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Unravelling the Seasonal Dynamics of Limnological Parameters and Assessment of Ecological Health: A Case Study of Lingadheeranahalli Lake in Bangalore North, Karnataka, India

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The present study investigates the seasonal dynamics of limnological variables and the developmental response of D. rerio in the wetland ecosystem of Lingadheeranahalli in the northern clutches of Bangalore in Karnataka. Once a vital water source for agriculture and replenishing groundwater, the lake faces degradation due to anthropogenic activities and the need for more awareness. A yearlong analysis was conducted with five sampling seasons and three sampling stations identified within the wetland. Parameters viz. physical, chemical, and biological were analyzed following American Public Health Association (APHA) guidelines. Somite development was studied using embryos while the heart rate was counted during the torpedo stage of D. rerio. The results of this comprehensive study revealed unique and significant seasonal variations over limnological parameters, providing novel insights into the dynamics of the wetland ecosystem. pH values are slightly acidic and influenced by precipitation and terrestrial vegetation. Turbidity spiked during winter due to colloidal dispersions, while conductivity peaked in spring due to sewage disposal. Reduced dissolved oxygen, high biochemical and chemical oxygen demand indicated organic pollution and microbial activity, particularly affecting the inlet station. Elevated phosphate and nitrate levels in spring indicated eutrophication potential. The influence of rains and mineral leaching during monsoons affected parameters such as alkalinity, total dissolved solids, total hardness, and Magnesium. Analysis of D. rerio demonstrated delayed development and decreased heart rates in the inlet and deposit stations, indicative of potent stressors in the wetland ecosystem. All-inclusive Lingadheeranahalli Lake exhibited poor water quality, focusing on the need for adaptive management strategies to mitigate pollution and safeguard wetland ecosystems. Continued wetland research gives more insights into water quality and seasonal dynamics, paving the way for its conservation.

Keywords: Bangalore North; Lingadheeranahalli Lake; Limnology; Wetland ecology; Zebrafish Development.

Lakes, a precious resource on our planet, are subjected to continuous chemical change due to the inflow and outflow of materials. Reduced mobility and increased sedimentation contribute to high biological activity [1]. These lakes hold significant economic value, providing food through fish and aquatic products [2]. Bangalore, the capital city of Karnataka in southern India, was renowned

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for its serene lakes and landscapes. However, the city's unplanned development has caused a gradual decline of these wetlands that play a significant role in supplying water for irrigation and drinking, supporting fish culture, replenishing groundwater, and mitigating natural calamities [3]. A balanced environment maintains the effectiveness of the water quality, encompassing the physical, chemical, and biological variables within these inland water resources [4]. Rapid urbanization, anthropogenic activities, and dumping of untreated sewage and waste have led to the degradation of lakes, reducing them into cesspools [5]. The weathering of rocks generates ions within the catchment area that serve as natural pollutants [6]. Lake chemistry is reflected in the seasons and catchment characters [7]. These wetlands quickly pile pollutants from various industrial and domestic sources, leading to the deterioration of water quality and loss of biodiversity, making them a fragile ecosystem [8].

The limnological approach to assess physical, chemical, and biological variables comprehends a region's water quality and seasonal landscape [9, 10]. Declining water quality causes increased waterborne diseases and disrupts the sustenance of an ecosystem [11, 12]. Solid waste disposal causes havoc in water percolation and impacts groundwater recharge [13]. Population outbreaks, sewage discharge, and agricultural practices have resulted in the inflow of nutrients within these lakes, causing drastic eutrophication and creating an imbalance in natural functioning [14, 15]. Variations in water quality parameters compromise the ecological health of these wetlands and signify the influence of urbanization [16]. Parameters such as Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) help researchers understand the pollution levels of lakes [17]. In addition, the Most Probable Number analysis focuses on microbial ecology [18]. Overgrowth of aquatic weeds like *Eichorrnia crassipes* has degraded these inland water resources [19]. These indicate the threatened survival of lakes and call for immediate conservation efforts [20]. Physico-chemical and microbial analysis of a few lakes in Bangalore emphasizes immediate conservation [13].

Using the vertebrate model system, zebrafish (*Danio rerio*) provides valuable insights to assess the ecological health of a water body [10]. Organic and inorganic pollutants accumulate within the fish organs, leading to structural abnormalities [21, 22, 23]. Thus, ecological responses and their influence on heart rate, behavior, physiology, and neurotransmission can be assessed [24, 25, 26]. The integration of limnological analysis and *D. rerio* assessments has proven to be a valuable tool in monitoring the ecological health of a lake and has alerted sustainable water management [24]. In this context, the present research aims to understand the water chemistry, its influence over seasons, and its impact on a biotic system focusing on three grab sampling stations named Open surface (O), Deposit (D), and Inlet (I) over a time frame of one year in the distinct setting of Lingadheeranahalli Lake located in north Bangalore.

MATERIALS AND METHODS

Study area – Lingadheeranahalli Lake

Lingadheeranahalli Lake is a small wetland near the D group employee's layout in Bangalore North. It is 870 meters long and located at 13.0035° N latitude and 77.4827° E longitude. The lake offers walkers a pathway and a serene landscape for nearby residents. Mongooses, peacocks, and snakes are frequent sights in and around the lake.

Limnological assessments

Water samples were collected, and limnological sampling was conducted between June 2022 and July 2023. Three sample stations were marked within the lake, namely, Open Surface (O), characterized by its direct atmospheric exposure and minimal obstruction at 13.003° N latitude and 77.482° E longitude. Deposit (D) station marked for high sedimentation and plant growth with coordinates 13.002° N latitude, 77.482° E longitude, and Inlet (I) station where treated water is discharged into the water body located at 13.002° N latitude, 77.483° E longitude. Water samples were analyzed in triplicates, and the mean value was considered. Temperature, humidity, and pH were measured on-site, and dissolved oxygen (DO) was fixed at the site. Water samples were collected in sterilized bottles and further transported to the laboratory for subsequent analysis of chemical and biological parameters. American Public Health Association [27] standard procedures were followed to analyze various parameters.

Physical parameters

Physical parameters such as pH, temperature, atmospheric humidity, turbidity, and conductivity were measured using calibrated instruments such as a pH meter, thermometer, hygrometer, turbidimeter, and conductivity meter. The total dissolved solids were measured using a TDS meter.

Chemical parameters

Dissolved oxygen (DO) was fixed at the site using manganous sulfate and measured using a DO meter. Biochemical oxygen demand (BOD) was determined via the DO meter and Winkler's method. The ferrous ammonium sulfate method was used to measure Chemical oxygen demand (COD). Alkalinity, total hardness, calcium, and magnesium levels were determined using titration. Sodium and potassium were measured using a flame photometer. The silver chloride method was used to detect chlorides, the barium chloride method was used to quantify sulfate, phosphate concentration was analyzed using the Fiske Subbarow method, and a UV spectrophotometer was used to screen nitrates. Prescribed techniques outlined in APHA 2017 were followed.

Most Probable Number (MPN) Analysis

MPN analysis was conducted to detect the presence of coliforms in the water sample utilizing standardized techniques [28].

Statistical Validation

Descriptive statistics, mean and standard deviation, were determined for the physical, chemical, and biological parameters. Data distribution was measured using the Shapiro-Wilk and Kruskal-Wallis tests, following which the post-hoc analysis was conducted using the Dwass-Steel-Critchlow-Fligner (DSCF) comparison.

Zebra fish analysis

Aquaculture and Spawning

D. rerio and its embryos were chosen as the model organism and its embryos because of their genetic relatability to humans and the advantage of having transparent embryos [26]. Healthy *D. rerio* was maintained in temperature-regulated aquarium tanks with good ventilation and lighting. Spawning was facilitated during the day with a male and three female fishes confined in breeding tanks equipped with a mesh [29]. Fresh embryos collected were used for developmental assessments and to count the heartbeat.

Experimental setup

Three embryos were introduced into small glass tanks with Reverse osmosis (RO) water; like-wise, three were introduced into the lake water samples from the three stations. Embryos treated within the RO water setup were considered a control sample.

Embryo analysis

Vital characteristics, such as tube formation, somite development, and overall embryo structure, were examined using a compound microscope in the control and test sample setups. Heartbeat was counted during the torpedo stages [30, 25].

RESULTS

Seasonal pH, temperature, humidity, and alkalinity variation for the three sampling stations are recorded in Table 1.

The mean values for limnological parameters and the standard deviation for various seasons and sampling stations are represented in Figures 2- 5, respectively.

Data statistically validated through the Kruskal Wallis test for turbidity and MPN showing significance for the sampling stations are depicted in Table 2.

Table 3 represents pair-wise comparisons done through the Dwass Steel Critchlow Fligner (DSCF) post hoc test for turbidity and MPN index analysis between sampling stations.

Table 4 depicts significant data $^{**}p<0.001$ and $^{*}p<0.05$ for seasons through the Kruskal Wallis test for various limnological parameters. Table 5 represents pairwise season comparisons for various limnological parameters done through DSCF post hoc analysis $^{**}p<0.001$ and $^{*}p<0.05$. Table 6 represents the somite embryonic development stage of *D.* rerio. Figure 6 graphically represents the heartbeat changes recorded in *D. rerio*.

The pH of the lake water showed significant seasonal variations; a low pH of 5.73 ± 0.60 was recorded in the inlet station during the monsoon, while the highest was observed in the spring (6.88 ± 0.30). The pH remained slightly acidic throughout the year. The temperature of

Table 1. Seasonal variation in pH, temperature, humidity, and alkalinity for the sampling station Open Surface water, Deposit, and Inlet sampled between June 2022 and July 2023

Parameter/Sampling Station Open	Monsoon July – September	Autumn October - November	Winter December- January	Spring February- March	Summer April – June
pH	5.83±0.52	6.09±0.36	6.18±0.52	6.13±1.45	6.13±0.33
Temperature	25.83±0.76	26.17±0.47	22±0.76	25.70±1.27	30.27±1.32
Humidity	59.67±2.89	65.00±7.07	35.60±2.89	37.40±1.70	42.27±10.46
Phenolphthalein alkalinity	0.00	0.00	0.00	2.50±3.54	0.00
Methyl Orange alkalinity	69.33±46.70	49.67±27.81	35.00±46.70	67.00±60.81	68.00±10.58
Hydroxide alkalinity	0.00	0.00	0.00	0.00	0.00
Carbonate alkalinity	0.00	0.00	0.00	5.00±7.07	0.00
Bicarbonate alkalinity	69.33±46.70	49.67±27.81	35±46.70	62±53.74	68±10.58
Parameter/Sampling Station Deposit					
pH	5.90±0.64	5.96±0.09	5.74±0.12	6.46±0.45	6.37±0.76
Temperature	25.57±0.75	25.73±0.24	21.65±0.35	26±0.57	30.33±1.02
Humidity	66.23±4.76	72±4.24	37.15±0.92	38.90±0.42	41.40±11.21
Phenolphthalein alkalinity	0.00	0.00	0.00	0.00	8.00±13.86
Methyl Orange alkalinity	66.67±46.19	48.33±25.93	20±14.14	52.50±31.82	66.67±37.86
Hydroxide alkalinity	0.00	0.00	0.00	0.00	0.00
Carbonate alkalinity	0.00	0.00	0.00	0.00	16.00±27.71
Bicarbonate alkalinity	66.67±46.19	48.33±25.93	20±14.14	52.50±31.82	50.67±11.02
Parameter/Sampling Station Inlet					
pH	5.73±0.60	6.09±0.50	5.89±0.12	6.88±0.30	6.39±0.45
Temperature	25.50±0.62	25.60±0.14	21.55±0.21	25.90±0.28	29.90±1.15
Humidity	64.53±2.84	73±7.07	40.25±0.64	39.90±2.40	43.83±8.94
Phenolphthalein alkalinity	0.00	0.00	0.00	7.50±10.61	0.00
Methyl Orange alkalinity	122.67±76.04	77.33±64.11	23±4.24	82±2.83	127.33±50.21
Hydroxide alkalinity	0.00	0.00	0.00	0.00	0.00
Carbonate alkalinity	0.00	0.00	0.00	15±21.21	0.00
Bicarbonate alkalinity	122.67±76.04	77.33±64.11	23±4.24	67±24.04	127.33±50.21

the study site that is deposit recorded the lowest temperature of 21.55 ± 0.21°C due to high plant growth, while the open water station recorded the maximum temperature of 30.33 ± 1.02°C. A usual seasonal trend in temperature was observed across all stations. The lowest humidity of 35.60 ± 2.89 was recorded during the winter in the open station, while the highest of 73 ± 7.07 was recorded during the autumn in the inlet. The water remained turbid throughout, and the lowest and highest levels were

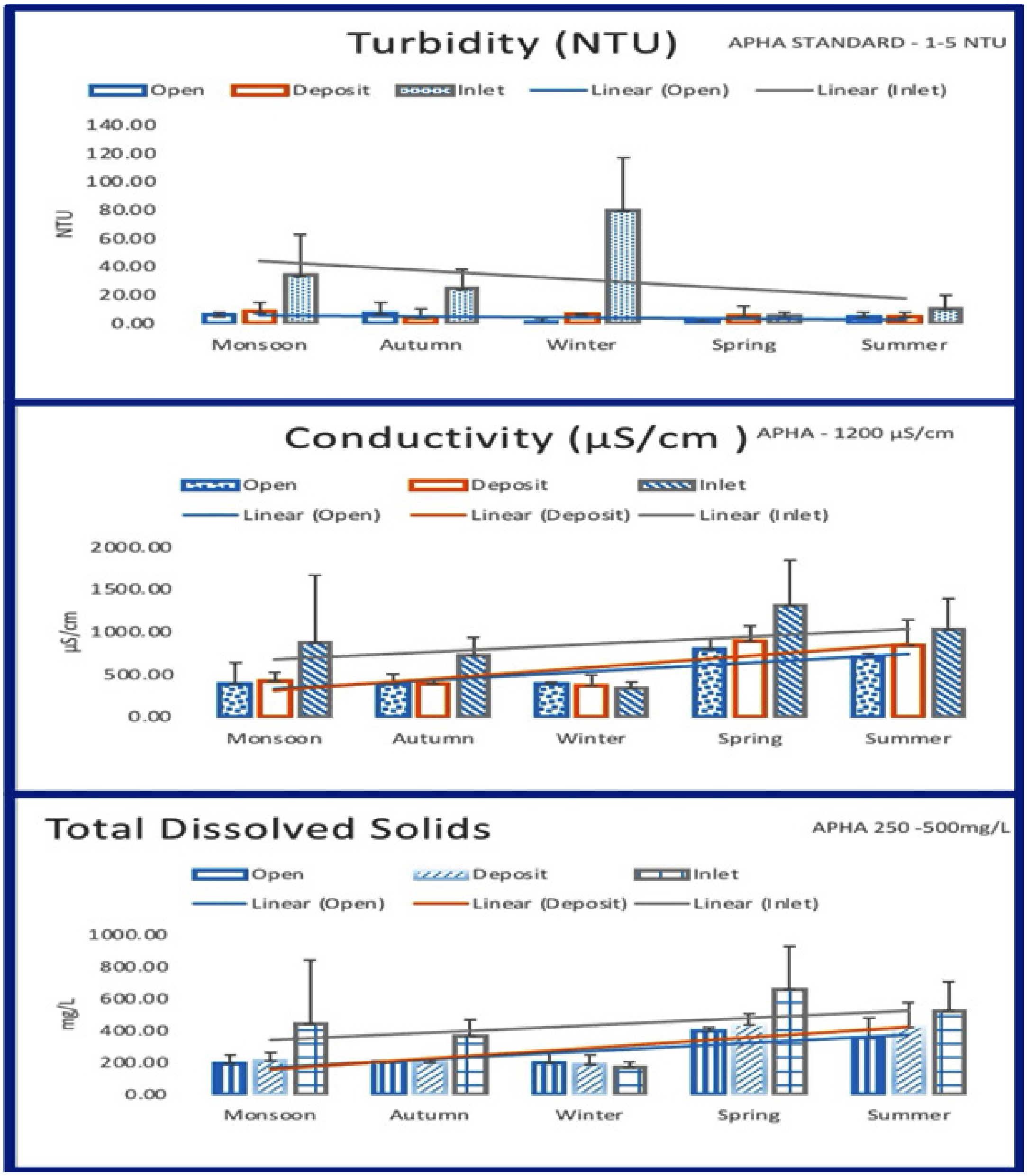

Fig. 1. Graphs representing turbidity, conductivity, and total dissolved solids for the sampling station Open Surface water, Deposit, and Inlet sampled between June 2022 and July 2023

noticed during winter. 1.00 ± 7.23 NTU was recorded in the open station, and the inlet was recorded with 80 ± 36.77 NTU. The conductivity of water highlights salinity and dissolved ion concentration; the lowest conductivity was recorded during the winter in the inlet station (340

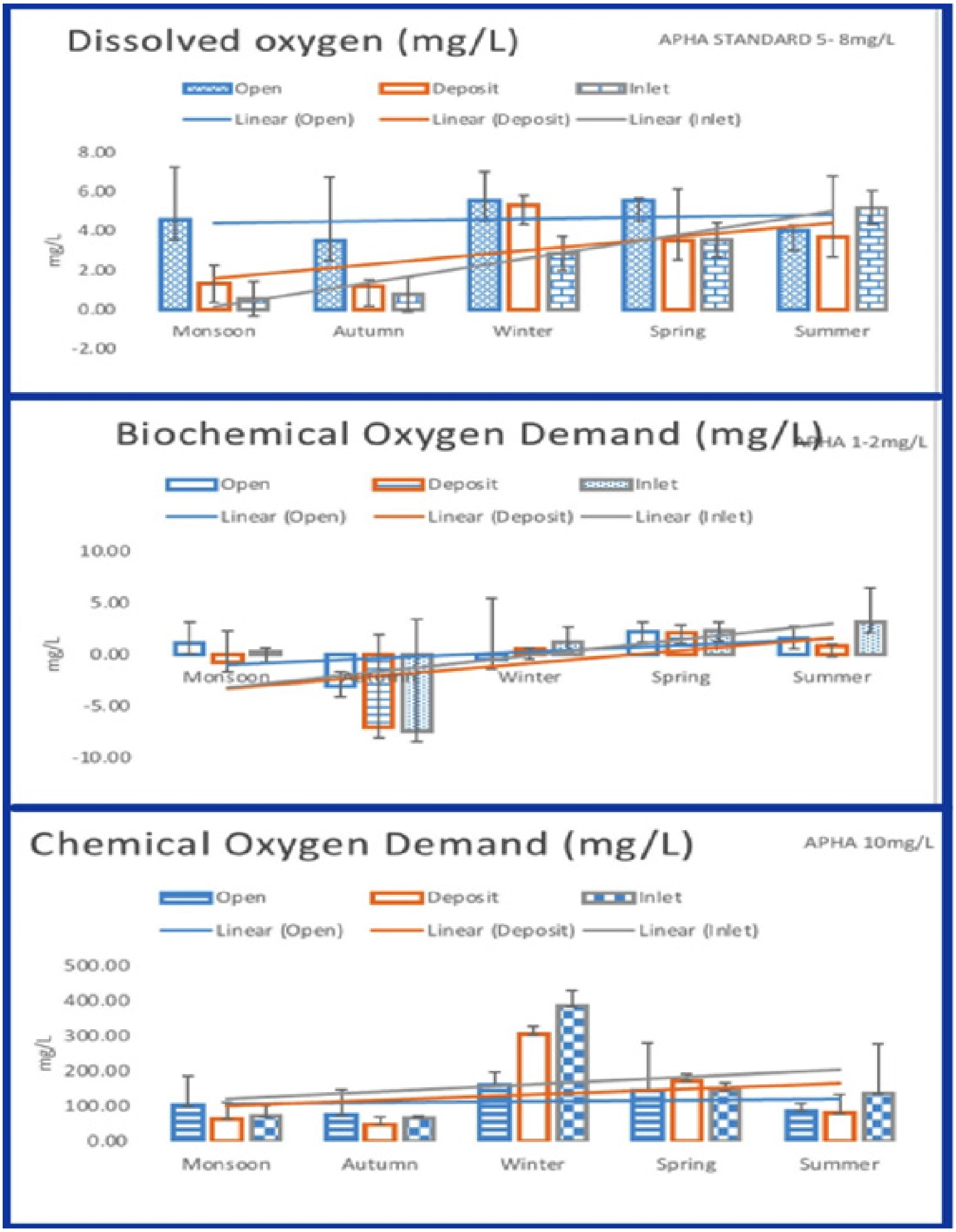

Fig. 2. Graphs representing dissolved oxygen, biochemical oxygen demand, and chemical oxygen demand for the sampling station open surface water, deposit, and inlet sampled between June 2022 and July 2023

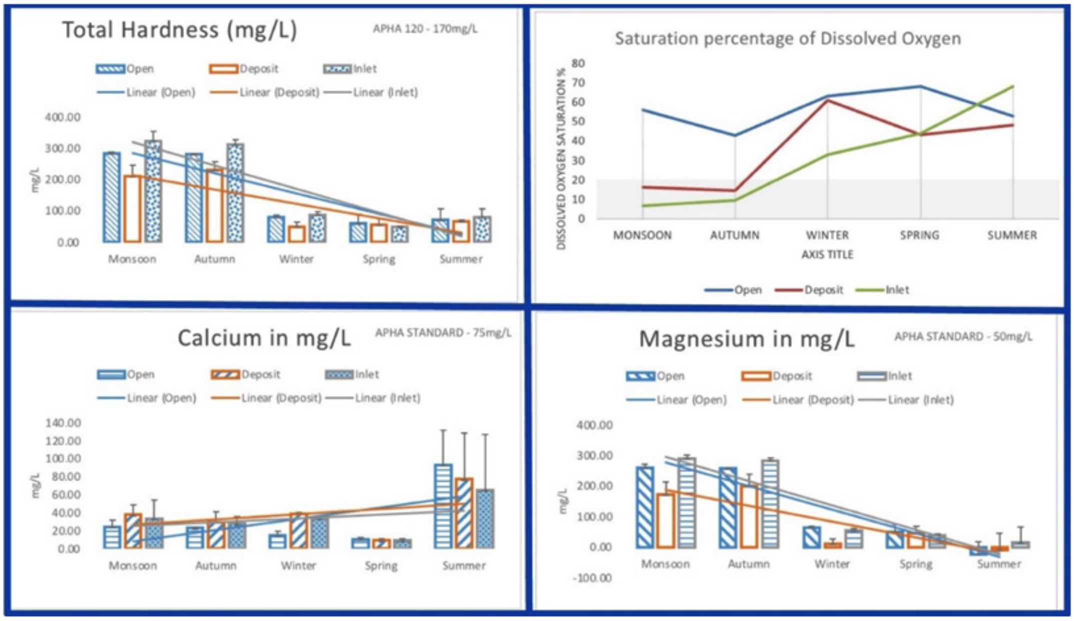

Fig. 3. Graphs representing total hardness, dissolved oxygen saturation percentage, calcium, and magnesium for the sampling station open surface water, deposit, and inlet sampled between June 2022 and July 2023

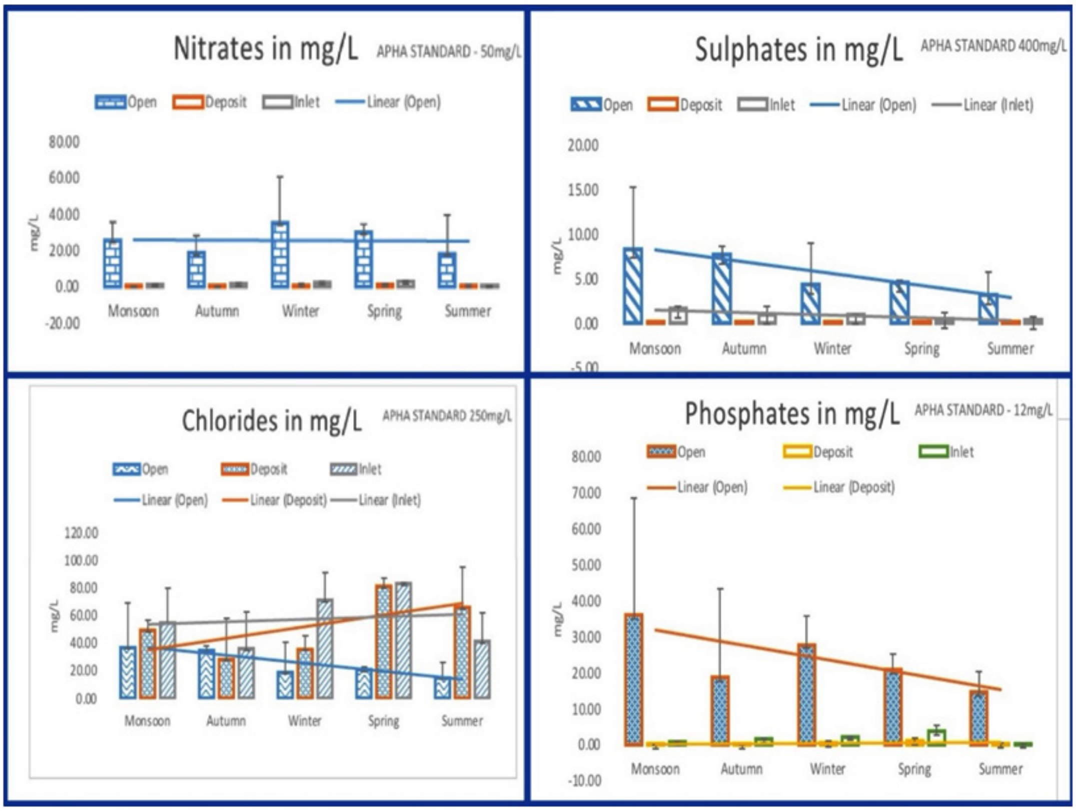

Fig. 4. Graphs representing anions for the sampling station open surface water, deposit, and inlet sampled between June 2022 and July 2023

± 70.71 µS/cm), while the highest (1314 ± 528.92 µS/cm) was also in the inlet during the spring.

The inlet recorded the lowest DO of 0.53 ± 0.92 mg/L during the monsoon, while the open station showed 5.50±0.28 mg/L during the spring. Overall, the DO of the wetland was found to be lesser than the APHA standard values. The saturation percentage of DO is represented in Figure 4; the percentage of DO saturation fluctuates across seasons and sampling stations, Peaking in spring (67.9%) and dipping in autumn (42.83%) in the open station. An increase in DO was seen during the winter (60.91%). It was low during the autumn (14.44%) in the deposit station, while in the inlet station, the highest was in summer (68.02%) and the lowest was during the monsoon (6.54%). BOD significantly varied within the lake. High organic pollution and high microbial activity were observed. A negative BOD was seen in all three stations during the autumn, indicating oxygen surplus due to microbial load, while a high BOD of 3.10 ± 3.28 mg/L was recorded in the inlet station. All stations recorded a very high COD exceeding the permissible limits, indicating pollution throughout all seasons. High COD was observed during the spring, while the highest of 384 ± 45.25 mg/L was recorded with the inlet station during winter. Alkalinity due to hydroxides was zero across all seasons and stations; carbonate alkalinity was recorded in the open 5.00±7.07 mg/L and inlet 15±21.21 mg/L stations during the spring, 16.00±27.71 mg/ L was recorded during the summers in the deposit station. Majorly, alkalinity was due to bicarbonates across seasons, with the highest range between 122.67±76.04 - 127.33±50.21 mg/L during the monsoon and summer in the inlet station. At the same time, low values were recorded during the winter.

The total hardness was within the permissible range during the winter, spring, and summer. In contrast, it increased during the monsoon and autumn. 324±31.75 mg/L was the highest value recorded in the inlet station. TDS was within the permissible value in the open and deposit station, while in the inlet, it surpassed the permissibility with values ranging between 171±32.53 mg/l and 658±265.87 mg/L. High values were recorded during the spring across all stations. Calcium ions increased during the spring and summer, with the highest value of 93.33±38.44 mg/L recorded in the open station and the lowest of 9.20±1.70 mg/L recorded in Deposit and inlet stations. 50mg/L being the permissible limit as per APHA, the wetland recorded very high magnesium content during the monsoon and the autumn, with values ranging from 172.13±42.20 to 290.40±11.78

Table 2. Kruskal Wallis Statistics indicating significance for Turbidity and Most Probable Number MPN Test *p<0.05

Variables	Sample Station	N	Mean	SD	Kruskal-Wallis
Turbidity	Deposit	12	5.86	4.46	8.91*
	Inlet	12	29.33	31.43	
	Open Water	12	4.31	4.11	
MPN index	Deposit	12	691.67	1076.58	8.30*
	Inlet	12	854.25	1141.97	
	Open Water	12	67.67	67.85	

Table 3. Dwass-Steel-Critchlow-Fligner pairwise comparisons for Turbidity and MPN Index *p<0.05

Turbidity				MPN index			
Pair Wise Comparison		W	p	Pair Wise Comparison		W	p
Deposit	Inlet	3.19	0.062	Deposit	Inlet	2.87	0.106
Deposit	Open Water	-1.23	0.660	Deposit	Open Water	2.01	0.330
Inlet	Open Water	-3.84	0.018	Inlet	Open Water	-4.02	0.012

Table 4. Kruskal Wallis Statistics indicating significance for various limnological parameters **p<0.001 and *p<0.05

Variables	Seasons	N	Mean	SD	Kruskal-Wallis
		Significance **p<0.001			
Temperature	Autumn	6	25.83	0.36	27.73**
	Monsoon	9	25.63	0.64	
	Spring	6	25.87	0.65	
	Summer	9	30.17	1.03	
	Winter	6	21.73	0.42	
Humidity	Autumn	6	70.00	6.23	26.72**
	Monsoon	9	63.48	4.30	
	Spring	6	38.73	1.74	
	Summer	9	42.50	8.94	
	Winter	6	37.67	2.27	
Total Hardness	Autumn	6	274.56	39.92	26.69**
	Monsoon	9	272.44	55.58	
	Spring	6	54.67	16.57	
	Summer	9	72.44	23.74	
	Winter	6	72.50	19.43	
Calcium Hardness	Autumn	6	26.91	7.01	21.87**
	Monsoon	9	31.82	13.80	
	Spring	6	9.60	1.60	
	Summer	9	78.58	46.21	
	Winter	6	29.17	11.46	
Magnesium Hardness	Autumn	6	247.64	42.62	28.1**
	Monsoon	9	240.62	57.83	
	Spring	6	45.07	16.18	
	Summer	9	-6.13	46.64	
	Winter	6	43.33	26.79	
Phosphates	Autumn	6	0.09	0.03	18.99**
	Monsoon	9	0.07	0.06	
	Spring	6	1.10	0.53	
	Summer	9	0.39	0.29	
	Winter	6	0.48	0.51	
Nitrates	Autumn	6	1.19	0.94	28.98**
	Monsoon	9	0.91	0.19	
	Spring	6	3.95	2.37	
	Summer	9	0.11	0.27	
	Winter	6	2.30	0.09	
		Significance *p<0.05			
Variables	Seasons	N	Mean	SD	Kruskal-Wallis
Conductivity	Autumn	6	504.89	196.87	17.78*
	Monsoon	9	558.44	468.39	
	Spring	6	1001.83	350.56	
	Summer	9	859.22	301.64	
	Winter	6	368.83	89.69	
DO	Autumn	6	1.80	1.48	10.75*
	Monsoon	9	2.13	2.74	
	Spring	6	4.18	1.58	
	Summer	9	4.28	2.28	
	Winter	6	4.55	1.64	
BOD	Autumn	6	-5.84	7.12	14.9*
	Monsoon	9	0.19	1.82	
	Spring	6	2.18	0.73	

	Summer	9	1.82	2.18	
	Winter	6	0.43	1.06	
COD	Autumn	6	63.47	23.36	15.34*
	Monsoon	9	78.93	48.90	
	Spring	6	153.50	22.00	
	Summer	9	101.07	89.44	
	Winter	6	282.67	120.44	
Methyl Orange alkalinity	Autumn	6	58.44	36.41	11.72*
	Monsoon	9	86.22	57.21	
	Spring	6	67.17	33.43	
	Summer	9	87.33	43.78	
	Winter	6	26.00	10.20	
Bicarbonate alkalinity	Autumn	6	58.44	36.41	11.62*
	Monsoon	9	86.22	57.21	
	Spring	6	60.50	30.64	
	Summer	9	82.00	43.60	
	Winter	6	26.00	10.20	
Total Dissolved/ Settleable Solids	Autumn	6	253.83	98.31	17.84*
	Monsoon	9	279.67	235.15	
	Spring	6	496.83	176.12	
	Summer	9	431.67	152.79	
	Winter	6	184.83	44.70	
Potassium	Autumn	6	0.14	0.30	10.76*
	Monsoon	9	0.39	0.69	
	Spring	6	0.00	0.00	
	Summer	9	0.09	0.07	
	Winter	6	0.00	0.00	
Chlorides	Autumn	6	33.69	23.36	10.21*
	Monsoon	9	54.59	22.09	
	Spring	6	81.89	3.00	
	Summer	9	54.12	26.20	
	Winter	6	54.43	23.19	

mg/L. Sodium and potassium levels remained consistently low across all seasons. Chloride concentrations were within the APHA standards; values increased during the spring. 83.09±0.98 mg/L was the maximum value recorded in the inlet station, while the lowest of 28.16±29.79 mg/L was seen in the deposit. Sulfate concentrations ranged between 8.32±6.98 mg/L and 34.92±25.38 mg/L, within the permissible limit (400 mg/L) as per APHA.

Nitrate concentrations were within the permissible value. A slight increase was found during the spring, with a maximum value of 5.36±4.29 mg/L recorded in the open station. Phosphate concentration ranged between 0.05±0.05mg/L to 1.33±0.30mg/L, with 0.05mg/l being the permissible value the open surface water recorded highest during the autumn. A low MPN index was observed during the spring and the summer, while MPN values exceeded the permissible range during the monsoon, with the Deposit and the inlet station showing the highest values. Significant variations between sampling stations and across seasons were observed through Kruskal Wallis statistics.

Somite developmental stages and heart rates in *D. rerio* embryos showed the following results. The embryos reached the 14^{th} somite stage after 16 hours in the open and the deposit station, similar to the control, while embryos reached only the 10^{th} somite stage in the inlet station. This delay in growth is due to pollutants. The heart rate recorded was 125 bpm in the control and 96-102 bpm in the open station. A gradual decrease in the number of beats (90-97 bpm) was recorded in the deposit station, while the inlet station recorded a drastically meager heart rate (64 bpm).

DISCUSSION

The study on Lingadheeranahalli Lake revealed significant seasonal dynamics insights into its physicochemical parameters and the developmental responses of *D. rerio*. Similar studies on other urban lakes have shown comparable trends. Seasons and anthropogenic activities have affected water chemistry. The pH of the lake water showed significant seasonal variations overall. The pH across all sampling stations remained slightly acidic throughout all seasons. Reduced water content and over vegetation were noticed in the study area. Previous studies indicate that drought or reduced water content results in the acidification of lake water [31], and inundated terrestrial vegetation can result in acidic pH [32]. Previous studies on Sankey Tank Mallathahalli Lake in Bangalore

Table 5. Dwass-Steel-Critchlow-Fligner pairwise comparisons for various limnological parameters **p<0.001 and *p<0.05

Season	Temperature Season	W	p	Season	Nitrates Season	W	P
Autumn	Summer	4.500	0.013	Autumn	Spring	4.08	0.032
Autumn	Winter	-4.083	0.032	Autumn	Winter	4.08	0.032
Monsoon	Summer	5.060	0.003	Monsoon	Spring	4.50	0.013
Monsoon	Winter	-4.508	0.013	Monsoon	Summer	-5.06	0.003
Spring	Summer	4.500	0.013	Monsoon	Winter	4.50	0.013
Spring	Winter	-4.083	0.032	Spring	Summer	-4.50	0.013
Summer	Winter	-4.504	0.013	Summer	Winter	4.50	0.013
	Humidity				Magnesium Hardness		
Autumn	Spring	-4.083	0.032	Autumn	Spring	-4.076	0.032
Autumn	Summer	-4.500	0.013	Autumn	Summer	-4.504	0.013
Autumn	Winter	-4.076	0.032	Autumn	Winter	-4.076	0.032
Monsoon	Spring	-4.516	0.012	Monsoon	Spring	-4.500	0.013
Monsoon	Summer	-5.065	0.003	Monsoon	Summer	-5.060	0.003
Monsoon	Winter	-4.512	0.012	Monsoon	Winter	-4.500	0.013
	Conductivity				Bicarbonate alkalinity		
Spring	Winter	-4.076	0.032	Monsoon	Winter	-3.865	0.049
Summer	Winter	-4.167	0.03	Summer	Winter	-4.425	0.015
	BOD				Total Hardness		
Autumn	Spring	4.076	0.032	Autumn	Spring	-4.0833	0.032
COD	Autumn	Summer	-4.5081	0.013			
Autumn	Spring	4.120	0.029	Autumn	Winter	-4.1050	0.030
	Methyl Orange alkalinity			Monsoon	Spring	-4.5081	0.013
Monsoon	Monsoon	-3.865	0.049	Monsoon	Summer	-5.0654	0.003
Summer	Monsoon	-4.425	0.015	Monsoon	Winter	4.5202	0.012
	Total Dissolved/Settleable Solids				Calcium Hardness		
Spring	Winter	-4.076	0.032	Autumn	Spring	-4.120	0.029
Summer	Winter	-4.167	0.027	Autumn	Summer	3.851	0.051
	Chlorides			Monsoon	Spring	-4.512	0.012
Autumn	Spring	4.0762	0.032	Spring	Summer	4.512	0.012
	Phosphates			Spring	Winter	3.984	0.039
Autumn	Spring	4.08	0.032	Chlorides			
Monsoon	Spring	4.52	0.012	Autumn	Spring	4.0762	0.032

Table 6. Effect of lake water on somite embryonic developmental stage of the *D. rerio*

Lingadheeranahalli Sampling Stations	Somite Developmental Stage *D. rerio*
Control	16 Hours - 14 SOMITE
Open	16 Hours - 14 SOMITE
Deposit	16 Hours - 14 SOMITE
Inlet	16 Hours - 10 SOMITE

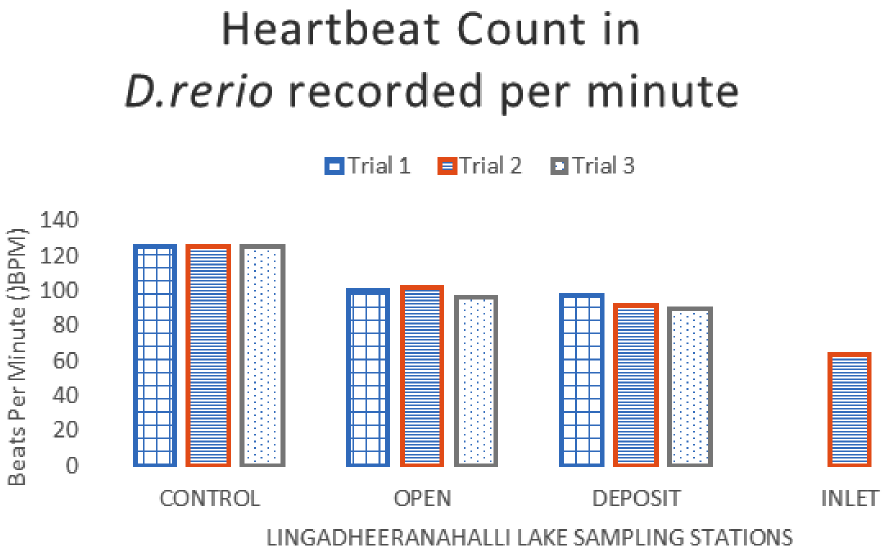

Fig. 5. Effect of lake water on Heartbeat count in *D. rerio*
Note: bpm stands for Beats per Minute

have similar findings. A usual seasonal trend in temperature was observed across all stations. Season trends are forecasted for freshwater wetlands [33, 34].

Humidity is attributed to water quality imbalance [35]. The findings suggest higher humidity during autumn and summer; previous research suggests that the higher the temperature, the higher the moisture [36]. Water turbidity consistently remained high, peaking during the winter. This is attributed to colloidal dispersions, common in lake ecosystems [13] and could be the reason for the study sites. Water conductivity was the lowest during the winter and the highest in the inlet during the spring. The peak in conductivity is due to waste disposal and sewage inflow [37, 13]. Previous studies on Kumaun Himalayan Lake indicated that seasons and human influence significantly affect pH, conductivity, and nutrient concentrations [1].

DO of the lake was low; comparative research on Bellandur and Varthur Lakes reported similar findings due to high organic pollution from untreated sewage [9, 10]. DO saturation percentage suggests significant variations in the inlet station, emphasizing the need for monitoring. Organic pollution suggests the waste accumulation capacity of the wetland [38]. Studies on Varthur Lake reported high levels of BOD, underscoring stress on aquatic life [39]. Previous studies suggest that the lesser the DO, the higher the BOD [24]. COD is reported to be high after the rainy season, reflecting a similar trend in Ulsoor Lake and other urban Lakes in Bangalore [40]. Urban waste and anthropogenic activity lead to high values of COD [41].

Rainfall increases alkalinity [42], as indicated in the present study; alkalinity tends to increase during summers, and enhanced carbon sources due to bicarbonates facilitate algae growth [43]. High values of bicarbonates reported in the study might be due to contact with carbonate rocks and atmospheric gases present in water [44]. Past studies show increased hardness during the dry seasons [45]. The present study indicates increased hardness during the monsoon, calcite, and dolomite dissolution due to rainfall might be the reason for the increase in hardness during the monsoon [20]. TDS is mainly due to anions and cations [13] and depends on seasons [46]. Calcium in fresh surface water could be due to gypsum, limestone, and calcium-containing rocks [47]. Inflow retention of pollutants also leads to high calcium content [48]. Leaching of dolomite and magnesite during the monsoon can cause high magnesium levels [49]. High values observed during the winter at the inlet station are hypothesized to result from mineral leaching, drainage, and oxidation of sulfides [50]. The presence of phosphates generally leads to eutrophication during the dry seasons, as suggested by past studies, which is similar to the current research [51]. Nitrate concentration in surface water is high, and spikes are only due to agricultural runoff and animal wastes [52, 53, 54]. Previous studies on MPN indicate values go high after monsoon, similar to the current study [54].

Statistical validation suggests significant environmental pollution between the inlet point and the open station, which aligns with previous studies showcasing spatial heterogeneity in water quality due to anthropogenic activities [54]. Additionally, temperature, humidity, total hardness, calcium, magnesium, phosphates, and nitrates displayed seasonal differences with a significance level of $p<0.001$. Furthermore, DO, BOD, COD, alkalinity, TDS, potassium, and chlorides showed potent variations, with $p<0.05$ being the significance level. *D. rerio* data of the current study, in contrast with earlier studies conducted on Iblur and Mallathahalli Lakes in Bangalore, are similar [24, 55]. The limnological parameters and the physiological responses indicate deficient water quality and highlight a detrimental effect on aquatic life, emphasizing stringent water quality management.

CONCLUSION

Comprehending various limnological variables of the wetland and physiological responses by *D. rerio*, the current investigation reports the influence of summer, monsoon and winter seasons on limnological parameters. Physiological responses of *D. rerio* embryos highlighted potent stressors present in the lake ecosystem, with delayed somite development and decreased heart rates. The water quality remains poor and continuous ecological stress was observed. The study emphasizes the importance of seasonal dynamics as an adaptive strategy in wetland monitoring to mitigate pollution and consciously spread awareness in society.

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Conflict of Interest

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This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Author Contributions

Mathews P Raj: Conceptualization, Methodology, Writing – Original Draft, Supervision; Reena Susan Philip: Data Curation, Formal Analysis, Writing – Review & Editing; All authors have read and approved the final version of the manuscript.

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