Evaluation of water quality using water quality index (WQI) and GIS in Beira Lake, Sri Lanka

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Abstract: **The impact of anthropogenic disturbances on urban lakes can be significant due to their size, depth, and stagnancy. Increased population, urbanization, and modernization are causing sewage disposal issues and contamination of surface waters bodies. The study established three goals to determine the current state of selected physio-chemical parameters in Beira lake's surface and deep water. Creating a map to demonstrate the distribution of water quality parameters identifies the correlation between water quality parameters and calculatesthe water quality index. The interpolation map for each parameter was created using the inverse distance weighted (IDW) interpolation method. The weighted arithmetic water quality index approach calculates the water quality index of the Beira lake's surfaces and deep water. Pearson linear correlation shows the relationship between water quality parameters, including temperature, salinity, pH, electrical conductivity, total dissolved solids, phosphate, nitrate, nitrite, and ammonia. According to the weighted arithmetic WQI technique, it can say that the quality of Beira lake is unfit for drinking and irrigation. It is incredibly polluted and receives an "E" rating. The findings reveal a strong positive relationship between electrical conductivity and salinity and TDS with salinity and electrical conductivity. It can be concluded that Beira lake is in terrible condition and that water treatment will be costly. As a result, immediate action is compulsory to prevent the inflow of contaminated water and restore the lake's overall water quality.**

Keywords: **Beira lake, IDW, weighted arithmetic water quality index, Pearson linear correlation**

I. INTRODUCTION

Water quality is a controversial issue in developing countries. Standard water quality is essential to human health, plants, and aquatic life. Only a tiny fraction of the area is dominated by lakes and ponds, known as freshwater[1]. The ponds and lakes are a substantial wealth of the nation, providing water for both agriculture and drinking[2]. Surface water quality is a sensitive and crucial problem in many countries since it is an integral aspect of the natural ecosystem[3].

Furthermore, as individuals become aware of the relevance of drinking water quality to public health thus, there is a greater need to analyze surface water quality.The quality of a region's surface water is mainly affected by natural processes like weathering and soil erosion and artificial contributions such as municipal and industrial wastewater discharge[4]. Human activities are a significant factor determining the surface and groundwater quality through the pollution of the atmosphere, degraded soils, effluent discharges, agricultural chemicals, and land use within the water basin[5].Lakes are prosperous ecosystem services providers on the earth's surface[6]. Lakes are used for various reasons, including industrial activity, transportation, drinking purposes, irrigation, recreation, and aquaculture[7].

The lake can be separated into four distinct zones. As the littoral zone, limnetic zone, profundal zone, and benthic zone. The littoral zone is the coast, which contains rooted aquatic plants and a variety of other aquatic creatures. The limnetic zone is the open portion of the lake. The profundal zone is the deeper water part that Fish adapted to the more remarkable, darker water, and lower levels of dissolved oxygen lives in this zone. Finally,the benthic zone is the deepest part of the lake with decomposes such as fungi,bacteria, and sediments[8].

Lake can be categorized into four based on its nutrient component. Those are oligotrophic with high water quality with clear water and low algal production. Mesotrophic is clear water with a medium level of nutrients which is known as the lake with excessive nutrients that dominate by algae bloom of aquatic plant growth. Eutrophic and hypereutrophic is highly nutrient water with excessive algae bloom with low transparency[9].

Lakes in cities are essential sources of freshwater. Sri Lanka has a large number of natural and manufactured lakes. These lakes are significant in terms of environmental, social, and economic value[10]. Because of unplanned urbanization, urban lakes face substantial difficulties. The impact of anthropogenic disturbances on these lakes can be significant due to their size, depth, and stagnancy[11]. The Beira lake is located in the heart of Colombo, Sri Lanka. East lake, South lake, South West lake, and Galle Face lake are the four basins that make up the reservoir (Fig. 1)[12].

The Portuguese built the lake as a means of defense against the country's kings[13]. The lake's original size was 1.65km^2. However, it has now shrunk to 0.65km^2 due to urban expansion. The average depth of the lake is 2m. It was used as an accessible transit corridor for goods and services within the city and suburbs during the Portuguese and Dutch colonial times.It currently has a densely inhabited watershed with hotels, industries, and colonies, as well as it has become a much-polluted lake. It was identified as one of the principal

wastewater receiving water bodies in the Colombo municipal council region, with wastewater discharged directly or indirectly into the lake[14].

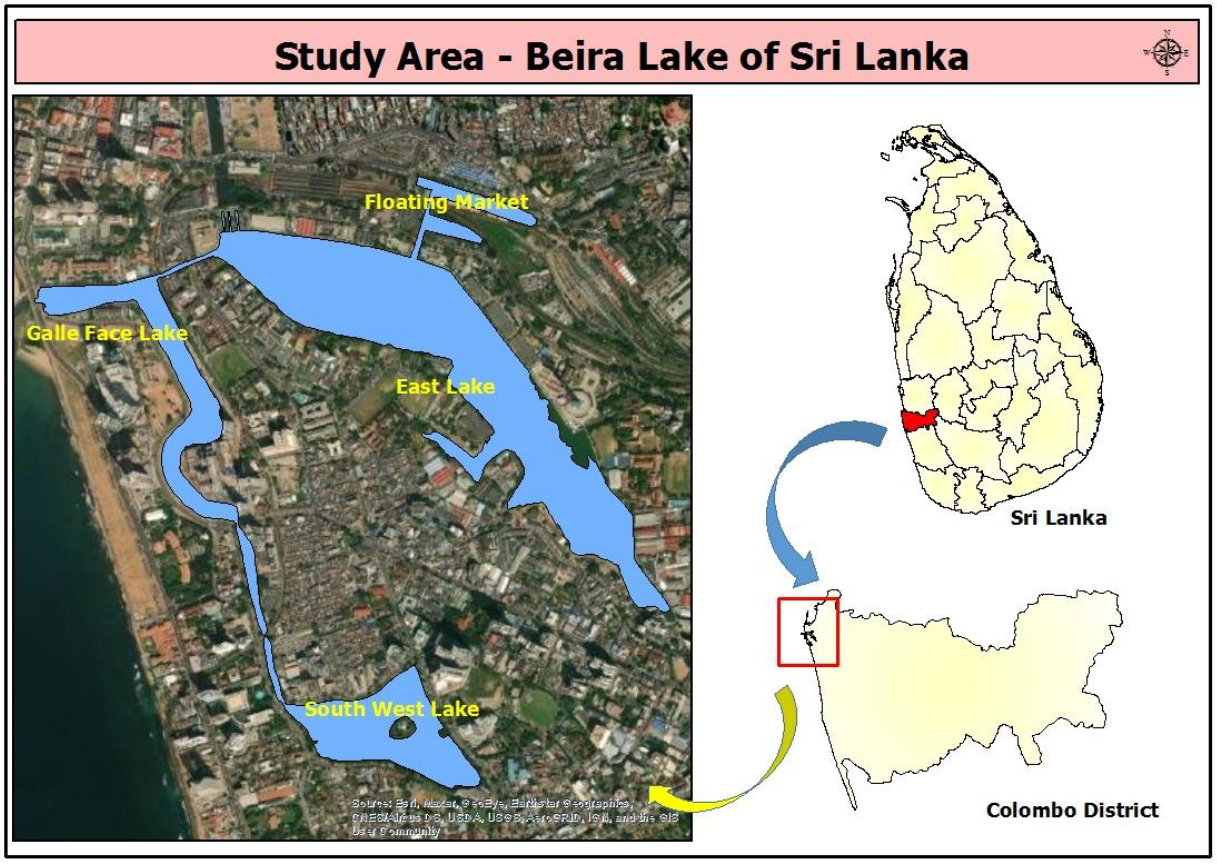

Fig.1. The location of Beira Lake

Although some studies on Beira lake have been undertaken in the past, the lake is currently affected by a hypereutrophic state due to anthropogenic activity and urbanization. Thus, this research is essential for the region. Three goals were established as a result of the study. They were determining the current state of selected physicochemical parameters in the surface and deep water of Beira lake and creating a map to demonstrate the distribution of water quality parameters, identifying the link between water quality parameters, and analyzing the water quality of Beira lake.

II. METHODOLOGY

A. Sample Collection

Water samples were taken at 39 (the longitude and lattitude points were shown in Table S1.) different locations around Beira lake, including the floating market, the east lake, the southwest lake, and the Galle face lake. The locations are shown in Fig. 2. The sample was taken from both the surface and deep waters of Beira lake.Surface water was directly filled with the container. The LaMotte water sampling bottle was used to collect the deepwater sample. It was the gadget used to collect water samples at 1.5m depth in the Beira lake. The attached stopper, calibrated line, and weight were used to take the sample at precise depths. The bottle is sent to the deep, and when the trip line is pulled, the sample collection bottle begins to fill. During the retrieval process, lowering water pressure prevents air and water interaction with the sample. For reliable sample temperature readings, the inside chamber also holds a LaMotte model 545 Armored Thermometer.Handheld water quality meter and laboratory analysis method were usedfor data generation (Detailed analysis methods areattached in the supplementary document). A sterile 250 mL Schott bottle was used to collect the sample.The material was kept at 4°C until it was used for analysis. Temperature, salinity, pH, electrical conductivity, total dissolved solids (TDS), nitrite concentration (NO_2^-), nitrate concentration (NO_3^-), phosphate concentration (PO_4^{3-}), and ammonia concentration (NH_4^+) are water quality parameters used to calculate the water quality in Beira lake[15]

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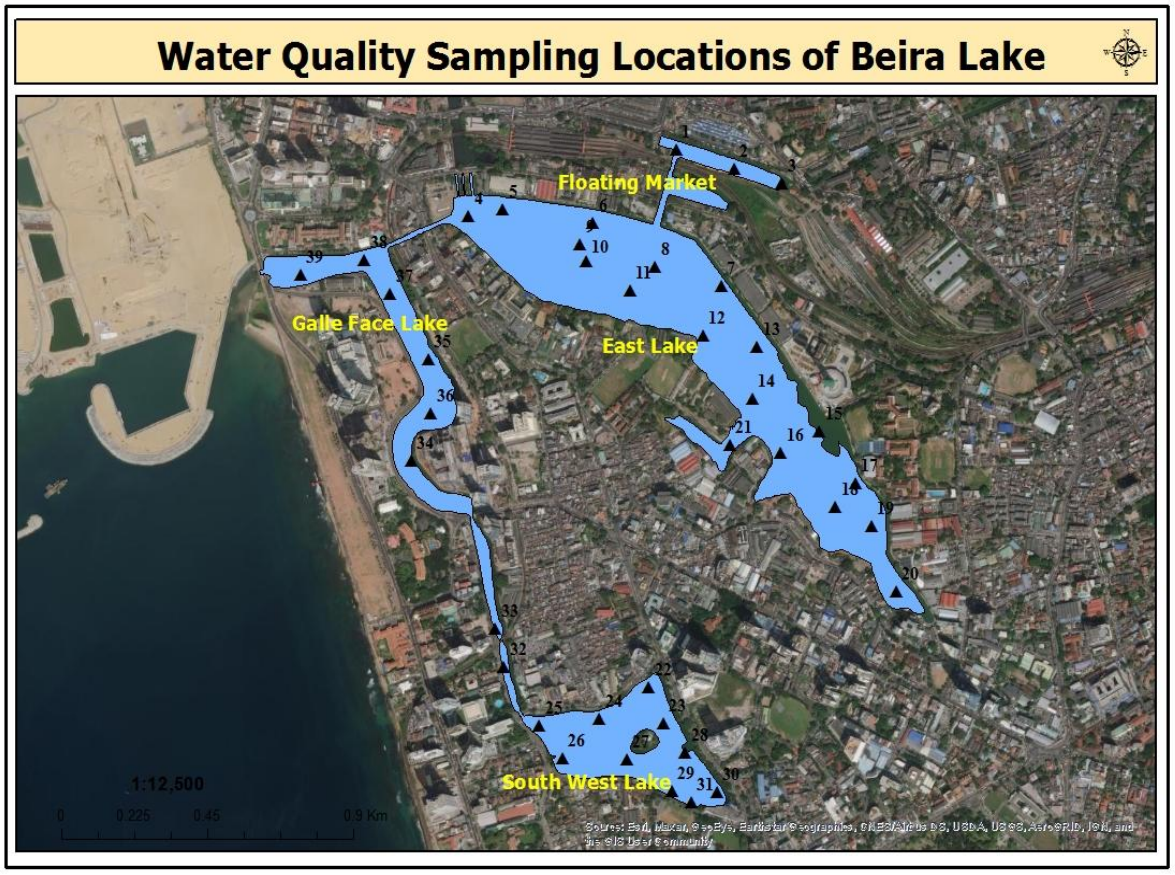


Fig.2. Water sample collected points of the Beira lake

B. Analysis

Geography information system, the weighted arithmetic water quality index method, and Pearson linear correlation method are the three analytical methods used to perform water quality analysis.

1. Geography information system (GIS): The maps of water quality for seven metrics within the Beira lake were created using ArcGIS 10.5 software[16], [17]. The interpolation map for each parameter was created using the inverse distance weighted (IDW) interpolation method[18]. The shapefile maps of the Beira lake boundary were used to interpolate in GIS software. The IDW approach is based on an accurate local deterministic interpolation methodology.

2. The weighted arithmetic water quality index method: The water quality index was applied in this research to determine the standard level of water quality in Beira lake. The analysis was carried out using the weighted arithmetic water quality index approach. It was determined using the criteria of the central environmental authority of Sri Lanka[19].

The data analysis process was broken down into three steps, as listed below:

Step 1: Using the algorithm below, calculate the unity weight (Wn) factors for each parameter

$$Wn = \frac{K}{S_n} \qquad (1)$$

WhereK denotes the proportionality constant; Sn is the desirable standard value for the nth parameter based on all specified parameters unit weight factors Wn= 1 (unity).

Step 2: Using the formula below, calculate the sub-index (Qn).

$$Qn = \frac{[(Vn - Vo)]}{[(Sn - Vo)]} \times 100 \qquad (2)$$

Where,Vnis the nth parameter's mean concentration; Sn is the nth parameter's standard desired value; Vo is the actual values of the parametersin the pure water (most water parameters have a zero value. However, exceptionally, the pH value is 7.0 and the DO value is 14.6 mg/L)

Step 3: WQI is calculated by adding steps 1 and 2 together.

$$\text{Overall WQI} = \frac{\Sigma\, Wn\ Qn}{\Sigma\, Wn} \qquad (3)$$

According to the arithmetic water quality index, water can be divided into excellent water quality, good water quality, poor water quality, very poor water quality, and Unsuitable for drinking purposes. The quality of the water, grading, and the corresponding values are tabulated in Table I[19].

Table I: The weighted Arithmetic Water Quality Index Approach for rating water Quality

WQI value	Rating of W Quality	Grading
0-25	Excellent water Quality	A
26-50	Good Water Quality	B
51-75	Poor Water Quality	C
76-100	Very Poor Water Quality	D
Above 100	Unsuitable for drinking purpose	E

3. Pearson linear correlation: Correlation coefficient used to show the relationship between water quality parameters includes temperature, salinity, pH, electrical conductivity,total dissolved solids, phosphate, nitrate, nitrite, and ammonia. Pearson linear correlation was used for the analysis[20]. The equation for the calculationis mentioned as below,

$$r = \frac{\Sigma(x_i - \bar{x})\,(y_i - \bar{y})}{\sqrt{\Sigma\,(x_i - \bar{x})^2\,\Sigma\,(y_i - \bar{y})^2}} \qquad (4)$$

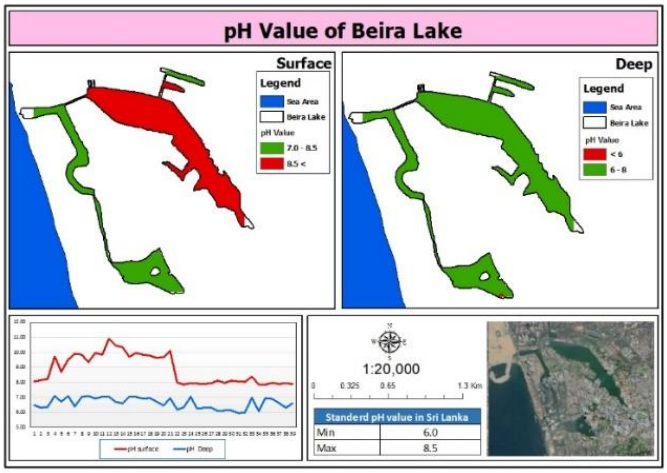
Where **r** is correlation coefficient; x_i is the value of the x-variable in a sample; $\bar{x}$ is mean of the values of the x-variable; y_i is values of the y-variable in a sample; $\bar{y}$ is mean of the values of the y-variable.

The result will show the value between -1 and 1, 1 shows a solid positive relationship, and -1 shows a solid negative relationship, and 0 indicates no relationship between the values.

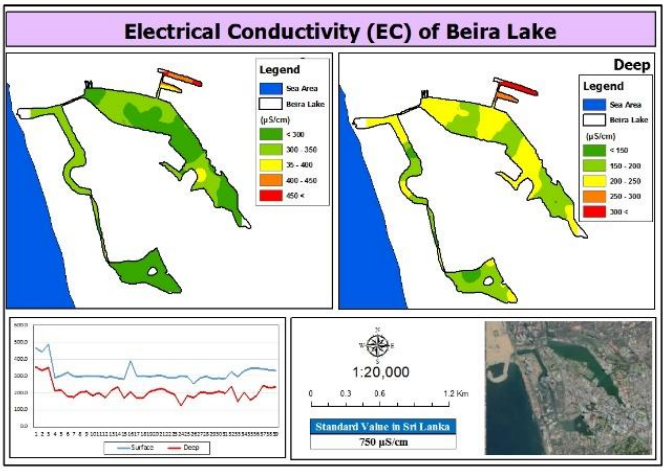
III. Result and Discussion

A. Map Analysis

The interpolation map was used to show the distribution of physio-chemical properties of the Beira lake. The water quality parameters pH, electrical conductivity, ammonia, nitrate, nitrite, phosphate, and total dissolved solids were analyzed in both deep and surface water.



(a)



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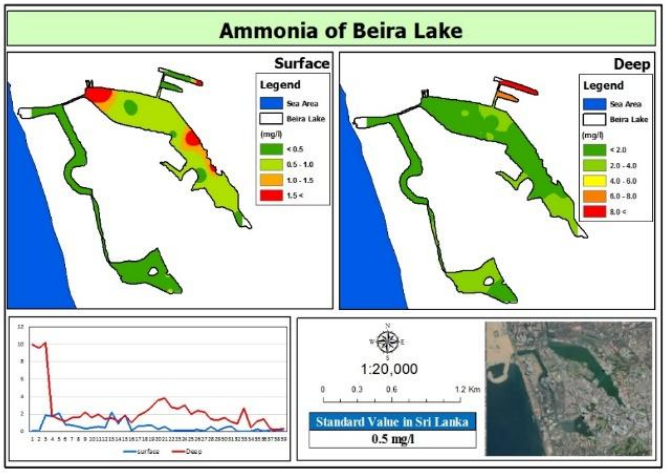

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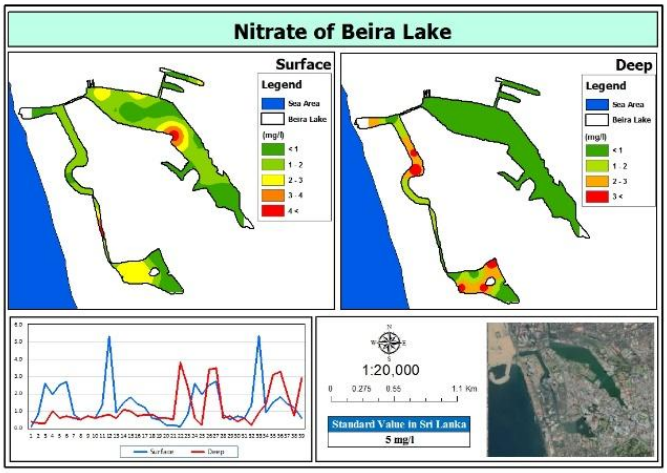

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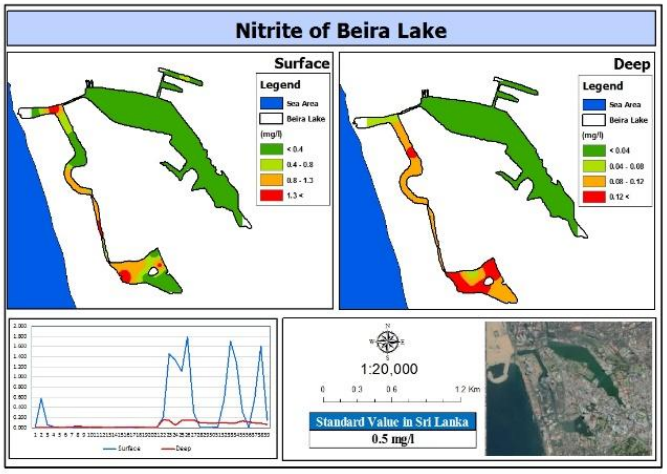

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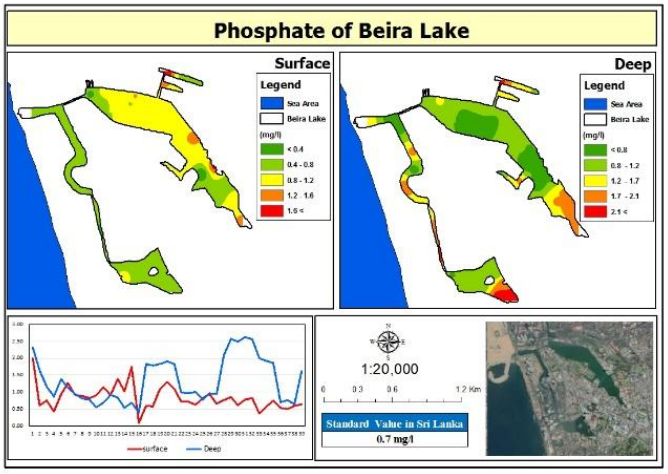

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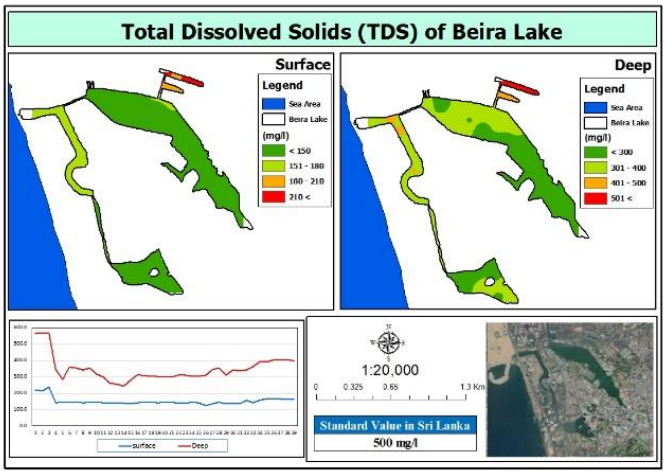

(g)

Fig. 3. The variations of physio-chemical parameters in both surface and deep of the Beira lake.(a) pH, (b) electrical conductivity, (c) ammonia concentration,(d) nitrate concentration,(e) nitrite concentration,(f)phosphate concentration,(g) total dissolved solids.

1. pH value: The pH of the water is the most important factor in determining the acidity of the water. The acidity of the water increases as the pH value decreases. The surface water pH differs from the Sri Lankan standard value (6-8.5) and is above 8.5, which increases the alkalinity of the water. Also, the pH of the deep water was within the standard range. The pH level of surface water and deep water vary. The surface water pH is 7.86 to 10.90, and the deepwater pH is 6.07 – 7.03.(Fig. 3(a)).

*2. Electrical conductivity:*Temperature, pH, calcium, total dissolved solids, chemical oxygen demand, and iron concentration of water significantly correlate with conductivity. Fortunately, the electrical conductivity of Beira lake did not increase above the standard level of Sri Lanka. Sri Lanka's standard levels of water quality parameters are shown in Table S2. It is recorded ata good level in both surface and deep water. But the range varies among the surface water and deep water. Comparatively, the electrical conductivity level of surface water is higher than in deep water. The electrical conductivity of surface water range from 256.0 uS/cm to 489.0 uS/cm, and the deepwaterelectrical conductivity range from 171.6 uS/cm to 350.0 uS/cm (Fig.3(b)).

*3. Ammonia concentration:*Ammonia in water bodies are toxic to aquatic life and non-toxic to humans. But it promotes the growth of algae[21]. Ammonia is higher than the standard level in almost all the areas in Beira lake's deep and surface water. It is lower only on the surface of South West lake of the Beira. The Ammonia level of surface water and deep water varies. The surface water Ammonia is 0.02 – 2.2, and deep water Ammonia is 0.90 – 1.60 (Fig. 3(c)).

*4. Nitrate:*Nitrate levels in surface water ranged from 0.1 to 5.4, while deepwater levels ranged from 0.4 to 0.9. The surface water of locations 12 and 33 is higher than the standard level of Sri Lanka, and the nitrate level in the rest of the Beira lake is in good condition (Fig. 3(d)).

*5. Nitrite:*As part of the nitrogen cycle, bacteria first convert ammonia to nitrite, which is converted to nitrate by other bacteria[22]. The range of the nitrite levels in the lake's surface is from 0.014 mg/l to 1.708mg/l, and deepwater from

0.006 mg/l to 0.084 mg/l, as per the laboratory analysis of nitrite levels in both surface water and deep water of Galle Face lake and the South West lake, the nitrite concentration is higher than the acceptable level of Sri Lanka's standard (0.5mg/l) (Fig. 3(e)).

*6. Phosphate:*Phosphate affects water quality by causing algae to thrive. Adding more phosphates to water causes a massive growth of algae, which can cause problems such as blocking out sunlight, preventing other photosynthetic organisms from surviving, lowering dissolved oxygen levels, reducing the beauty of the water body, and disrupting the ecosystem's normal functioning. The levels of phosphorus in the Beira lake fluctuate depending on whether the water is surface or deep. Phosphate levels in surface water ranged from 0.10 mg/l to 1.99 mg/l, with levels in the East lake and portion of the floating market lake exceeding the Sri Lankan standard (0.7 mg/l). Phosphate levels in deep water in Beira lake are higher than 0.7 mg/l across over 90% of the lake, with levels ranging from 0.40 mg/l to 2.3 mg/l (Fig.3(f)).

*7. Total dissolved solids:*Solids in a body of water can be suspended, volatile, or dissolved. Suspended solids cannot be filtered, whereas dissolved solids can. Total dissolved solids aresignificant in the treatment of water and wastewater. It is typically used to represent the number of organic solids in water. The total dissolved solids levels in Beira lake vary between surface and deep water. The surfacetotal dissolved solids are lower than the Sri Lankan standard level (500mg/l), but it is high in deep water, particularly at data collection points 1, 2, and 3, which are referred to as floating markets. The total dissolved solids level of surface water and deep water varies. The surface water total dissolved solids is 122.2 – 236.0 and deep water total dissolved solids is 309.0-566.0 (Fig.3(g)).

*8. Temperature:*Temperature is a varying parameter, and it remained in the range of 25.5 and 34°C. Uneven solar heating throughout the sample locations is the main reason for these variations.

B. Assessment of water quality using weighted arithmetic water quality index method

The study was performed to assess the quality of Beira's water for irrigation and drinking. The analysis was done using the weighted arithmetic water quality index approach. Each sampling point (39) in both surface and deep water was used for research, and the water quality parameters are pH, electrical conductivity, ammonia, nitrate, nitrite, phosphate, and total dissolved solids.The parameters and the value are shown in Table II. The complete calculation steps are shown in Table S4 and table S5.

Table II: Metrics of WQI of Beira Lake

Water Quality Parameters	Sn	Wn	Surface		Deep	
			Qn	WnQn	Qn	WnQn
pH	8.5	0.027	104.235	2.802	-30	-0.806
EC	0.7	0.326	451.428	147.345	297.143	96.987
$\mathbf{NH_4^+}$	1	0.228	53	12.109	236	53.920
NO_3^-	5	0.046	28.6	1.307	22	1.005
NO_2^-	0.5	0.457	67.6	30.890	220	100.53
PO_4^{3-}	0.7	0.326	120	39.168	185.714	60.617
TDS	500	0.001	30	0.0137	6.45	0.003

[Sn] Standard Value; [Wn] Unit Weight; [Qn] Quality Rating; [WnQn] Water Quality Index

The overall index of surface water is 233.635, and the total index of deep water is 312.256, according to the water quality index analysis.

According to the weighted arithmetic WQI technique, the water quality of Beira lakeis exceptionally polluted and receives an "E" rating. Thus the Beira lake water is unfit for drinking and irrigation. The data used for the analysis are given in Table S3.

C. Pearson linear Correlation Analysis

The Pearson linear correlation analysis was used to find the relationship of water quality parameters between Beira lake's surface water and deep water.The results obtained from Pearson linear correlation are shown in Table III. The average water quality parameter; temperature, salinity, electrical conductivity, pH, total dissolved solids, phosphate, nitrate, nitrite, and ammonia, are used to find the correlation.

Table III: pearsonlinear correlation analysis

Parameters	T	S	EC	pH	TDS	PO_4^{3-}	NO_3^-	NO_2^-	NH_4^+
T	1								
S	-0.076	1							
EC	-0.120	0.892	1						
pH	-0.053	-0.238	-0.281	1					
TDS	-0.154	0.918	0.839	-0.270	1				
PO_4^{3-}	0.108	0.129	0.087	-0.094	0.151	1			
NO_3^-	0.218	-0.155	-0.142	-0.014	-0.046	-0.205	1		
NO_2^-	0.161	-0.139	-0.167	-0.537	-0.021	-0.088	0.494	1	
NH_4^+	0.147	0.465	0.346	0.173	0.352	0.248	-0.056	-0.331	1

Strong Positive(0.5<) Positive(0.02-0.5) Neutral(+0.02 – 0.02) Negative(-0.02 - -0.5) Strong Negative(-0.5 >)

The findings reveal a strong positive correlation between electrical conductivity and salinity andtotal dissolved solids with salinity and electrical conductivity. Positive correlations are recorded asphosphate with temperature, salinity, electrical conductivity;total dissolved solids, and nitrate with temperature. Nitrite with temperature andnitrate, and ammonia with temperature, salinity, electrical conductivity, pH, total dissolved solids, and phosphate. Nitrate and pH on any correlation. There is a negative correlation between salinity and temperature, pH with temperature, salinity and electrical conductivity, total dissolved solids with temperature and pH.Phosphate with pH.Nitrate with salinity, electrical conductivity, total dissolved solids and phosphate, nitrite with Salinity electrical conductivity, total dissolved solids and phosphate, ammonia with nitrate and nitrite.A strong negative correlation is identified between nitrite and pH.

IV. Conclusion

The water quality of Beira lake, the distribution of water quality parameters, and the correlation between water quality parameters have all been evaluated in this study. It is a prominent landmark in the Colombo district. Thirty-nine sampling sites were identified, and ten water quality parameters were collected in both surface and deep water to evaluate the water quality of Beira lake. As per the weighted arithmetic WQI technique, the quality of Beira lake water is unfit for drinking and irrigation. It has an "E" rating because it is incredibly polluted. The study found a strong positive correlation between electrical conductivity and salinity, a strong negative correlation between nitrite and pH, and no correlation between nitrate and pH.

According to the analysis, the water quality of Beira lake is very poor, and the water purification method will be expensive. In addition, the quality of surface and deep water was changing. The leading cause of water quality degradation in Beira lake is waste and sewage discharge. As a result, effective preventing measures need to avoid the entry of contaminated water and improve the overall water quality of the lake are urgently required.

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