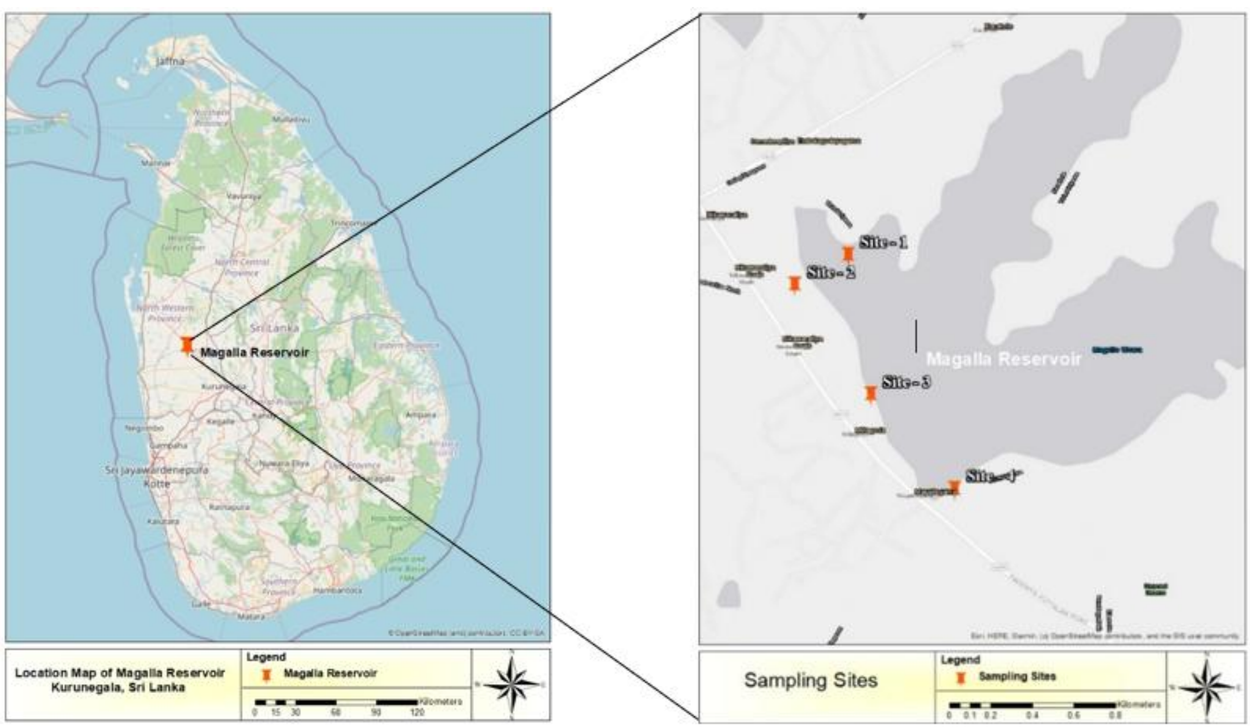

Fig 1. Map of the location of Magalla reservoir in Sri Lanka and selected sampling sites

Table 1. Description of sampling areas

Site	Coordination	Description
1	7^0 44$^/$ 54$^{//}$ N 80^0 07$^/$ 19$^{//}$ E	It is located in an area with illegal settlements. Domestic solid waste (polythene, plastic, food, animal waste) and wastewater (black and grey) are added to the site.
2	(7^0 44$^/$ 47$^{//}$ N 80^0 07$^/$ 10$^{//}$ E)	It is located near a bathing area, and there are some settlements far from the site. Soap, paper, and polythene waste are added to the site.
3	(7^0 44$^/$ 29$^{//}$ N 80^0 07$^/$ 19$^{//}$ E)	It is located near an urban area. Hotels, restaurants, parks, and shops surround this site. Through runoff, solid waste (plastic, polythene, food waste) and wastewater (black and grey) are added to the site.
4	(7^0 44$^/$ 17$^{//}$ N 80^0 07$^/$ 37$^{//}$ E) 1809 feet	Reference site. There was a little disturbance in this area, and a forest reserve is near this area, with very limited human activities in this area.

Sample Collection and Analysis

Daily rainfall data of the study area were obtained from a rain gauge at the Irrigation Office, Nikaweratiya, located near the reservoir. Monthly rainfall values (from May 2023 to December 2023) were obtained by calculating the average rainfall for each month using daily rainfall data. Monthly rainfall = sum of rainfall in the month (mm)/ number of days for the month. Daily reservoir water level data from May to December 2023 were obtained from the Irrigation Office, Nikaweratiya. Monthly reservoir water level = sum of water level in the month (m)/ number of days for the month.

Water (depth of 20.0 cm) and phytoplankton (depth of 0.5 m) samples were collected monthly from the four selected sites between 6.00 a.m. and 10.00 a.m. Plankton samples were collected using a plankton net (mesh size of 50 µm). The plankton net was lowered just beneath the water surface and towed for a distance of 5 meters. The collected samples were transferred to 100 mL plastic sample bottles and preserved with 5% Lugol's solution (Edler and Elbrächter, 2010; Abolude *et al*., 2012). For each water quality parameter, six replicates were measured at each site, and the average value was calculated. Water temperature was measured by using a mercury-in-glass thermometer at the same time in all sites. Dissolved Oxygen (DO), pH values, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) of water were measured by using a calibrated multi-parameter (HACH/Model: HQ40d multi-parameter). The water transparency was measured by a Secchi disk (20 cm diameter) with a measuring tape. A subsample (1 mL) of the mixed water sample was discharged into the chamber, which was placed on the Sedgewick-rafter counting slide, and planktons were observed and counted in each grid through a light microscope (10 × magnification). This method was applied to 10 mL of each sample (Ramachandra and Solanki, 2007; Ajayan and Ajit Kumar, 2017). The following formula was used for counting the plankton densities (individuals per litre) of water samples in each site (Ramachandra & Solanki, 2007). Total plankton count per Liter = A * (1/L) * (N/V)

A = Number of phytoplankton cells in 1 ml of plankton sample, L = Volume of the original sample (Liter), N = Total volume of the concentrated sample (Liter), V = Volume of the subsample (Liter)

Calculations based on the diversity and abundance of aquatic organisms

The diversity of each sampling area in the reservoir, based on fish and plankton, was estimated using the Shannon Wiener Diversity Index (*H*) and Pielou's Evenness Index (*E*) using the Shannon–Wiener Diversity Index (H) and Pielou's Evenness Index (E) (Omayio *et al*., 2019).
Shannon Wiener Diversity Index (*H*)

$$H = -\Sigma p_i \times ln(p_i)$$

Where, Σ: sum, *ln***:** Natural log, p_i**:** The proportion of the entire community made up of species *i*
Pielou's Evenness Index (*E*)

$$E = H / H_{max}$$

Where, *H***:** The Shannon Diversity Index,
H_{max}**:** Natural logarithm of the total number of species categories/ types of species in the sampled ecosystem (LN(n)

Data analysis

All data were analysed using Minitab software (Version 19). Mean and standard deviation were calculated for the replicate data of in situ physicochemical parameters of water. Normality was tested using the Anderson-Darling test with a significance threshold of $P > 0.05$. For parameters not meeting normality, data were transformed and analysed using non-parametric statistical methods. The water quality parameters were analysed using the Kruskal-Wallis test, followed by the Mann-Whitney U test, to compare each variable across the four sampling sites. Principal Component Analysis (PCA) was used to analyze the water quality parameters. All water quality parameters (e.g., calculating z-scores) were standardised before running the PCA to account for the differences in scales. Due to normal distribution, the abundance, Shannon Wiener diversity index, and Pielou's Evenness Index of phytoplankton among the sampling sites were assessed using the one-way analysis of variance with Tukey's pairwise comparison test. The relationship between the water quality parameters and phytoplankton species abundance at each sampling site over time was analysed. The relationships between (i) water quality parameters and phytoplankton abundance, (ii) reservoir water level and phytoplankton abundance, and (iii) reservoir water level and phytoplankton diversity over time were analyzed using Pearson correlation analysis. Statistical significance was accepted at $P < 0.05$.

RESULTS

Water quality parameters of the sampling sites of the Magalla reservoir

The water quality parameters of sites 1, 2, and 3 were significantly different from site 4 except for temperature at site 2 and pH at site 3 (Mann-Whitney U test, $P < 0.05$). The water quality parameters in each site were assessed using the Kruskal-Wallis test followed by the Mann-Whitney U test ($P < 0.05$). DO concentrations (mg/L) of all four sites from May to December 2023 are presented in Figure 2. In all months, the highest DO values were observed in the reference site, and the lowest DO values were observed in site 3. At all sites, DO concentrations have decreased in October and November. The highest DO value was observed in May at all four sites.

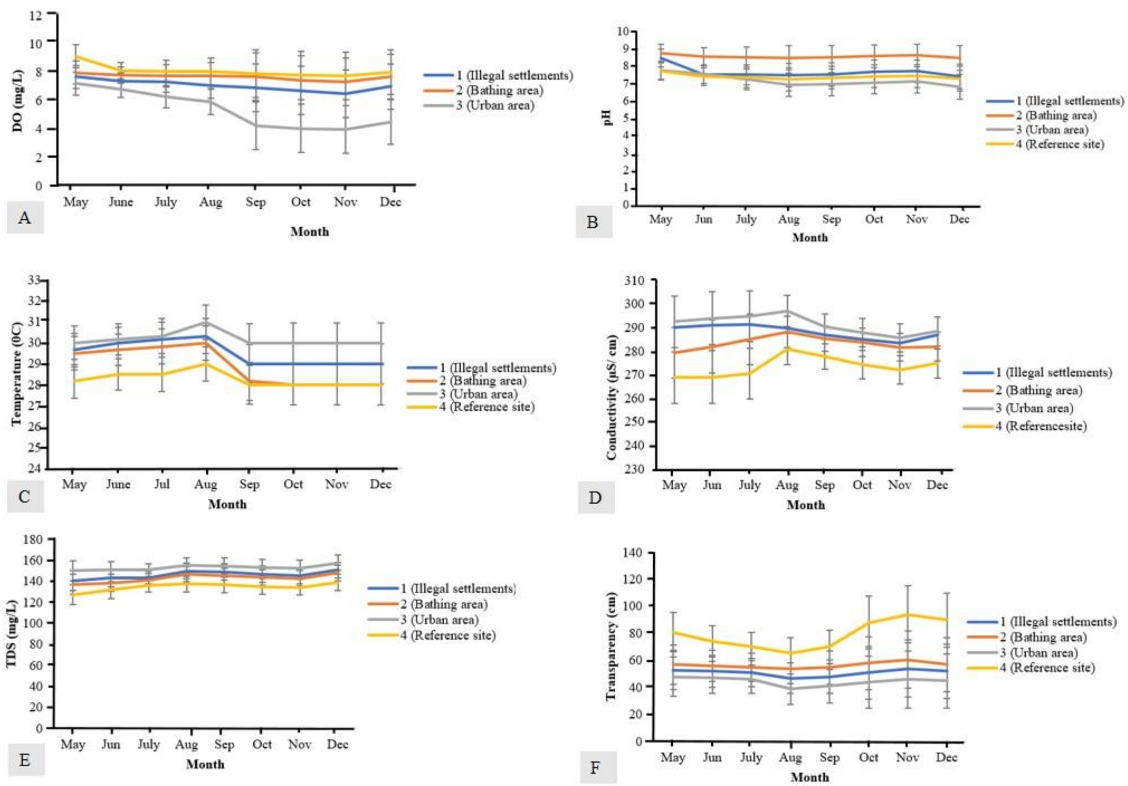

Fig 2. (A) DO concentration ± SD (mg/L) of all four sampling sites from May – December 2023; (B) pH ± SD of all four sampling sites from May to December 2023; (C) Temperature ± SD (^{0}C) of all four sampling sites from May to December 2023; (D) Conductivity ± SD (µS/ cm) of all four sampling sites from May – December 2023; (E) TDS ± SD (mg/L) of all four sampling sites from May to December 2023; (F) Transparency ± SD (cm) of all four sampling sites from May to December 2023

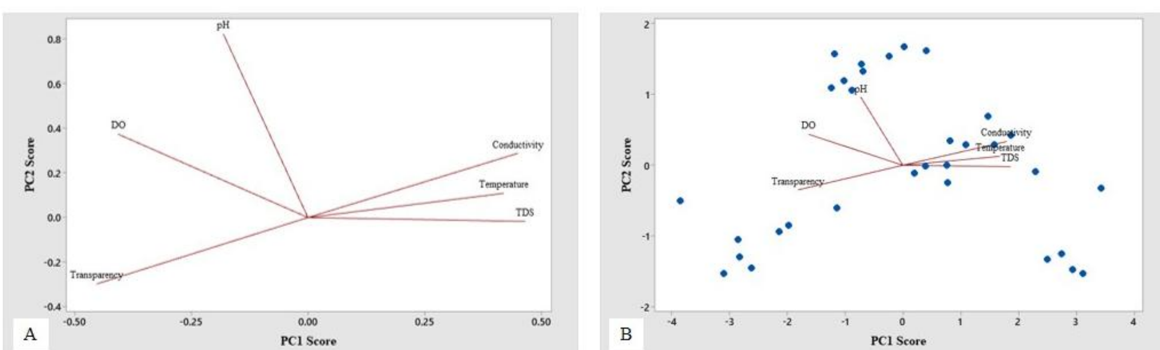

Fig 3. (A) Loading plot of water quality parameters; (B) biplot of water quality parameters

The water temperature (°C) at all four sites during the study period are presented in Figure 4. Throughout the study, the highest temperature values were observed at site 3, while the lowest temperatures occurred at the reference site. At sites 1,2, and 3, temperature values decreased after August. The highest temperature value was observed in August at sites 1,2,3. At the reference site from August to December temperature was 29 ^{0}C. The highest temperature was 31 ^{0}C which was observed in August at site 3.

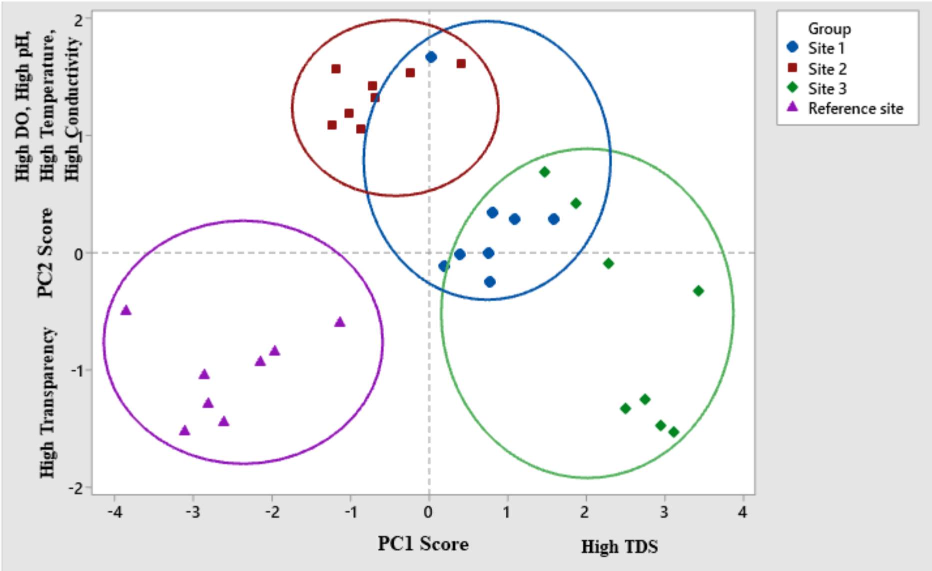

Fig 4. Ordination of the water quality parameters among the four sampling sites

The conductivity (µS/ cm) at all four sites during the study period is presented in Figure 2 (D). Throughout the study period, the highest conductivity values were recorded at site 3, while the lowest occurred at the reference site. At all four sites, the conductivity values gradually decreased from August to November.

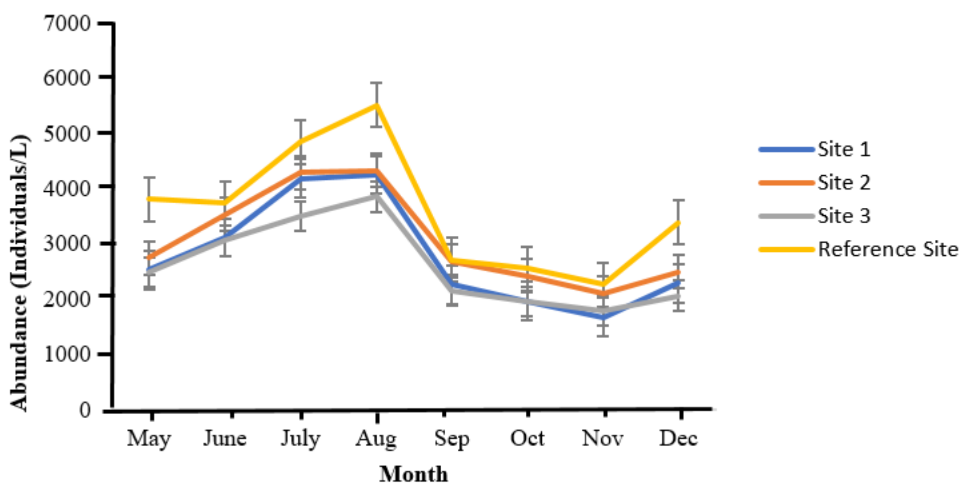

Fig 5. Phytoplankton abundance (individuals L^{-1}) in all four sampling sites

The TDS values (mg/L) at all four sites during the study period are presented in Figure 2(E). Throughout the study, the highest TDS values were observed at site 3, and the lowest at the reference site. At all four sites, the highest TDS value was observed in August.

The transparency (cm) values of all four sites during the study period (May to December 2023) are presented in Figure 2(F). Throughout the study period, the reference site exhibited the highest water transparency, whereas Site 3 consistently recorded the lowest transparency values. At all sites, transparency values gradually increased from July to November and decreased from May to August 2023. The highest transparency value was observed in November at all sites, and the lowest in August.

Principal Component Analysis (PCA) to determine the water quality in each sampling site

Only had two eigenvalues, which were greater than 1 (Table 2). Therefore, most of the values are captured in these two components. The first two principal components (PCs) were sufficient for further analysis. When the first two PCs explained more than 70% of the total variance (66.6% + 19.4% = 86%), it indicated that they captured the majority of the variability in the data.

Table 2. Eigenvalues of the correlation matrix

	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.9938	1.1659	0.4677	0.2139	0.1037	0.0550
Proportion	0.666	0.194	0.078	0.036	0.017	0.009
Cumulative	0.666	0.860	0.938	0.974	0.991	1.000

The cumulative proportion of total variance is explained by including each additional eigenvalue. It's obtained by summing up the proportions from the top (Table 3).

Table 3. Cumulative proportion of total variance from the top to the bottom

Eigenvalues		
1st eigenvalue	0.666	
2nd eigenvalue	0.666 + 0.194	0.86
3rd eigenvalue	0.86 + 0.078	0.938
4th eigenvalue	0.938 + 0.036	0.974
5th eigenvalue	0.974 + 0.017	0.991
6th eigenvalue	0.991 + 0.009	1.00

Table 4 presents the variable loadings on the PCs, highlighting the contribution of each variable to the variance explained by these components. Loadings represented the correlation between variables and PCs, with higher absolute values indicating stronger associations. In this dataset, for instance, variables such as temperature, conductivity, TDS, and transparency exhibited high positive loadings on PC1. This suggested that they were closely aligned with the structure represented by PC1 and were positively correlated with each other within the dataset. Conversely, variables like DO and pH have negative loadings on PC1.

Table 4. Eigenvectors (Coefficients in the linear combinations of variables making up PCs)

Variables	PC1	PC2	PC3	PC4	PC5	PC6
DO	-0.407	0.374	-0.449	-0.561	-0.272	-0.322
pH	-0.182	0.823	0.318	0.330	0.275	-0.066
Temperature	0.420	0.108	-0.712	0.408	0.214	-0.305
Conductivity	0.450	0.288	-0.126	-0.520	0.341	0.559
TDS	0.466	-0.017	0.409	-0.351	0.142	-0.687
Transparency	-0.453	-0.297	-0.088	-0.127	0.818	-0.118

As the graph suggests (Figure 3), the variables Temperature, TDS, Salinity, and Conductivity are closer to each other than Transparency, pH, and DO. Figure 4 shows that the reference site clustered separately from Sites 1, 2, and 3, reflecting its higher water transparency. pH and DO concentrations were high at sampling site 2 whereas conductivity, temperature, and total dissolved solids (TDS) were higher at sites 1 and 3.

Composition of the phytoplankton in Magalla Reservoir

A total of 29 phytoplankton species, belonging to seven classes, were recorded across the four sampling sites during the study period: Trebouxiophyceae and Euglenophyceae (1 species each), Chrysophyceae and Zygnemophyceae (2 species each), Cyanophyceae (4 species), Bacillariophyceae (7 species), and Chlorophyceae (12 species). In Table 5, the classes and phytoplankton species observed are presented.

Table 5. Composition of phytoplankton species in the Magalla reservoir and their taxonomic classes

Class	Phytoplankton species
Bacillariophyceae	*Asterionella formosa*
Bacillariophyceae	*Cocconeis scutellum*
Bacillariophyceae	*Fragilaria capucina*
Bacillariophyceae	*Gomphonema olivaceum*
Bacillariophyceae	*Melosira granulata*
Bacillariophyceae	*Navicula radiosa*
Bacillariophyceae	*Surirella linearis*
Chlorophyceae	*Chlorella vulgaris*
Chlorophyceae	*Closterium acerosum*
Chlorophyceae	*Echinosphaerella limnetica*
Chlorophyceae	*Golenkinia radiata*
Chlorophyceae	*Microspora sp.*
Chlorophyceae	*Pediastrum biradiatum*
Chlorophyceae	*Pediastrum clathratum*
Chlorophyceae	*Pediastrum duplex*
Chlorophyceae	*Pediastrum simplex var. clathratum*
Chlorophyceae	*Pediastrum simplex var. duodenarium*
Chlorophyceae	*Tetrastrum heteracanthum*
Chlorophyceae	*Volvox globator*
Chrysophyceae	*Dinobryon bavaricum*
Chrysophyceae	*Dinobryon sociale*
Cyanophyceae	*Aphanizomenon flos-aquae*
Cyanophyceae	*Merismopedia glauca*
Cyanophyceae	*Mycrocystis aeruginosa*
Cyanophyceae	*Lyngbya limnetica*
Euglenophyceae	*Trachelomonas hispida*
Trebouxiophyceae	*Closteriopsis sp.*
Zygnematophyceae	*Desmidium sp.*
Zygnematophyceae	*Zygnema sp.*

Phytoplankton Abundance

Phytoplankton abundance (individuals L^{-1}) data at sites 1, 2, and 3 in each month were not significantly different from the reference site (ANOVA, Tukey's method P > 0.05). Phytoplankton abundance was consistently highest at the reference site and lowest at Site 3 throughout the study period." (Figure 5). At all four sampling sites, the highest abundance was observed in August and July, and the lowest abundance in September, October, and November.

When considering the abundance of phytoplankton species belonging to sampling sites, a high abundance of *Fragilaria capucina*, *Melosira granulata*, *Pediastrum duplex*, *Mycrocystis aeruginosa* was observed at site 1. A high abundance of *Fragilaria capucina*, *Melosira granulata*, *Chlorella vulgaris*, *Merismopedia glauca*, *Closteriopsis sp.* were observed at site 2. A high abundance of *Melosira granulata*, *Microspora sp.*, *Pediastrum duplex*, *Aphanizomenon flos-aquae*, *Merismopedia glauca* was observed at site 3, and a high abundance of *Fragilaria capucina*, *Gomphonema olivaceum*, *Melosira granulata*, *Aphanizomenon flos-aquae*, *Merismopedia glauca*, *Zygnema sp.* were observed at the reference site. Among the phytoplankton species identified throughout the study period from all sampling sites *Melosira granulata* (69.42%), *Fragilaria capunica* (3.78%), and *Zygnema sp*. (2.57%) were the abundant species (individuals L^{-1}) (Table 6).

Table 6. Abundance (individuals L^{-1}) of phytoplankton species in each site during the study period

Phytoplankton species	Abundance (Individuals/L) in the study period					
	Site 1	Site 2	Site 3	Site 4	Total Abundance	Relative abundance %
Asterionella formosa	0	105	0	550	655	0.68
Cocconeis scutellum	0	585	0	315	900	0.93
Fragilaria capucina	895	1185	270	1300	3650	3.78
Gomphonema olivaceum	360	630	215	750	1955	2.02
Melosira granulata	16260	17075	15035	18740	67110	69.42
Navicula radiosa	310	220	330	0	860	0.89
Surirella linearis	235	425	5	495	1160	1.20
Chlorella vulgaris	105	875	30	185	1195	1.24
Closterium acerosum	255	0	265	0	520	0.54
Echinosphaerella limnetica	210	160	380	0	750	0.78
Golenkinia radiata	245	365	100	250	960	0.99
Microspora sp.	375	90	535	0	1000	0.40
Pediastrum biradiatum	20	245	45	70	380	0.40
Pediastrum clathratum	390	75	0	110	575	0.60
Pediastrum duplex	425	265	525	200	1415	1.46
Pediastrum simplex var. clathratum	200	145	480	180	1005	1.04
Pediastrum simplex var. duodenarium	255	170	105	410	940	0.97

Tetrastrum heteracanthum	255	55	390	100	800	0.83
Volvox globator	260	50	310	50	670	0.70
Dinobryon bavaricum	0	90	0	355	445	0.46
Dinobryon sociale	0	295	55	475	825	0.85
Aphanizomenon flos-aquae	0	275	30	505	810	0.84
Merismopedia glauca	275	485	170	505	1435	1.48
Mycrocystis aeruginosa	580	0	1010	0	1590	1.64
Lyngbya limnetica	0	295	0	455	750	0.78
Trachelomonas hispida	220	0	470	0	690	0.71
Closteriopsis sp.	165	480	135	0	780	0.80
Desmidium sp.	0	0	0	365	365	0.38
Zygnema sp.	0	0	0	2480	2480	2.57

Diversity of phytoplankton

The Shannon Wiener Diversity Index values of phytoplankton species at sites 1,2 and 3 were significantly different from site 4 (reference site) (ANOVA, Tukey's method, $P < 0.05$) (Table 7). Pielou's Evenness Index values of all three sites were not significantly different from the reference site (ANOVA, Tukey's method, $P > 0.05$). Within a column, values with different superscript letters differ significantly from each other. Every month, the highest phytoplankton diversity was observed at the reference site and the lowest at site 3 (Figure 3). In all four sampling sites, the highest phytoplankton diversity was observed in August, and the lowest in November.

Table 7. SWDI and PEI values for the phytoplankton of the sampling sites

	Shannon Wiener Diversity Index				Pielou's Evenness Index			
Month	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4
May	1.315^{ab}	1.338^{ab}	1.291^{b}	1.498^{a}	0.447^{a}	0.440^{a}	0.431^{a}	0.492^{a}
June	1.329^{ab}	1.349^{ab}	1.317^{b}	1.526^{a}	0.469^{a}	0.467^{a}	0.456^{a}	0.518^{a}
July	1.358^{ab}	1.369^{ab}	1.349^{b}	1.534^{a}	0.480^{a}	0.494^{a}	0.476^{a}	0.531^{a}
August	1.365^{ab}	1.564^{ab}	1.354^{b}	1.610^{a}	0.493^{a}	0.552^{a}	0.488^{a}	0.568^{a}
September	1.146^{ab}	1.219^{ab}	1.135^{b}	1.370^{a}	0.397^{a}	0.430^{a}	0.401^{a}	0.450^{a}
October	1.127^{ab}	1.146^{ab}	1.047^{b}	1.306^{a}	0.390^{a}	0.405^{a}	0.370^{a}	0.429^{a}
November	1.069^{ab}	1.081^{ab}	0.968^{b}	1.208^{a}	0.370^{a}	0.381^{a}	0.342^{a}	0.397^{a}
December	1.285^{ab}	1.310^{ab}	1.197^{b}	1.416^{a}	0.437^{a}	0.430^{a}	0.400^{a}	0.465^{a}

Correlation between phytoplankton abundance and water quality parameters in each sampling site in the Magalla reservoir

Pearson correlation analysis was used to examine the relationship between phytoplankton abundance (Table 8) and water quality parameters. At sites 1, 2, and 3, temperature exhibited a strong positive correlation with phytoplankton abundance. Additionally, conductivity showed a strong positive correlation with phytoplankton abundance at sites 1 and 3. Conversely, transparency showed a negative correlation with phytoplankton abundance at sites 1, 2, and the reference site (Pearson correlation $p < 0.05$, 95% CI).

Table 8. Correlation Analysis between the phytoplankton abundance and water quality parameters of each sampling site

Parameter	Site 1		Site 2		Site 3		Site 4	
	R-value	P Value	R-value	P Value	R-value	P Value	R-value	P Value
DO (mg L^{-1})	0.41	0.32	0.52	0.19	0.69	0.06	0.39	0.34
pH	-0.24	0.57	-0.42	0.3	0.2	0.64	-0.23	0.59
Temperature (^{o} C)	0.93	0	0.88	0	0.86	0.01	-0.17	0.68
EC (µS cm^{-1})	0.83	0.01	0.62	0.1	0.96	0	0.18	0.68
TDS (mg L^{-1})	-0.04	0.93	-0.05	0.91	-0.23	0.58	0.08	0.85
Transparency (cm)	-0.81	0.02	-0.78	0.02	-0.22	0.59	-0.72	0.04

The average reservoir water level (m) and average rainfall (mm) of Magalla reservoir from May to December 2023 are presented in Table 9. The lowest average rainfall and reservoir water level were observed in August, and the highest average rainfall and reservoir water level were observed in November.

Table 9. Average reservoir water level and average rainfall for each month

Month	Average reservoir water level (m)	Average rainfall (mm)
May	5.18	8.06
June	4.09	0.35
July	2.22	0.30
August	2.01	0.13
September	2.15	8.39
October	4.38	10.82
November	5.56	17.73
December	5.49	8.10

Correlation between phytoplankton abundance and diversity and average reservoir water level in each sampling site in the Magalla reservoir

According to Table 10, in the Magalla reservoir, at all sampling sites, phytoplankton abundances and SWDI did not show a significant correlation with the reservoir water level.

Table 10. Correlation Analysis of water level with abundance and SWDI of phytoplankton

Phytoplankton	Site 1		Site 2		Site 3		Reference Site	
	R-value	P Value	R-value	P Value	R-value	P Value	R-value	P Value
Abundance	-0.705	0.051	-0.738	0.036	-0.676	0.066	-0.560	0.149
SWDI	-0.332	0.421	-0.511	0.196	-0.474	0.235	-0.517	0.190

Correlation between phytoplankton abundance and average rainfall in each sampling site in the Magalla reservoir

According to Table 11, in the Magalla reservoir, at all sampling sites, phytoplankton abundances exhibited a negative correlation with the average rainfall.

Table 11. Correlation Analysis of average rainfall with the abundance of phytoplankton

Phytoplankton	Site 1		Site 2		Site 3		Reference Site	
	R-value	P Value	R-value	P Value	R-value	P Value	R-value	P Value
Abundance	-0.898	0.002	-0.911	0.002	-0.900	0.002	-0.853	0.007

DISCUSSION

The abundance and diversity of phytoplankton in freshwater depend on various physicochemical parameters, such as water temperature, pH, dissolved oxygen, electrical conductivity, and total dissolved solids. The season, meteorological depth, and water properties are important factors influencing plankton abundance and diversity n (Sarwade and Kamble, 2014; Dhanasekaran *et al*., 2017; Sharma *et al*., 2016; Bera, 2021). Bright sunlight and high water temperature contribute to increased phytoplankton biomass. . This study, conducted in the Magalla Reservoir, also reported the highest phytoplankton abundance and diversity in August, when water temperature was higher, and the lowest in November, when water temperature was lower. Similar results have been reported by Shekhar *et al.,* (2008) in the Bhadra River, India. In this study, temperature showed a significant positive correlation with phytoplankton abundance at Sites 1, 2, and 3. Also, in the selected sampling sites in Magalla reservoir the abundance of phytoplankton was high in the months with low rainfall. Similar results have been recorded by Shekhar *et al.,* (2008) in the Bhadra River, India. The results of a study conducted in Gregory Lake, Sri Lanka, revealed that the concentration of plankton was higher in the dry season than the wet season (Perera *et al.*, 2012)

The pollution stress in the water bodies is increased by the nutrient enrichment and the reduction of the DO concentration. Pollutants such as organic wastes, oxidizable inorganic substances, Ammonia (NH_3), nitrates, and Sulfuric acid (H_2S) reduce the dissolved oxygen concentration in the water body (Kumari *et al*., 2019). . Low DO concentrations are associated with lower phytoplankton abundance in freshwater bodies (Sharma *et al*., 2016). Sampling site 3, which was associated with urban runoff, showed the minimum abundance and diversity of phytoplankton, likely due to its low DO levels. The reference site with the minimum disturbances showed the highest DO values. At that site, the abundance and diversity of phytoplankton were high. Similar results were reported by Sharma *et al*. (2016). According to the ambient water quality suitable for aquatic life declared by the Central Environmental Authority, the 2019 standard value for DO is 5 mg/L. At all sites, DO values were above 5 mg L^{-1}.

The DO concentrations were highest during the dry season. In the wet season, wind-generated turbulence promotes mixing of the surface water layers of the water body, which can result in lower DO concentrations. Also in the wet season, an oxygen equilibrium is established between the air and water (Kumari et al., 2019). In this study, DO concentrations at all four sites were higher during the dry season, when rainfall was lower, than during the wet season, when rainfall was higher. Similar results were reported by Kumari *et al.* (2019).

The production of inland water reached optimum levels in a slightly alkaline reaction with a pH of 7.5 to 8.5. When the pH is low, the abundance and diversity of phytoplankton can be reduced (Shekhar *et al.,* 2008; Dhanasekaran *et al*., 2017). According to the National Environmental ACT No. 47 of 1980, the pH range of water suitable for aquatic life is 6.0-8.5. In the present study, pH ranged from 6.70 to 8.72, suggesting that the water conditions were suitable for phytoplankton growth. In the study conducted in the Magalla reservoir, the phytoplankton diversity and abundance were lowest at site 3, where the pH value was lowest. Similar results were reported by Shekhar *et al.* (2008) and Dhanasekaran *et al*. (2017). When phytoplankton production is high, photosynthetic activity is also elevated. Higher photosynthetic activity absorbs more CO_2 from the water, which contributes to an increase in pH in the water body (Dhanasekaran *et al*., 2017). However, the phytoplankton diversity and abundance were highest at the reference site, where the pH value was approximately 7. The pH value can be increased by anthropogenic activities such as using detergents for washing clothes and sewage mixing with water (Dhanasekaran *et al*., 2017). In this study, the pH value was also slightly higher at site 2, which is associated with the bathing area compared to the other sites.

Water transparency is affected by suspended inorganic particles such as silt, clay, sand grains, phytoplankton, and zooplankton. Reservoirs with clayey bottoms tend to exhibit higher turbidity. The turbidity acts as a limiting factor in water bodies by decreasing the sunlight penetration through water and the photosynthesis of aquatic organisms. The aquatic weed growth is high in less turbidity. High turbidity in water bodies can cause sand particles to accumulate in the gills of aquatic organisms, such as fish and prawns, leading to excessive mucus secretion and respiratory stress. When turbidity increases in water, it reduces the ability of light to travel in straight lines, causing the light to scatter predominantly. Therefore, the light penetrates only into shallow depths. Therefore, the photosynthetic ability of plants is reduced, leading to dissolved oxygen depletion, and finally fishes and other organisms go to death in the layers of water associated with the bottom of the water body (Kumari *et al.,* 2019).

In this study , there were the lowest transparency values and lowest phytoplankton diversity and abundance at site 3, and in the reference site, where transparency was high with maximum phytoplankton diversity and abundance. According to the results of a study in the Bandagiriya Lake in Sri Lanka, a low density and diversity of phytoplankton were observed due to high turbidity and total suspended solids, which interrupt the light penetration through water (Gunawardana *et al.,* 2024). Also, in the Bomo Reservoir, no phytoplankton species showed a significant positive correlation with turbidity (Abolude *et al*., 2012).

The highest transparency values were recorded in the monsoon season, and the lowest in the pre-monsoon period (Kumari *et al.,* 2019). According to Offem *et al.,* (2011), during the monsoon period, flooding caused by heavy rainfall and nutrient runoff, along with rising water levels carrying fine particles and debris, resulted in higher water transparency values. In the study of the Magalla reservoir, higher transparency values were recorded in the wet season than in the dry season. Also in this study, the transparency showed a negative correlation with phytoplankton and zooplankton abundance at sites 1, 2, and 4 (Pearson correlation $p < 0.05$, 95% CI). Similar results have been reported by Odulate *et al*., (2017) in the River Ogun, Abeokuta, Southwestern Nigeria.

With the increased anthropogenic events associated with water bodies, evaporation and stagnation of water due to high temperature, adding drainage water into water bodies with large amounts of small particles such as clay, silt, etc., and decreasing the inflow of freshwater into the water body, are the primary factors responsible for elevated TDS in the water r (Dhanasekaran *et al*., 2017). In this study, the phytoplankton abundance and diversity were lowest at site 3, where the TDS was highest, and the phytoplankton abundance and diversity were highest in the reference site, where the TDS was lowest.

The nutrient status and the salts that dissolve in water in ionic form contribute to the Electrical Conductivity (EC) of water. EC can be low with natural water possessed but increased by contaminants in water (Dhanasekaran *et al*., 2017). The highest conductivity ranges are obtained in the wet season. The surface runoff and groundwater inflow increase the concentration of ionic substances such as nitrate, phosphate, and chloride, leading to higher conductivity values during the monsoon periods (Offem *et al.,* 2011). In this study, in the Magalla reservoir, the EC was also lowest at reference sites, where the site with a little disturbance and natural water was inhabited. Also, in the wet season, higher conductivity values were recorded. Conductivity displayed a strong positive correlation with phytoplankton abundance at sites 1 and 3. Similar results have been reported by Odulate *et al*., (2017) in the River Ogun, Abeokuta, Southwestern Nigeria.

The results from Magalla Reservoir indicate that the reference site clusters separately, attributable to its higher water transparency, which reflects minimal anthropogenic influence. pH and DO concentrations were high at sampling site 2, where the abundance and diversity were at average amounts. The reason for the high pH at site 2 is soap associated with the water. Site 1 was associated with domestic waste, and site 3 with urban contamination. Consequently, conductivity, temperature, and TDS were higher at sites 1 and 3, where phytoplankton abundance and diversity were lowest.

According to the study done in the river Bhadra in India, the phytoplankton species of *Melosira granulate* and *Mycrocystis sp.* were abundant at the sampling site associated with domestic sewage (Shekhar *et al.,* 2008). In the Magalla reservoir, a high abundance of *Fragilaria capucina*, *Melosira granulata*, *Pediastrum duplex*, and *Mycrocystis aeruginosa* was observed at site 1, which was associated with domestic sewage. A high abundance of *Fragilaria capucina*, *Melosira granulata*, *Chlorella vulgaris*, *Merismopedia glauca*, and *Closteriopsis sp.* was observed at site 2, which was associated with soap and detergents. A high abundance of *Melosira granulata*, *Microspora sp.*, *Pediastrum duplex*, *Aphanizomenon flos-aquae*, and *Merismopedia glauca* was observed at site 3, which was associated with urban waste. According to the study done in the upstream of the River Bhadra in India, the phytoplankton species of *Zygnema sp.*, *Melosira granulate*, *Gomphonema sp.,* and *Fragilaria sp.* have been recorded from the unpolluted site. (Shekhar *et al.,* 2008) In Magalla reservoir, a high abundance of *Fragilaria capucina*, *Gomphonema olivaceum*, *Melosira granulata*, *Aphanizomenon flos-aquae*, *Merismopedia glauca*, *Zygnema sp.* was recorded at the reference site, which was minimally disturbed.

Although water level fluctuations occur naturally in some water bodies, climate-related factors such as changes in precipitation can intensify these fluctuations, leading to droughts and floods. The water level fluctuation in waterbodies such as reservoirs and lakes causes adverse impacts on food security, water supply, habitats, biodiversity, and water quality in aquatic ecosystems (Pan *et al.,* 2018). How the water level fluctuations impact the aquatic communities is mostly studied in association with rivers, reservoirs, and lakes. The spatial and temporal variations of water level fluctuations can change the structure and dynamics of the phytoplankton and zooplankton communities in water bodies (Kahl *et al*., 2008; Pan *et al*., 2018). Water level fluctuations associated with reservoirs may affect the composition of plankton species and biomass (Mac Donagh *et al*., 2009). During the dry season, which has a low reservoir water level, the diversity and abundance of phytoplankton are maximised compared to the wet season, which has a high reservoir water level (Dhanasekaran *et al*., 2017). Similar results were obtained in the Magalla reservoir, and phytoplankton did not show a significant correlation with the reservoir water level.

CONCLUSIONS

The water quality parameters across sites 1, 2, and 3 significantly differed from the reference site ($P < 0.05$). Of the 29 phytoplankton species identified, the reference site exhibited the highest abundance and diversity, whereas site 3 showed the lowest. *Melosira granulata* constituted 69.4%, and *Fragilaria capucina* constituted 3.78% of the recorded phytoplankton population, indicating their dominance in the reservoir. Shannon Wiener Diversity Index (SWDI) of phytoplankton at site 3 significantly differed ($P < 0.05$) due to different water quality conditions, and phytoplankton abundance and Pielou's Evenness Index of phytoplankton at all three sites were not significantly different ($P > 0.05$) from the reference site. Abundance and SWDI of phytoplankton did not show a significant correlation (Pearson correlation analysis) with the reservoir water level. Based on the study results, appropriate measures should be implemented to maintain suitable water quality for aquatic species in Magalla Reservoir.

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