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Effects of Water Quality on Birds at Singanallur Lake, Coimbatore, Tamil Nadu, India

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ABSTRACT

Wetlands in India are seriously threatened by pollution due to rapid urbanization, industrial activities and unsustainable agricultural practices. The water quality of an urban lake is a key concern. A survey by line transects and point count method were conducted around Singanallur lake, Coimbatore, Tamil Nadu, India. The surface water samples were collected in sterile containers from the inlets and outlets of Singanallur lake between 2009 and 2011 and the physicochemical parameters, nutrient properties and heavy metals were analyzed using Atomic Absorption Spectroscopy. The pH value consistently appears to be above 7, indicating the alkaline nature of the water. Total suspended solids, total solids and total dissolved solids were exceeded the WHO permissible limit. Among the metals analyzed, copper was found to be the most prevalent at a concentration of 39.4 µg/ml. Stepwise linear regression (R = - 0.87) shows a strong negative relationship, suggesting that as the pollution load index (PLI) increases, the bird population correspondingly decreases. Specifically, the PLI was recorded at 4.5 in 2009 and had risen to 8.43 by 2011. The high PLI **adversely** affects the abundance and health of aquatic organisms, which serve as primary food sources for many bird species. The poor water quality of the surface water due to anthropogenic pressures in Singanallur lake gives out a serious warning, highlighting the urgent need to conserve the fragile ecosystem.

Keywords: *Singanallur lake, Physico-chemical parameters, Nutrient load, Heavy metals, Pollution load index, Bird population.*

Introduction

Wetlands are water-covered low-lying areas characterized by aquatic vegetation and hydric soils. They have an important function in ecological equilibrium and supporting biodiversity. This ecosystem provides direct as well as indirect services in terms of economic values to human beings (Costanza *et al*., 1997; Smardon *et al*., 2009). Therefore, it is one of the most important and productive ecosystems (Smardon *et al*., 2009; Mitschand Gosselink, 2015). But nowadays, wetland degradation and destruction are predominantly driven by human activities. Freshwater bodies of the world on the whole are experiencing accelerating rates of qualitative and quantitative degradation (Wetzel, 1992). Hence, these wetlands are considered the most endangered ecosystems in the world. The primary causes of lake degradation include waste dumping, industrial discharges, and modern agricultural practices

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(Chandra *et al*., 2010).

Freshwater biodiversity is under threat due to climate change and human activities, which introduce various stressors such as nutrient pollution, changes in water flow, alterations in habitat structure, temperature fluctuations, and other toxic and chemical contaminants (Reid *et al*., 2019; Albert *et al*., 2020; Birk *et al*., 2020). The declines of biodiversity in fresh waters are far greater than those that in the most affected terrestrial ecosystems (Sala *et al*. 2000). These freshwater wetland habitats provide essential breeding grounds for various taxa, many of which are uniquely adapted to the wetland environment. Wetland ecosystems play a crucial role in maintaining environmental balance by ssupporting biodiversity. Unfortunately, the heavy metal load in water bodies cause severe damage to the ecosystem. Many studies using nanotechnology to remove these heavy metals and other chemical pollutants have appeared appear in the literature (Tiwari *et al*. 2008; Bruggen and Vandercasteele, 2003; Rahman *et al*., 2013; Nowack and Bucheli, 2007).

The freshwater ecosystem supports a large number of avian species in and around urbanized localities. Waterbirds are susceptible to changes in their ecosystems. As a result, they serve as effective indicators of the overall health of wetland environments (Kushlan, 1992). Birds can also reflect the quality of an ecosystem and give an early warning of environmental changes. Hence, the present study was carried out to assessthe effect of surface water quality on birds of Singanallur lake, Coimbatore, Tamil Nadu, India.

Study Area

Singanallur lake is one of the largest lake in Coimbatore district of Tamil Nadu, India, located at latitude 10°59'46''N and longitude 77°01'11''E. Situated at an altitude of 411 m above sea level, the lake covers an area of 288 acres. The region experiences a mild winter, a moderate summer and receives an average annual rainfall of 618.5 mm, with the peak occurring between September and November. The lake is located in Singanallur block of Coimbatore district, Tamil Nadu. The bund of Singanallur lake extends up to 3102 m and the water spread area is 1.153 sq.km.A railway line crosses through the lake and has five underpasses. The lake has a total catchment area of 30.50 sq.km and a water holding capacity of 52.27 m.cft. The registered ayacut of this lake is 845 acres and the full tank level is 4.25 m which can reach the maximum level of 5.17 m. The annual storage in the tank is 132 m.cft. Earlier, the lake was equipped with three functional sluices of an average 1.37 m sill height. Three major channels namely, Rajavaikkal, Sanganoor channel and Ganapathy - Uppilipalayam odai were worked as the water inlets for the lake. The outlets were two weir dam and three sluices. The sluices can be used in flood control. The lake is bounded by farmlands and townships on three sides, with a busy highway to the north.

Methodology

Survey of Bird Species

A survey by line transects and point count methods were conducted around Singanallur lake, Coimbatore, Tamil Nadu, India. For the population study of bird species, a weekly survey was done on the fixed transect from June 2009 to December 2011. Bird observations were predominantly conducted during peak activity hours, specifically in the morning from 06:00 to 10:00 and in the evening from 16:00 to 18:00. The observations were facilitated through the use of an 8×40 binoculars and the observed bird species and the field characteristics were noted on designated data sheets. Identification of bird species was carried out with the help of the field guides such as Ali (2002), Grimmet *et al*. (2011). The standard scientific names (Praveen *et al*. 2016) and vernacular names (Ratnam, 2004) were adopted to make the consolidated list. The birds were classified as resident (R), migratory (M) and as Resident migrant (RM) (Ali, 2002). In addition to this, the compilation of opportunistic sightings and secondary sources were collated to prepare the checklist. The analysis was carried out by clumping of some species into groups, namely Egrets, Bitterns, Quails, Sandpipers, Stints, Doves, Swifts, Larks, Swallows, Starlings, Warblers, Pipits, Wagtails, Sunbirds and Munias. Hence, the total numbers of species were considered as 100 for analysis. The analyses was carried out for 30 months.

Water Quality Analysis

Surface water samples in five different points for all the three seasons were collected in sterile containers from the inlets and outlets of Singanallur lake between 2009 and 2011. The collected water samples were pooled and analyzed for physicochemical parameters and nutrient content such as, temperature (°C), pH, suspended solids (mg/l), dissolved solids (mg/l), total solids (mg/l), alkalinity (mg/l), biological oxygen demand (BOD) (mg/l), chemical oxygen demand (COD) (mg/l), dissolved oxygen (DO) (mg/l), nitrate (mg/l), chloride (mg/l), fluoride (mg/l), calcium (mg/l), magnesium (mg/l) and sulphate (mg/l), using standard methods (APHA, 2005).

Heavy Metal Analysis

For the analytical determination of heavy metals such as Iron (Fe), Lead (Pb), Chromium (Cr), Copper (Cu) and Cadmium (Cd), the collected water samples were digested in 10 ml nitric acid (HNO_3) and 1 ml perchloric acid ($HClO_4$), in a microwave digestion system (Noman*et al.* 2022). The digested samples were filtered and reconstituted to 25 ml using Milli-Q water for heavy metal analysis. The heavy metals were estimated by employing an Atomic Absorption Spectrophotometer (Thermo Fisher, iCE 3000 series).

Results and Discussion

Bird Diversity

A total of 189 species of birds belonging to 20 orders and 59 families were recorded during the study period. Out of 189 species of birds, 108 species were resident, followed by 48 species of resident migratory and 33 species of migratory. Of the 189 species, 90 species of birds were categorized as terrestrial birds, 79 species as wetland birds and 20 species as wetland associated birds. While looking into the foraging guilds, 89 species were insectivorous, 36 species were picivorous, 19 species were omnivorous, 18 species were carnivorous, 13 species were granivorous, 10 species were frugivorous, and four species were insectivoros.

Out of 189 species of birds 26 species were listed in Schedule I and 161 species were listed in Schedule II of Wildlife Protection Act 1972. Among the bird species recorded, the following species were list as threatened by International Union for Conservation of Nature (IUCN) (2007): Black-bellied Tern (*Sterna acuticauda*), an endangered bird species, three vulnerable species namely, Lesser Adjutant (*Leptoptilos javanicus*), River Tern (*Sterna aurantia*) and Tawny Eagle (*Aquila rapax*) and 10 Near Threatened species namely, Black-headed Ibis (*Threskiornism elanocephalus*), Black-tailed Godwit (*Limosa limosa*), Eurasian Curlew (*Numenius arquata*), Lesser Fish

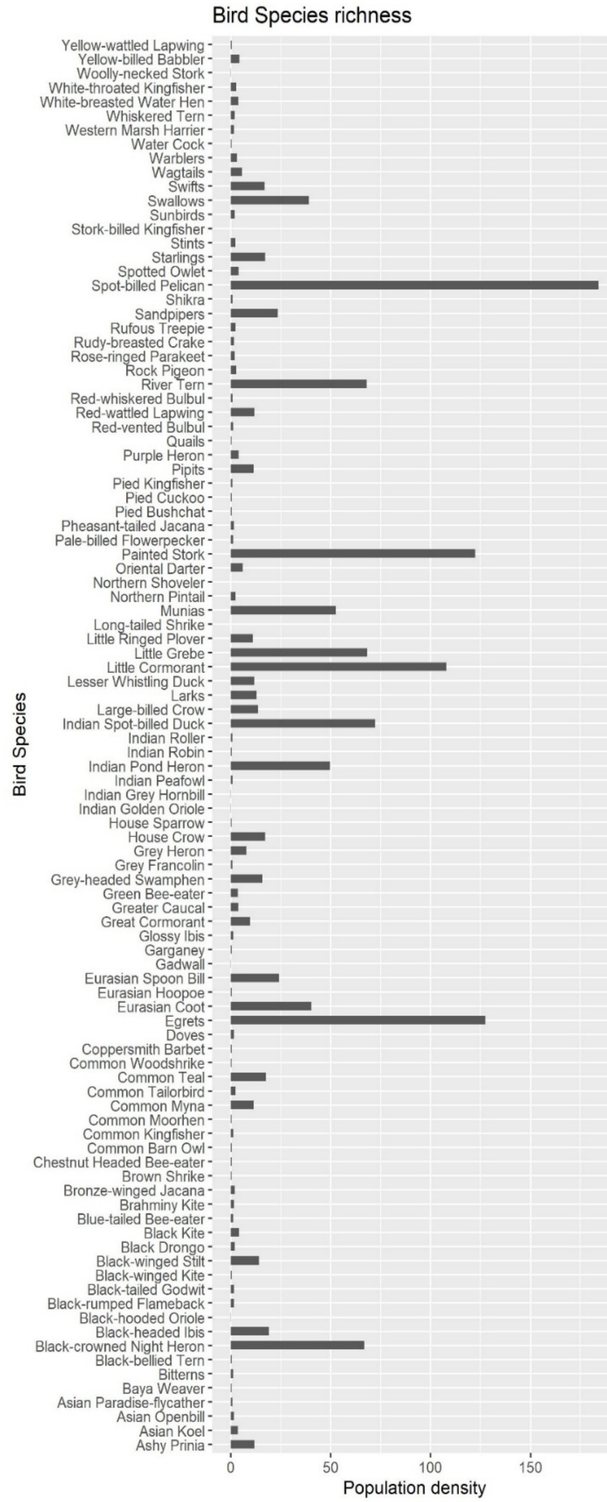

Fig. 1. Population density and species richness of birds recorded from Singanallur lake

Eagle (*Haliaeetus humilis*), Oriental Darter (*Anhinga melanogaster*), Painted Stork (*Mycteria leucocephala*), Pallid Harrier (*Circus macrourus*), Red-necked Falcon (*Falco chicquera*), Spot-billed Pelican (*Pelecanus philippensis*) and Woolly-necked Stork (*Ciconia episcopus*). Out of 189 species of birds, 59 species have been reported to be nesting at Singanallur Lake. Even though there are not many trees available for roosting, the threatened species, such as the Spot-billed Pelican (*Pelecanus philippensis*), Painted Stork (*Mycteria leucocephal*), and Black-headed Ibis (*Threskiornis melanocephalus*) have preferred roosting in a single Rain Tree (*Samanea saman*) at the southwest side of the lake and sometimes on the ground.

As mentioned above, out of 189 species of birds, 100 species (Figure 1) were considered for population study. This reveals the potential of this lake to provide habitat for a large number of birds in an urban environment. The highest numbers of bird species were recorded during the migratory season (October to February) and the lowest during summer season (March to June). The most abundant bird species recorded in Singanallur lake was Spot-billed pelican (*Pelecanus philippensis*). In general, it is considered that the presence of raptors is an indication of a healthy ecosystem (Withaningsih, 2017). 15 species of raptors were recorded during the study period at Singanallur lake. Among them, Brahminy Kite (*Haliastur indus*) was the most common raptor, followed by Black Kite (*Milvus migrants*). A study conducted by Reginald *et al*. (2007) documented 116 species of birds from the same lake. During the study period, certain factors which threaten the wetland ecosystem and the population of wetland birds were observed. Landscape alteration and the presence of the exotic weed species such as Water hyacinth (*Eichhornia crassipes*) were the major threats to the wetland ecosystem. Generally, the wetland with moderate presence of water hyacinth support the resident birds, such as herons, common coots, common moorhens, and purple swamphens etc. This is probably due to the abundance of insects and vegetation that serve as potential food sources (Villamagna *et al.,* 2012; Kaur *et al.,* 2018). However, when the density of these exotic plants increases, the overall ecosystem of the lake gets affected. Discharge of sewage water is the main reason for the uncontrollable growth of this exotic species , which results in eutrophication. This is reflected by the nutrient profile of water samples collected from the lake.

Physico-chemical Properties of the Surface Water

Different parameters of the water samples in various seasons collected from Singanallur lake between 2009 and 2011 were considered for the study (Table 1). Comparison of the results was done against the standards of WHO, 2011 and B.I.S, 2003. Higher temperatures were recorded during the summer and lower values were observed during the mon-

Table 1. Physico-chemical Parameters and Nutrient loads of Surface Water Samples Collected from Singanallur Lake

S. No.	Parameter	2009			2010			2011		
		M	W	S	M	W	S	M	W	S
1	Temperature (°C)	27.4	28.9	30.0	27.1	27.9	30.5	27.2	28.3	30.7
2	pH	7.9	7.3	7.5	7.6	7.2	7.5	8.1	7.2	7.7
3	Suspended Solids (mg/l)	2.56	1.28	5.5	2.94	1.35	5.29	3.2	1.29	6.1
4	Dissolved Solids (mg/l)	4550	4478	1226	4768	4687	1320	4356	4629	1339
5	Total Solids (mg/l)	1120	1003	1620	1290	987	1579	1078	945	1580
6	Alkalinity (mg/l)	523.0	404.0	398.0	513.6	399.6	372.0	566.6	433.0	456.0
7	Hardness (mg/l)	410.0	320.0	480.0	430.0	390.0	496.0	420.0	360.0	520.0
8	BOD (mg/l)	42	20.8	39.7	45	19.8	41.2	43	21.3	39
9	COD (mg/l)	148	106	182	142	110	191	156	108	178
10	DO (mg/l)	5.1	5.1	5.3	5.3	4.9	5.1	5.3	5	5.1
11	Nitrate (mg/l)	45.0	27.3	28.6	42.0	29.9	26.8	54.0	36.3	37.6
12	Chloride (mg/l)	486.0	396.0	254.0	456.0	379.0	237.0	502.0	402.0	272.0
13	Fluoride (mg/l)	0.9	0.7	0.7	0.7	0.6	0.6	1.0	0.9	0.7
14	Calcium(mg/l)	18	34	72	21	39	60	24	42	59
15	Magnesium (mg/l)	11.8	27	29	13	24.8	27.9	12.2	27	28.8
16	Sulphate (mg/l)	74.3	69	86.6	74.8	71	89.2	77	68.8	84

M - Mansoon (July to October), W - Winter (November to February), S - Summer (March to June) soon. The pH value ranged between 7.6 and 8.1 in the monsoon, 7.2 and 7.3 in the winter and 7.4 and 6.7 in the summer. The values were high (8.1) in 2011 summer, acceptable by WHO (6.5 to 8.5). This values indicate that the water is slightly alkaline and is due to the presence of ammonium compounds that enter the lake through the urban sewage. The anthropogenic activities as well as natural processes may possibly influence the pH value. The higher pH value in the monsoon could be due to bicarbonates and carbonates of calcium and magnesium in water. The slightly alkaline nature indicates that about 95% of the CO_2 in the water is present as bicarbonate (Azeez *et al*., 2000). Higher values are also possibly due to monsoon spell which brings a significant amount of rain carrying dissolved minerals. Mohanraj *et al*. (2000) and Chandra *et al*. (2010) observed the same. Basic pH was found to promote photosynthesis during summer and monsoon (Sunkad and Patil, 2004).

The values of Total Suspended Solids (TSS) were recorded in the range from 1.28 to 6.1 mg/l, while the Total Solids (TS) varied between 945 and 1620 mg/l through out the study period. Summer 2011 recorded the highest TSS and TS. The Total Dissolved Solids (TDS) was significantly higher in the winter than the other seasons as can be observed from a close scrutiny of values displayed in Table 1. It is noteworthy that the amount of TDS surpass the WHO recommendations (WHO, 2011). The elevated TDS values in comparison with earlier studies (Mohanraj *et al*. 2000; Chandra *et al*. 2010) might have been caused by the untreated wastes from the dye industries as observed by Rahman *et al*. (2013).

The total alkalinity (TA) and total hardness (TH) varied from 372 to 566.6 mg/l and from 320 to 520 mg/l, respectively. Among the seasons, monsoon registered high TA (566.6 mg/l). Summer 2011 recorded a higher total hardness of 520 mg/l, which exceeds the WHO (2011) recommended limits of 300 mg/l. Mohanraj *et al*. (2000) published s**imilar results in urban lakes.** Chandra *et al*. (2010) reported that elevated total alkalinity is due to household wastes and defecating publicly. Virha *et al*. (2011) suggested that industrial and biomedical wastes contribute to increased total hardness.

Dissolved oxygen (DO) is a key measure of the health of aquatic ecosystems. A DO level above 5 mg/l supports aquatic life. However, if DO levels drop below 3 mg/l, it can pose health risks to humans and animals (Radhakrishanan *et al*., 2007). In this study, the DO levels ranged from 5.1 to 5.3 mg/l during the monsoon 4.9 to 5.1 mg/l in winter, and 5.1 to 5.3 mg/l in summer. According to Iqbal *et al*. (2013), DO levels were higher in the winter (5.20 mg/l) compared to the summer (4.09 mg/l) at Pakistan's Rawal lake. The variations in DO levels observed in this study may be attributed to temperature fluctuations as well as human interventions.

The biological oxygen demand (BOD), values ranged from 42 to 45 mg/l during the monsoon, 19.8 to 21.3 mg/l in the winter, and 39 to 41.2 mg/l in the summer. These levels exceeded the WHO tolerance limit (WHO, 2011) in all three seasons. The chemical oxygen demand (COD) levels ranged between 142 and 156 mg/l in the monsoon, 106 and 110 mg/l in winter, and 178 and 191 mg/l in summer. The elevated BOD and COD levels are linked to large amounts of chemical wastes entering these lakes.

Nutrient Loads in the Surface Water

Variations in the nutrient loads of surface water collected from Singanallur lake during the study period for monsoon, winter, and summer are depicted in Table 1. Calcium and magnesium levels varied from 18 mg/l to 72 mg/l and from 11.8 mg/l to 29 mg/l, respectively, with the highest concentrations recorded during the summer. Chloride concentrations ranged from 237 to 502 mg/l, showing elevated levels during the monsoon, likely due to increased municipal waste accumulation, as also noted by Chaturvedi and Pandey (2006). Chloride levels in the lake exceeded the permissible limits set by WHO (2011). Additionally, fluoride concentrations ranged between 0.55 mg/l and 1 mg/l. The sulphate and nitrate concentrations ranged from 68.8 mg/l to 89.2 mg/l and 26.8 mg/l to 54 mg/l, respectively. Nitrate concentrations slightly exceed the recommend limit of (45 mg/l).

Metal Concentration in the Surface Water and Pollution Load Index

The heavy metals considered in this study contribute greatly to the contamination of lake water. Among the metals analyzed, copper was found to be the most prevalent at a concentration of 39.4 µg/ml. This was followed by iron at 36.7 µg/ml, chromium at 20.6 µg/ml, and lead at 18.2 µg/ml. Cadmium was found to have the lowest concentration at 0.88 µg/ml (Figure 2). High concentration of metals are attributed to both natural and anthropogenic sources (Fang *et al.* 2021). Industrial activities at vicinity such as mining, metal processing, and the use of heavy metal containing products contribute significantly to metal discharges (Tomlinson *et al*., 1980). Additionally, agricultural practices involving metal-based pesticides and fertilizers also contribute to heavy metals pollution in the environment (Briffa *et al.,* 2020). Urban run off and wastewater discharge into the lake potentially sinks the metals into precious water body reducing ecosystem health. Moreover, the present study observed that over the study period, an increase in the Pollution Load Index (PLI). Specifically, by 2009, the PLI was recorded at 4.5, and by 2011, it had risen to 8.43. Kruskal-Wallis test indicated strong statistical significance ($P<0.05$).

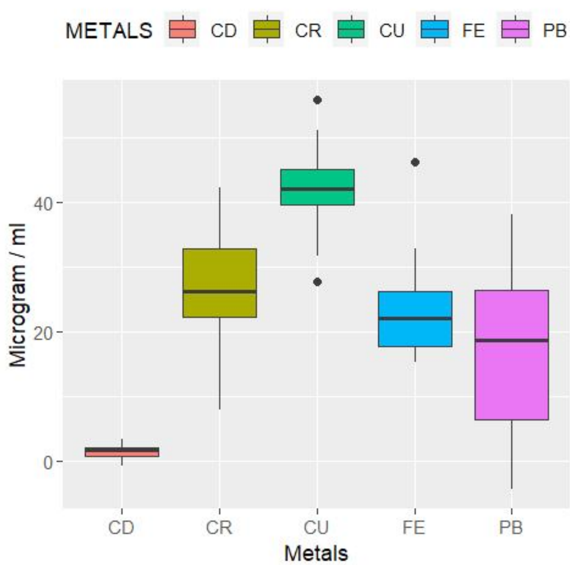

Fig. 2. Heavy metal concentration of the surface water during the study period collected from Singanallur lake

Spearman Correlation between Physico-chemical Parameters and Heavy Metal Levels of the Surface Water

Correlation analysis indicated a very strong negative correlation between water pH and the concentration of heavy metals. This suggests that as the pH of the water decreases, the levels of heavy metals increase. This relationship underscores the importance of monitoring pH levels as a potential indicator of heavy metal pollution in aquatic environments (Figure 3). Moreover, the inverse relationship between water pH and heavy metal concentrations can be explained by the chemistry of metals in aquatic environments. When the pH of water decreases, it becomes more acidic. This increased acidity can cause the dissolution of metal compounds, which are otherwise less soluble at higher pH levels (Ayejoto and Egbueri, 2024). As a result, metals that were previously bound to sediments or present as insoluble compounds become more mobile and bioavailable in the water column causing further damage to the aquatic environment (Czerwiñska *et al.* 2024). Recently, nanotechnology has given a cost-effective solution to remove heavy metal ions from polluted water bodies (Liu *et al*., 2019).

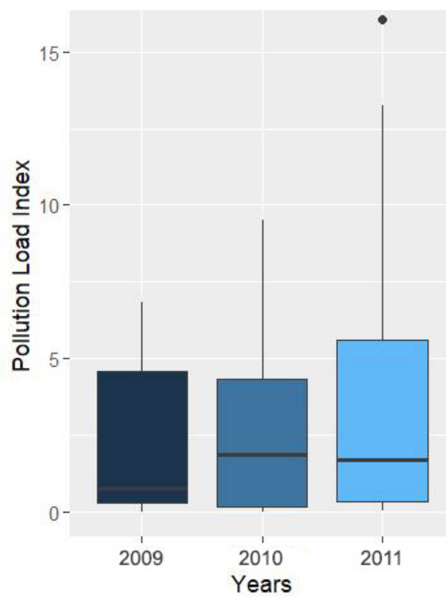

Fig. 3. Pollution Load Index of the surface water during the study period collected from Singanallur lake

Effects of Pollution Load Index of the Surface Water on the Bird Population

Stepwise linear regression analysis indicates a significant inverse relationship between the bird population and the PLI of the lake. The R value ($R = -0.87$) demonstrates a strong negative relationship, suggesting that as the PLI increases, the bird population correspondingly decreases. This significant inverse relationship highlights the detrimental impact of pollution on avian species in aquatic environments (Figure 4 and Table 2). An increased PLI adversely affects the habitat and food resources for birds (Sharma *et al.* 2024). A high PLI can alter the physical and chemical properties of the water and surrounding environment, making it incompatible for nesting, feeding, and breeding. Habitat loss and degradation are also the major factors contributing to the decline in bird also the populations (Gillings *et al.,* 2024).

Moreover, high pollution affects the abundance and health of aquatic organisms, such as fish and invertebrates, which serve as primary food sources for many bird species. Contaminants can cause bioaccumulation and biomagnification, leading to toxic effects in prey species and reducing their availability and quality as food for birds (Manjula *et al.,* 2015). Birds are also directly exposed to pollutants through ingestion of contaminated water, sediments, and prey. Heavy metals like lead, mercury, and cadmium are particularly toxic and can cause neurological, reproductive, and physiological damage in birds, leading to increased mortality and reduced population sizes (Menon *et al.,* 2023). Several studies indicate that heavy metals affect 19% of the physiological activities in bird communities. This impact is compounded by other pollutants, including pesticides, oil, noise, light, plastic, air pollution, and both pharmaceutical and radioactive contaminants (Ceballos *et al.,* 2017, Garcýa-Fernández, 2014; Tartu *et al.,* 2013). Toxic metals threaten the wetlands habitats and various species of fauna and flora, depending on the wetlands (Sun *et al.,* 2023). Further more, pollution can impact the reproductive success of birds by causing eggshell thinning, reduced hatching success, and developmental abnormalities in chicks(Fry, 1995). Elevated levels of pollutants can interfere with hormonal systems, leading to decreased fertility and survival rates of off springs (Barwisch *et al.,* 2024).

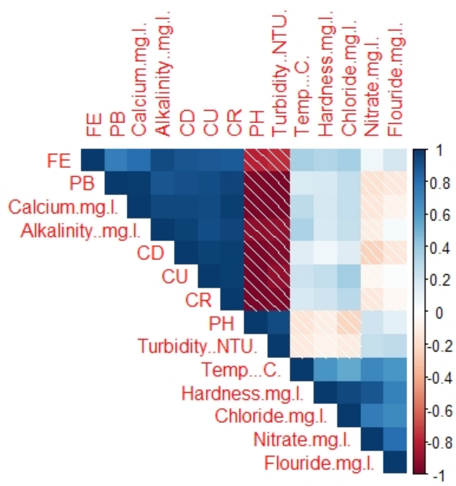

Fig. 4. Spearman correlation between physico-chemical parameters and heavy metal levels of surface water collected from Singanallur lake

Conclusion

The study reveals the potential of this urban lake to provide shelter for urban biodiversity and support in maintaining the ecosystem balance. However, all the studied factors imply an urgent need to conserve the fragile ecosystem of Singanallur Lake. Overgrowth of exotic plant species like water hyacinth threatens lake's biodiversity, especially the bird populations. This highlights the urgency for adopting sustainable wetland management strategies to conserve this ecosystem. Conserving Singanallur lake and protecting its water quality are crucial to ensure the continued harmony and sustainability of this rich and diverse urban ecosystem, safeguarding its nature and functionality for the benefit of both present and future generations. Nanotechnology has the potential to enhance water treatment beyond the traditional water treatment method. As mentioned by Zhang *et al*. (2016), Qu *et al*. (2013) and Fry (1995), nanomaterials such as zinc oxide (ZnO) due to their small size, offer a larger surface area, which improves contact with water. They also feature high reactivity, fast kinetics, and specificity for contaminants. Additionally, the cost of nanomaterials is decreasing, making them a more viable option.

Table 2. Stepwise linear regression model testing the effects of Pollution Load Index of the surface water on the bird population during the study period at Singanallur lake

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	48.742184	0.604034	80.69	<2e-16 ***
Bird Population	-0.403698	0.008914	-45.29	<2e-16 ***

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.213 on 58 degrees of freedom Multiple R-squared: 0.9725, Adjusted R-squared: 0.872 ; F-statistic: 2051 on 1 and 58 DF, p-value: < 2.2e-16

Acknowledgement

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Conflicts of Interest

The authors declare that there is no conflict of interest.

References

Albert, J.S., Destouni, G., Duke-Sylvester, S.M., Magurran, A.E., Oberdorff, T., Reis, R.E., Winemiller, K.O. and Ripple, W.J. 2020. Scientists' warning to humanity on the freshwater biodiversity crisis. *Ambio*. 50(1): 85-94. DOI: 10.1007/s13280-020-01318-8

Ali, S. 2002. *The Book of Indian Birds*. 13th Revised Edition, Oxford University Press, New Delhi, India.

Anonymous, 1972. *The Indian Wildlife (Protection) Act*. Ministry of Environment and Forests, Government of India, New Delhi.

APHA. (21sted.). Washington, D.C. 2005

Ayejoto, D.A. and Egbueri, J.C. 2024. Human health risk assessment of nitrate and heavy metals in urban groundwater in Southeast Nigeria. *Ecological Frontiers*. 44(1): 60-72.

Azeez, P. A., Nr Nadarajan and Mittel, D.D. 2000. The impact of a monsoonal wetland on ground water chemistry. *Pollution Research*. 19(2): 249-255.

B.I.S. (Bureau of Indian Standards drinking water specification). 2003. 2nd revision, IS 10500.

Barwisch, I., Mewes, W., Schmitz Ornés, A. and Guenther, S. 2024. Heavy metal residues in eggshells of Common Cranes (Grus grus) nesting in an agricultural region in north-eastern Germany. *Journal of Ornithology*. 165(2): 507-520.

Birk, S., Chapman, D., Carvalho, L., Spears, B.M., Andersen, H.E. and Argillier, C. 2020. Impacts of multiple stressors on freshwater biota across spatial scales and ecosystems. *Nat. Ecol.*4, 1060–1068.

Briffa, J., Sinagra, E. and Blundell, R. 2020. Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*. 6(9): e04691 https://doi.org/10.1016/j.heliyon.2020.e04691

Bruggen, V.D.B. and Vandercasteele, C. 2003. Removal of pollutants from surface water and groundwater by nanofiltration: Overview of the possible applications in the drinking water industry. *Environmental Pollution*. 22: 435- 445.

Ceballos, G., Ehrlich, P.R. and Dirzo, R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proc. Natl. Acad. Sci.* USA.114, E6089-E6096.

Chandra, R., Nishadh, K.A. and Azeez, P.A. 2010. Monitoring water quality of Coimbatore wetlands, Tamil Nadu, India, *Environ. Monit. Assess*. 167: 671-676

Chaturvedi, J. and Pandey N.K. 2006. Physico-chemical analysis of river Ganga at Vindhyachal Ghat. *Curr. World. Environ.* 1: 177-179 DOI:http://dx.doi.org/10.12944/CWE.1.2.14

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B. and Van Den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature*. 387(6630): 253-260.

Czerwiñska, K., Wieroñska-Wiœniewska, F., Bytnar, K., Mikusiñska, J., Œliz, M. and Wilk, M. 2024. The effect of an acidic environment during the hydrothermal carbonization of sewage sludge on solid and liquid products: The fate of heavy metals, phosphorus and other compounds. *Journal of Environ Managt*. 365, 121637.

Efaq, Ali Noman, Adel Al-Gheethi, Mohammed Al-Sahari, Radin Maya Saphira Radin Mohamed, Rich Crane, Nur Adila Ab Aziz and Muthusamy Govarthanan, 2022. Challenges and opportunities in the application of bioinspired engineered nanomaterials for the recovery of metal ions from mining industry wastewater, *Chemospher*. 308(1)

Fang, T., Jiang, T., Yang, K., Li, J., Liang, Y. and Zhao, X. 2021. Biomonitoring of heavy metal contamination with roadside trees from metropolitan area of Hefei, China. *Environmental Monitoring and Assessment*. 193(3). https://doi.org/10.1007/s10661-021-08926-1.

Fry, D.M. 1995. Reproductive effects in birds exposed to pesticides and industrial chemicals. *Environmental Health Perspectives.* 103 (7): 165- 171.

Garcýa-Fernández, A.J. 2014. Ecotoxicology, Avian. *Encycl. Toxicol.* 2: 289-294.

Gillings, M.M., Ton, R., Harris, T., Taylor, M.P. and Griffith, S.C. 2024. Blood lead increases and haemoglobin decreases in urban birds along a soil contamination gradient in a mining city. *Environmental Research*. 257, 119236.

Grimmet R., Inskipp C. and Inskipp, T. 2011. *Birds of the Indian Subcontinent* (Second Edition), Oxford University Press, New Delhi, India.

Iqbal, J., Shah, M. H. and Akhter, G. 2013. Characterization, source apportionment and health risk assessment of trace metals in freshwater Rawal Lake, Pakistan, *J. Geochem. Explor.* 125: 94-101.

IUCN, 2007. IUCN Red List of Threatened Species. Retrieved December 01, 2023 from https://www.iucnredlist.org/

Kaur, S., Kler, T.K. and Javed, M. 2018. Abundance and Diversity of Water Bird Assemblages in Relation to Village Ponds in Punjab. *J. Entomol. Zool. Stud.* 6: 1375-1380.

Kushlan, J.A. 1992. Population biology and conservation of colonial waterbirds. *Colonial Waterbirds.*15; 1-7.
Liu, L., Luo, X., Ding, L. and Luo, S. 2019. *4-Application of nanotechnology in the removal of heavy metal from water, Nanomaterials for the removal of pollutants and resource reutilization*, Chapter. 4: 83-147. https://doi.org/10.1016/B978-0-12-814837-2.00004-4.
Manjula, M., Mohanraj, R. and Devi, M.P. 2015. Biomonitoring of heavy metals in feathers of eleven common bird species in urban and rural environments of Tiruchirappalli, India. *Environmental Monitoring and Assessment*. 187(5): 1-10. https://doi.org/10.1007/s10661-015-4502-x
Menon, M., Mohanraj, R., V.B.J. and Prasath, R.V.A. 2023. Bioaccumulation of heavy metals in a gastropod species at the Kole wetland agroecosystem, a Ramsar site. *Journal of Environmental Management*. 329 https://doi.org/10.1016/j.jenvman.2022.117027
Mitsch, W. J. and Gosselink, J. G. 2015. *Wetlands*. 5th edition, John Wiley & Sons, New York. USA.
Mohanraj, R., Sathishkumar, M., Azeez, P.A. and Sivakumar, R. 2000. Pollution status of wetlands in urban Coimbatore, Tamil Nadu, India, *Bull. Environ. Contam. Tox*. 64(5): 638-643.
Nowack, B. and Bucheli, T.D. 2007. Occurrence behaviour and effects of nanoparticles in the environment. *Environmental Pollution.* 150: 5-22.
Praveen, J., Jayapal, R. and Pittie, A. 2016. A checklist of the birds of India. *Indian Birds.* 11(5 and 6): 113-172.
Qu, X., Alvarez, P.J.J. and Li, Q. 2013. Applications of nanotechnology in water and wastewater treatment. *Water Research*. England. 47 (12): 3931-3946.
Radhakrishanan, R., Dharmaraj, K. and Renjithakumari, B. D.J. 2007. *Environ. Biol.* 28: 105-108.
Rahman, M.S., Saha, N. and Molla, A.H. 2013. *Environ. Earth. Sci*. 12665, 013-2631-5 21.
Ratnam, K. 2004. *Birds of Tamilnadu*, 1st Ed. Manivasagar Pathippagam, Chennai.
Reginald, L.J., Mahendran, C., Kumar, S.S. and Pramod, P. 2007. Birds of Singanallur Lake, Coimbatore, Tamil Nadu. *Zoos' Print Journal*. 22(12): 2944–2948.
Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A. and Johnson, P.T. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol. Rev.* 94: 849–873.
Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, R., Bloomfield, J., Dirzo, R., Huber Sanwald, E., Huenneke , L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. and Wall, D.H. 2000. Global biodiversity scenarios for the year 2100. *Sci*. 287: 1770-1774.
Sharma, M., Kant, R., Sharma, A.K. and Sharma, A.K. 2024. Exploring the impact of heavy metals toxicity in the aquatic ecosystem. *International Journal of Energy and Water Resources*. 1-14.
Smardon, R.C. 2009. *Sustaining the Worlds Wetlands: Setting Policy and Resolving Conflicts*. Springer, New York, USA.
Sun, F.; Yu, G.; Han, X.; Chi, Z.; Lang, Y. and Liu, C. 2023. Risk assessment and binding mechanisms of potentially toxic metals in sediments from different water levels in a coastal wetland. *J. Environ. Sci.* 129: 202-212.
Sunkad, B.N. and Patil, H.S. 2004. Water quality assessment of Fort lake of Belgaum (Karnataka) with special reference to zooplankton, *J. Environ Biol.* 25(1): 99-102.
Tartu, S., Goutte, A., Bustamante, P., Angelier, F., Moe, B., Clément-Chastel, C. and Chastel, O. 2013. To breed or not to breed: Endocrine response to mercury contamination by an Arctic seabird. *Biol. Lett.* 9: 20130317.
Tiwari, D.K., Behari, J. and Sen, P. 2008. Applications of nanoparticles in wastewater treatment, *World Applied Sciences Journal.* 3(3): 417-433.
Tomlinson, D. L., Wilson, J. G., Harris, C. R. and Jeffrey, D. W. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen*. 33(1–4): 566-575 https://doi.org/10.1007/BF02414780
Villamagna, A.M., Murphy, B.R. and Karpanty, S.M. 2012. Community-Level Waterbird Responses to Water Hyacinth (*Eichhornia crassipes*). *Invasive Plant Sci. Manag.* 5: 353-362.
Virha R., Biswas A.K., Kakaria V.K., Qureshi T.A., Borana K. and Malik, N. 2011. *Bull. Environ. Contam. Toxicol*. 86, 168-174.
Wetzel, R.G. 1992.Clean water: a failing resource. *Hydrobiologia.* 243(1): 21-30.
WHO. 2011. *World Health Organisation*. Geneva, 17.
Withaningsih, S., Parikesit, P., Iskandar, J. and Megantara, E. 2017. Breeding behavior of different raptor species in human modified landscape. *Biodiversitas Journal of Biological Diversity*. 18(3): 1234-1242.
Zhang, Y., Wu, B., Xu, H., Liu, H., Wang, M., He, Y. and Pan, B. 2016. Nanomaterials-enabled water and wastewater treatment. *Nano Impact*. 3: 22-39.