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Article

Surface water eutrophication assessment in Noakhali Sadar Upazila using the Carlson Trophic State Index

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Abstract
This study aimed to assess the trophic status and water quality characteristics of twenty ponds in Noakhali Sadar Upazila using the Carlson Trophic State Index (CTSI). Key physical-chemical parameters measured included temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO), electrical conductivity (EC), total nitrogen (TN), total phosphorus (TP), chlorophyll-a, and Secchi depth. The observed ranges for these parameters were: temperature (24÷32 °C), pH (6.7÷8.42), TDS (46÷1604 ppm), DO (4.33÷7.46 ppm), EC (91÷3208 µS cm⁻¹), TN (0.7÷5.6 mg L⁻¹), TP (1.6÷122 µg L⁻¹), chlorophyll-a (0.545÷8.250 µg L⁻¹), and Secchi depth (0.22÷1.13 m). CTSI values ranged from 38.31 to 68.38, indicating trophic conditions from oligotrophic to eutrophic, with Pond-8 approaching hypereutrophic status. Strong positive correlations were found between TDS and EC (r=1.00), TDS and Secchi depth (r=0.63), and EC and Secchi depth (r=0.63). Chlorophyll-a exhibited a positive correlation with temperature (r=0.57) and TP (r=0.52), while showing a moderate negative correlation with Secchi depth (r=–0.46). These relationships underscore the complexity of nutrient dynamics and transparency in these aquatic systems. The results highlight significant spatial variation in pond water quality and trophic status, emphasizing the need for continuous monitoring to prevent nutrient over-enrichment and ecological degradation. This study provides essential baseline data for informed water resource management and supports the implementation of sustainable practices to preserve the ecological health of pond ecosystems in the region.

Keywords: *eutrophication, Chlorophyll-a, ecological stress, TN, TP, water quality*

INTRODUCTION

Water is a basic resource required for human health, economic stability, and ecological balance. However, it faces substantial challenges globally due to pollution and nutrient enrichment, leading to deteriorating water quality in many locations [1]. Maintaining safe and clean freshwater resources is becoming more and more important due to the fast urbanization, population increase, and industrial expansion [2]. Because nutrient contamination can cause eutrophication, which is characterized by excessive algae growth, decreased dissolved oxygen (DO), and ecological instability, surface water quality is especially at danger. Along with their ecological effects, these effects also have an impact on economic pursuits including agriculture, tourism, and fishing [3, 4].

Eutrophication is induced mostly by excess nitrogen and phosphorus from different sources such as agricultural runoff and wastewater discharge. These nutrients build up and encourage algae blooms, which can obstruct sunlight, limit dissolved oxygen, and cloud the water, resulting in hypoxic "dead zones" that are inhospitable to aquatic life [5]. Since of the intricate nature of ecosystems, which essentially favor limited self-removal processes, eutrophication in lakes is especially concerning since it is characterized by substantial pollution of the water with nutrients that accumulate over time [6]. The trophic status, a crucial characteristic of aquatic environments, reveals the impact on aquatic ecosystems [7]. According to Doods and Cole [8], the trophic state is a good indicator of the biological production in these settings. Aquatic ecosystems' trophic status is determined by nutrient dynamics [9]. Many trophic status indices have been developed to evaluate these specific ecosystem variations because shifts in nutrient contents can cause changes in the community structure at a certain trophic level [10].

Carlson's Trophic State Index (CTSI) is a commonly used technique for tracking and managing eutrophication. The CTSI classifies the trophic condition of aquatic bodies by measuring characteristics like Secchi disc transparency, total phosphorus, and chlorophyll-a [11]. This method supports efficient water management techniques and enables objective monitoring of the degree of eutrophication [12]. The most appropriate and popular metric for determining the trophic state of aquatic environments is total phosphorus [13]. The reason for this is that, in aquatic environments, phosphorus is more limiting than nitrogen [14]. The concentration of chlorophyll-a, a green pigment produced by sunlight present in algae, can be a helpful indicator of the phytoplankton population's density (biomass) [15]. A contaminated water quality is indicated by a greater chlorophyll-a concentration [16]. Transparency, which is essentially affected by the algal density, is measured by the Secchi depth [17].

The Noakhali Sadar Upazila region of Bangladesh, which is well-known for its large number of ponds, is also at risk since the water bodies are essential for irrigation, fisheries, and biodiversity. These ponds are under risk of eutrophication due to rising nutrient inputs brought on by rapid urbanization, intensified agriculture, and insufficient wastewater treatment. Despite the importance of these ponds, little study has been done on trophic evaluations and nutrient-driven eutrophication in this area. Prior research mostly concentrated on seasonal fluctuations in water quality, under examining the effects of eutrophication and nutrient health. Addressing this gap is essential for evidence-based management of these water resources.

The objectives of this study were to (a) examine differences in water quality characteristics across 20 ponds in Noakhali Sadar Upazila and (b) use Carlson's Trophic State Index to determine each pond's trophic status. This study yielded crucial information for local water quality management and policy formation. It also advances our knowledge of the processes of eutrophication in tropical freshwater systems.

MATERIALS AND METHODS

Studied area

The study was carried out in Noakhali Sadar Upazila, a district in Bangladesh, which has a total area of 336.06 km² and is situated between 22'38' and 22'59' north latitude and 90'54' and 91'15' east longitude [18]. The studied area is distinguished by large inland and coastal water bodies, including a large number of ponds (Figure 1). In consequence of excessive nutrient enrichment, these water bodies which are essential for irrigation, aquaculture, and residential uses face eutrophication issues, which result in algal blooms and deteriorated water quality.

Sampling design

Twenty locations (Figure 1) were chosen for water sampling, representing both urban and rural regions of Noakhali Sadar (for example, those close to family activities, fisheries, and agricultural land). GPS coordinates of all sampling sites were recorded (Table 1). Water samples were collected over two consecutive days (6÷7 May 2024) to ensure the results were representative. Using 250 mL brown and transparent plastic bottles, surface water samples were taken 10 cm below the surface [19]. Transparent bottles were utilized for other water quality measures, while brown bottles were employed for chlorophyll-a measurement to block sunlight penetration. The plastic bottles were pre-cleaned, rinsed with distilled water before being used for sample collection, and stored in an ice box for transportation to the laboratory.

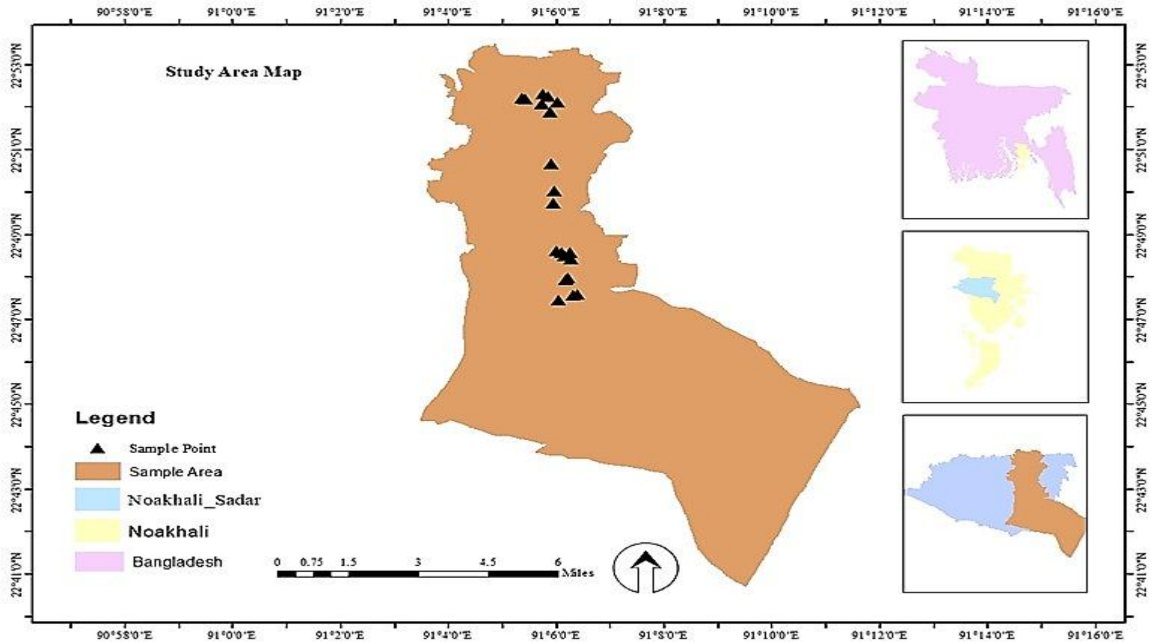

Fig. 1. Map of the study area by ArcGIS 10.8.2

Table 1. Geographic location of the sampling site

Sampling area	Latitude	Longitude	Sampling area	Latitude	Longitude
Pond-1	22.8688 N	91.1003 E	**Pond-11**	22.79325 N	91.10662 E
Pond-2	22.8710 N	91.0975 E	**Pond-12**	22.79297 N	91.10535 E
Pond-3	22.86827 N	91.0951 E	**Pond-13**	22.79933 N	91.10291 E
Pond-4	22.87043N	91.0894 E	**Pond-14**	22.79968 N	91.10371 E
Pond-5	22.87012 N	91.09042 E	**Pond-15**	22.8097 N	91.10182 E
Pond-6	22.86829 N	91.09566 E	**Pond-16**	22.81063 N	91.10025 E
Pond- 7	22.86498 N	91.09829 E	**Pond-17**	22.80995 N	91.10418 E
Pond-8	22.84462 N	91.09848 E	**Pond-18**	22.80866 N	91.10282 E
Pond-9	22.83401 N	91.09949 E	**Pond-19**	22.80722 N	91.10454 E
Pond-10	22.82934 N	91.09908 E	**Pond-20**	22.79098 N	91.10072 E

Sample processing and preservation

For chlorophyll-a (Chlo-a), measurement, water samples were filtered through cellulose nitrate filters with a pore size of 0.45 µm. The filter pads were then wrapped in aluminum foil and stored at –20 °C for preservation [20]. Samples were kept in a freezer and delivered within 48 hours to the Soil Research and Development Institute (SRDI), Noakhali, for determinations of total Phosphorus (TP) and total Nitrogen (TN).

Water quality analysis

Temperature, Secchi disk depth (SDD), pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), Chlo-a, TP, and TN were the parameters that were measured using both field and laboratory methods. Water transparency was measured using a 20 cm diameter Secchi disk(Lamotte, USA), and the average of the disappearance and reappearance depths was recorded as the SDD [11]. The temperature of each sampling site was measured using a digital water temperature thermometer, three readings were performed, and the average was recorded. pH, DO, EC, and TDS were measured five to six hours after sample collection using HI98194 multi-parameter equipment (Hanna instruments, Romania). Following the manufacturer's instructions, the multiparameter was calibrated. Chlo-a was examined with a UV-Vis spectrophotometer (Jenway 6850 UV-Vis, UK) using 90% acetone technique. Before measure absorbance at 630 nm, 664 nm, 647 nm, and 750 nm, filter pads were frozen, removed with acetone, and centrifuged [20]. The Bray and Qurtz method was used to determine TP [21]. Ammonium molybdate-ascorbic acid was used to digest the samples, and absorbance at 890 nm was determined. The Kjeldahl method, which includes digestion, distillation, and titration with 0.05 M NaOH, was used to analyze TN [22].

Calculation of trophic status index

The following formulas were used to calculate Carlson's trophic status index (CTSI) [11]:

$$TSICA = 9.81\times \ln(\text{Chlorophyll-a}) + 30.6 \quad (1)$$

$$TSISD = 60-14.41\times\ln(\text{Secchi depth}) \quad (2)$$

$$TSITP = 14.42\times\ln(\text{total Phosphorus}) + 4.15 \quad (3)$$

$$CTSI = (TSICA + TSISD + TSITP)/3 \quad (4)$$

where,

ln: natural logarithm

(CA) Chlorophyll-a, µg L-1

(SD) Secchi depth, water transparency in meters

(TP) total Phosphorus, µg L-1

TSI_{CA}, TSI_{SD}, TSI_{TP}: individual trophic state indices.

Classification of water bodies using TSI values provided by Carlson [23] is presented in table 2.

Table 2. Classification and TSI range by Carlson [23]

TSI	Trophic status	Qualities
< 30	Oligotrophic	Clean water; oxygen in the hypolimnion all year round.
30 – 40	Oligotrophic	In shallower lakes, hypolimnion can turn anoxic.
40 – 50	Mesotrophic	Water somewhat clear; summer time hypolimnetic anoxia is more likely.
50 – 60	Less Eutrophic	Possible difficulties with macrophytes and anoxic hypolimnion.
60 – 70	Eutrophic	Most common are blue-green algae, algal scums, and macrophyte issues.
70 – 80	Hypereutrophic	Light-limited production; dense algae and macrophyte growth dominate.

Data analysis

MS Excel 2013 was used to calculate the data which were obtained from the water samples analyzed. Using R Studio software, statistical analysis was done. Tables, graphs, charts, and other visual aids were used in the presentation of the results. A location map of the study area was also made using ArcGIS 10.8.2 software.

RESULT AND DISCUSSION

Variation of water temperature among sampling areas

The temperature of water body has a major impact on the metabolism of aquatic life in lakes [24]. Pond-1 through Pond-10 temperatures were generally constant, varying only slightly around 32.5°C (Figure 2). Beginning at Point-11, the temperature dropped significantly to approximately 28.0 °C, marking a clear departure from the previously stable trend. Although temperature fluctuations continued, they occurred at a noticeably reduced rate. At Pond-16, the temperature fell further to 24.0 °C, before rising again to 29.0 °C at Pond-20. Water temperature varies in response to fluctuations in air temperature. The water sample from ponds 1 to 10 was collected when the air temperature was about 36°C. However, the temperature decreased to approximately 30°C due to heavy rainfall when the sample was collected from ponds 11 to 20. The water's temperature was within the ideal range for aquatic life, between 20 and 30ºC [25]. The highest temperature was found to be 32.5°C (Pond-9) and the lowest temperature was found 24°C (Pond-16) where the temperature ranged from 25.0°C to 32.5°C (Figure 2).

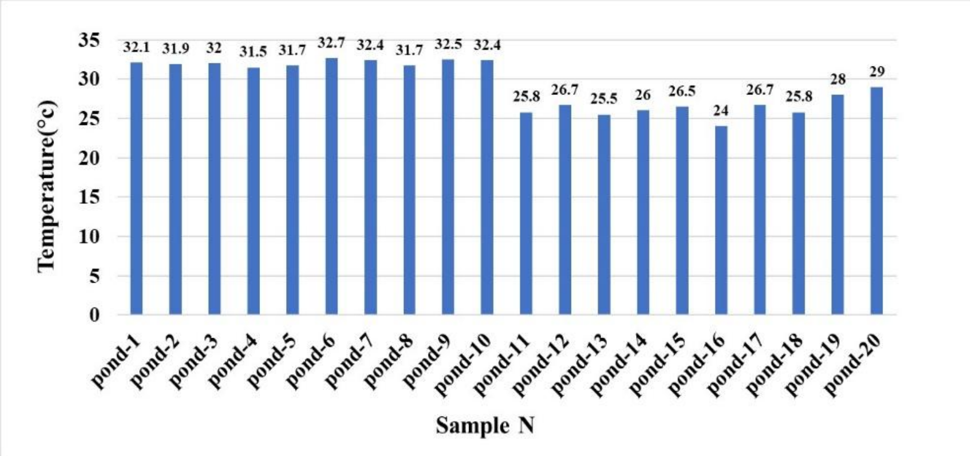

Fig. 2. Spatial variation of temperature

Variation of pH among sampling areas

The sedimentary phosphorus cycle and eutrophication are strongly influenced by the pH level of the water. Factors such as climate, geological background, and nutrient inflow also play critical roles. There is a close relationship between pH and algal growth, as algal photosynthesis affects the CO_2 buffering system, which in turn alters pH levels. While a pH of 9.5 is detrimental to algal growth, a pH of 8.5 is generally considered optimal [26]. For inland surface water, the normal pH ranges from 6.5 to 8.5 [25]. All sampling sites in this study exhibited pH values within the generally accepted range of approximately 7.0 to 8.5 (Figure 3). Ponds 1 to 3 had pH values ranging from 7.0 to 7.5, indicating neutral conditions, which are not optimal for peak algal growth. [27]. In Ponds 4 to 6, the pH increased to around 8.4, approaching the optimal range for algal growth [28], with the highest value of 8.42 observed in Pond-6. Ponds 7 to 11 exhibited pH values between 7.5 and 8.0, reflecting fairly favorable conditions for balanced phosphorus cycling and algal development. A further increase was observed in Ponds 12 to 14, particularly in Pond-13, which reached a pH of 8.14, again indicating excellent conditions for algal growth [28]. However, pH levels declined to approximately 7.0 in Ponds 15 to 17, suggesting less favorable conditions. Finally, in Ponds 18 to 20, pH was around 8.0, once more indicating moderately favorable conditions for algal growth.

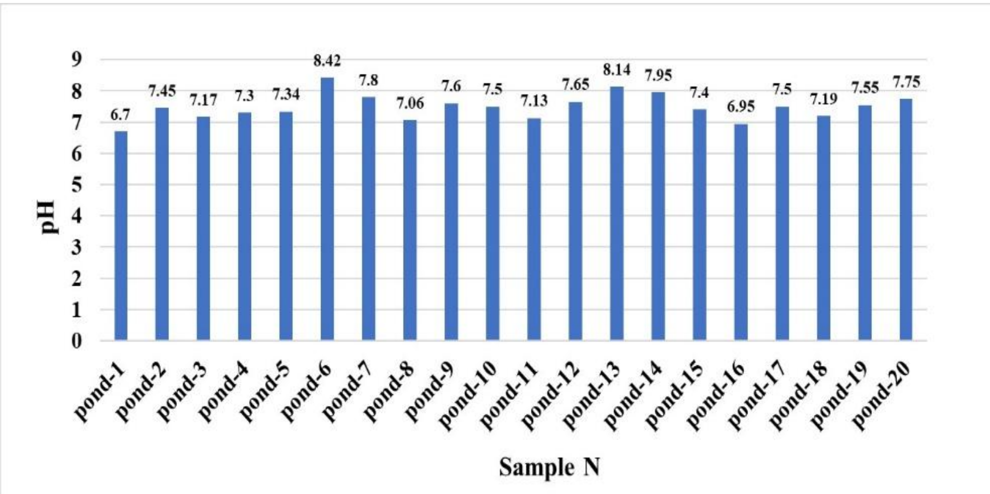

Fig. 3. Spatial variation of pH

Variation of TDS among sampling areas

For fisheries or aquatic environments, the standard TDS limit is 500 ppm [25]. TDS levels in Ponds 1 to 4 ranged from 100 to 200 ppm, indicating relatively pure water with low levels of dissolved contaminants (Figure 4). TDS levels in Ponds 5 to 7 peaked at Pond-6, reaching 566 ppm, slightly above the commonly accepted threshold of 500 ppm. In contrast, TDS values for Ponds 8 to 19 generally remained below 500 ppm, with a localized peak of 384 ppm observed in Pond-13. Notably, Pond-20 recorded a significantly elevated TDS value of 1606 ppm, which may indicate influences such as seawater intrusion [29]. Elevated TDS levels can adversely affect aquatic life, as many organisms depend on stable mineral concentrations for survival. High TDS can disrupt osmoregulation, potentially leading to dehydration in aquatic organisms due to excess dissolved salts. Additionally, increased TDS may raise water temperature, creating thermal conditions that are unsuitable for many species [19].

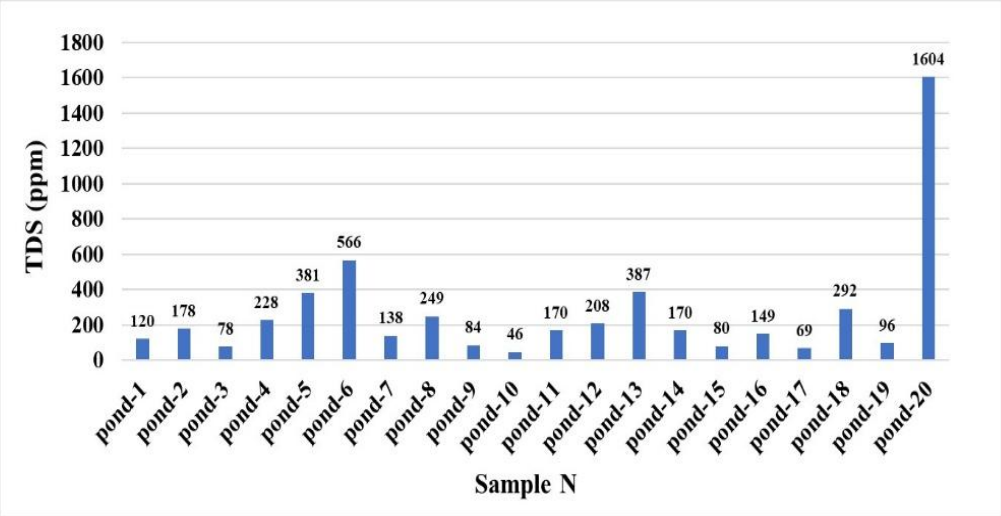

Fig. 4. Spatial variation of TDS (ppm)

Variation of DO among sampling areas

DO levels in Ponds 1 to 4 ranged from 4.33 ppm to 7.46 ppm (Figure 5). Lower DO concentrations may indicate elevated biological oxygen demand (BOD) or degraded water quality [30]. The observed increase in DO in Ponds 2 and 3 suggests either a reduced organic load or improved aeration, both of which enhance habitat conditions for aquatic life. In Ponds 7 to 11, DO levels ranged from 5.47 ppm to 6.41 ppm. Although not indicative of severe eutrophication, these moderate DO values suggest some degree of nutrient enrichment. DO is one of the most critical indicators of water quality, as it is essential for the survival of fish and other aquatic organisms. Oxygen enters surface waters through wind-induced aeration and is also produced via photosynthesis. Both processes contribute to maintaining adequate DO levels. When dissolved oxygen becomes too low, aquatic organisms may experience stress or mortality [31].

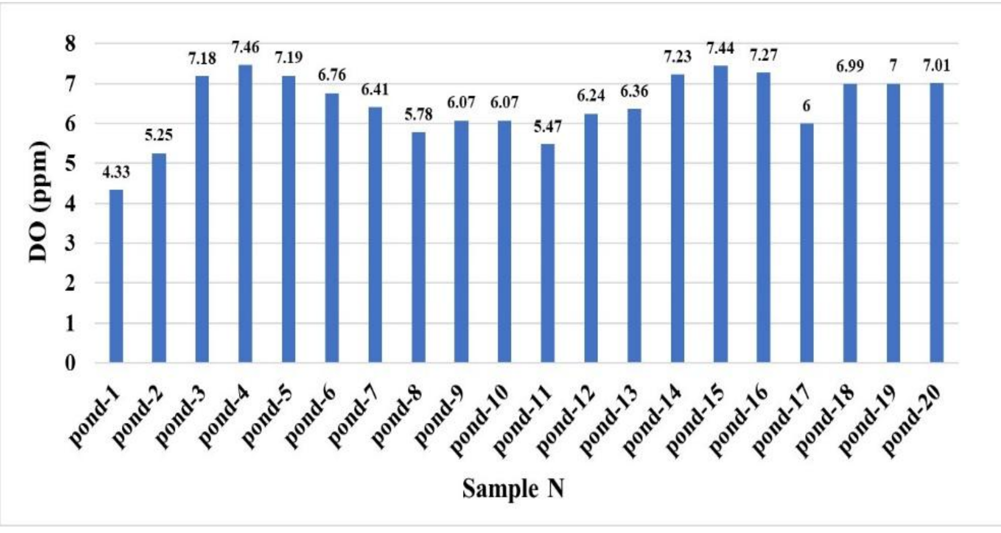

Fig. 5. Spatial variation of DO (ppm)

Variation of EC among sampling areas

In inland surface water, EC values between 800 and 1000 µS cm^{-1} are considered appropriate for aquatic environments [32]. The EC levels of the samples were considerably lower than the standard, except for Ponds 6 and 20, which had EC levels of 1132 µS cm^{-1} and 3208 µS cm^{-1}, respectively (Figure 6). A discharge or other disturbance source may be the cause of significant changes in EC, which are usually upward and indicate a degradation in the general status or condition of the water body and its biota [33].

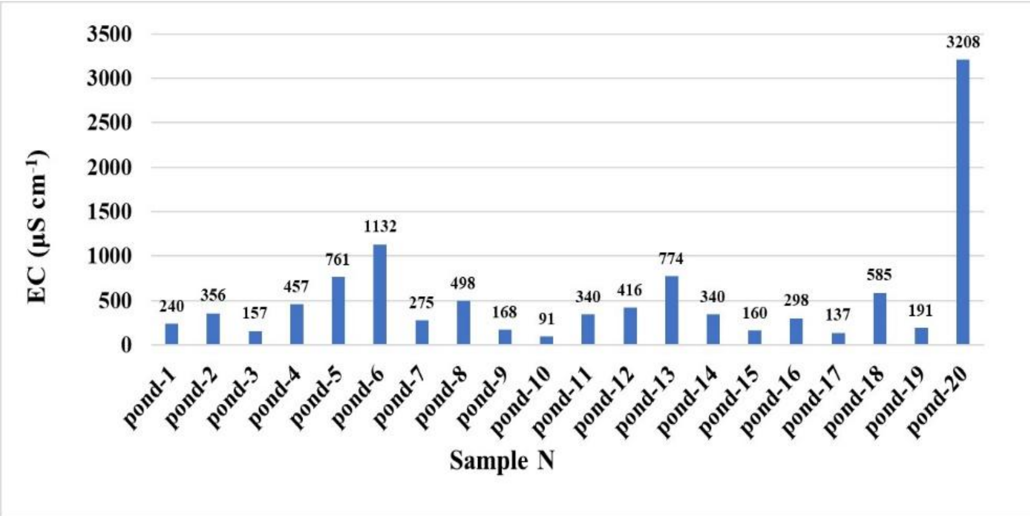

Fig. 6. Spatial variation of EC (µS cm^{-1})

Variation of total Nitrogen among sampling areas

TN is a key parameter for assessing the nutrient status of aquatic habitats. Elevated nitrogen levels can promote eutrophication, characterized by excessive growth of algae and aquatic plants [34, 35]. The highest TN concentrations were observed in Ponds 17, 6, and 20, reflecting significant nutrient inputs likely originating from sources such as sewage discharge, organic matter decomposition, or agricultural runoff (Figure 7), [5]. On the contrary, the lowest TN levels were detected in Pond-9 (0.7 mg L^{-1}), Pond-3 (1.4 mg L^{-1}), and Pond-4 (1.4 mg L^{-1}), suggesting these sites experience relatively lower anthropogenic impacts [36].

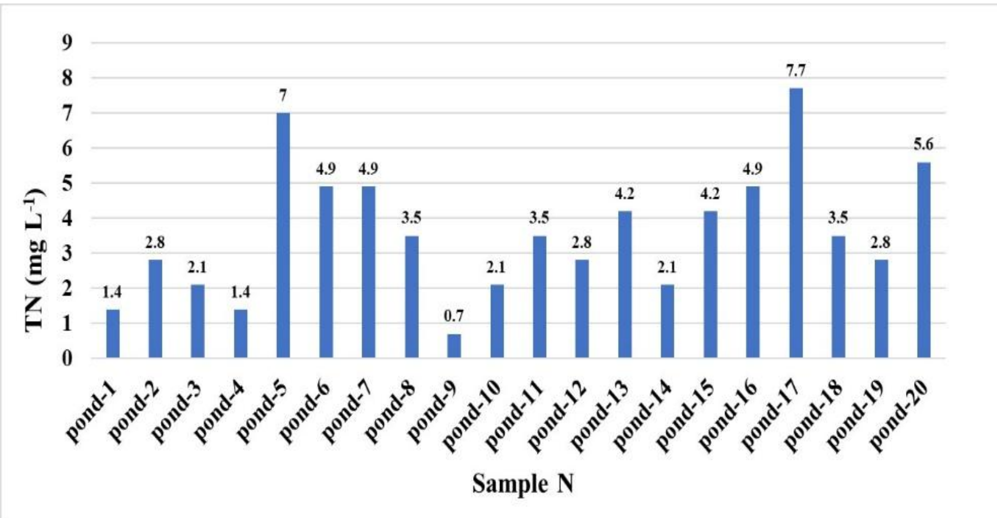

Fig. 7. Spatial variation of total Nitrogen (mg L^{-1})

Variation of total Phosphorus among sampling areas

The highest TP levels were found in Pond 13, followed by Ponds 9 and 7, indicating substantial nutrient enrichment likely from external sources such as wastewater discharge or agricultural runoff

(Figure 8) [37]. In contrast, the lowest phosphorus concentrations were observed in Ponds 17, 19, and 20, suggesting minimal nutrient inputs at these sites [38]. According to Carlson's Trophic State Index (TSI), a water body is classified as hypereutrophic when its TP concentration exceeds 100 µg L^{-1}, signaling excessive algal blooms and poor water quality [39]. While some ponds remained oligotrophic with TP levels below 30 µg L^{-1}, many others fell within the mesotrophic to eutrophic range of 30 to 100 µg L^{-1} [40].

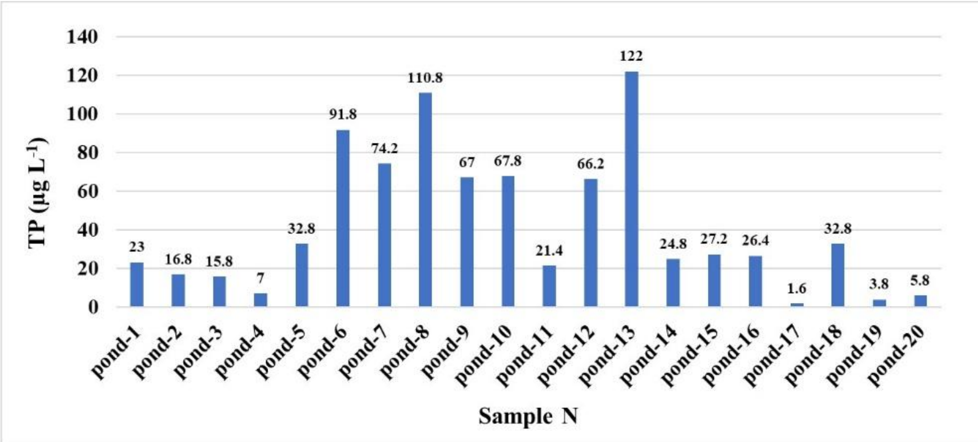

Fig. 8. Spatial variation of total Phosphorus (µg L^{-1})

Variation of Secchi disk depth among sampling areas

SD is a key parameter in eutrophication studies, used to assess water transparency [41]. It is affected by algal particles, dissolved colored substances, and suspended solids in the water, all of which absorb or scatter light and thereby reduce Secchi depth [42]. Pond-20 recorded the highest SD value, indicating enhanced water clarity, likely due to reduced concentrations of suspended particles or algal biomass (Figure 9). Similarly, Ponds 5, 10, and 3 exhibited relatively high transparency. In contrast, Ponds 9, 12, and 13 showed the lowest SD values, suggesting high turbidity resulting from suspended solids, dense algal blooms, or organic matter decomposition. Ponds with moderate SD readings between 0.3 and 0.4 m, such as Ponds 14, 15, and 16, reflected mesotrophic conditions [39, 40].

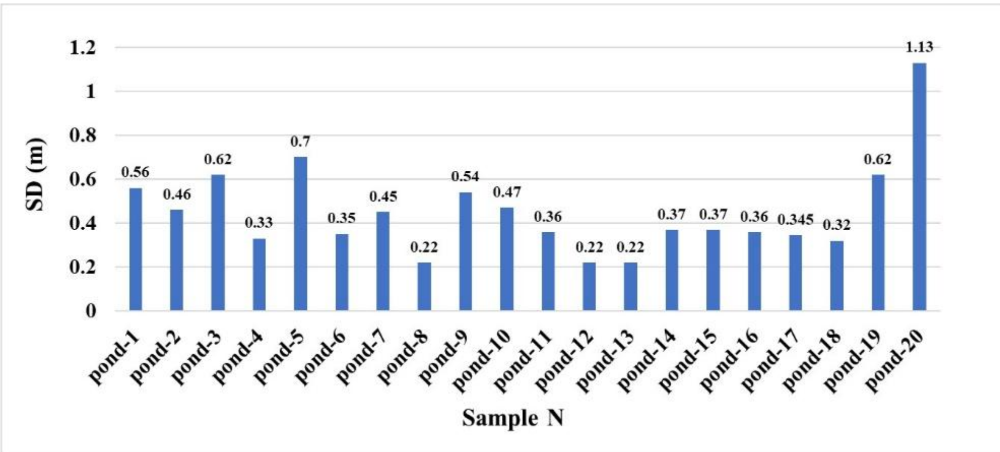

Fig. 9. Spatial variation of Secchi disk depth (m)

Variation of Chlorophyll-a in sampling areas

One of the most important markers of phytoplankton biomass and total eutrophication levels is the concentration of Chlo-*a* [43]. The ponds with the highest Chlo-*a* concentrations, Pond-8 (8.250 µg L^{-1}), Pond-9 (4.022 µg L^{-1}), and Pond-6 (4.295 µg L^{-1}), may have higher algal production due to nutrient enrichment, especially phosphorus and nitrogen inputs (Figure 10). However, Pond-19 and Pond-20 had the lowest Chlo-*a* values, suggesting comparatively lower algal biomass and possibly improved water quality conditions. With intermediate Chlo-*a* concentrations ranging from 1.154 to 3.808 µg L^{-1}, the majority of the other ponds indicated mesotrophic to eutrophic environments [23].

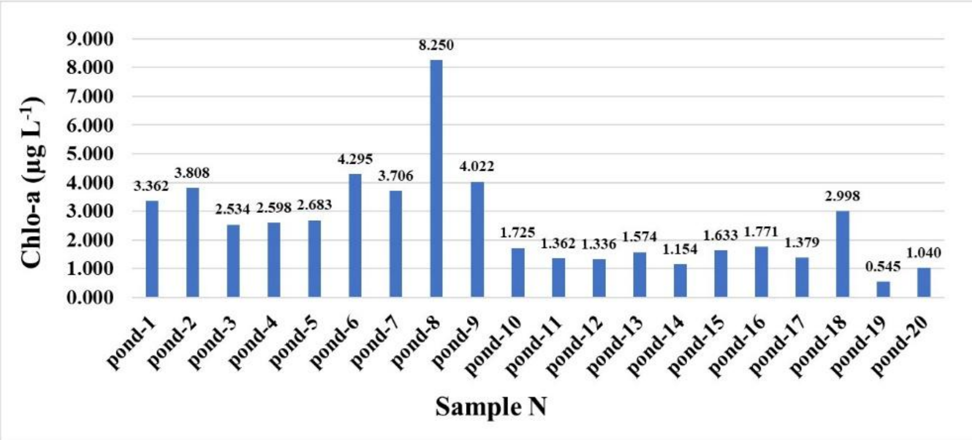

Fig. 10. Spatial variation of Chlorophyll-*a* (µg L^{-1}).

Carlson Trophic State Index estimation

Chlo-*a*, SD, and TP were used to calculate the Carlson Trophic State Index (CTSI) for the 20 ponds. Table 3 presents the nutrient status and potential ecological conditions of each pond based on their CTSI values, while Table 2 provides reference thresholds for interpreting the trophic states. The CTSI ranges from 0 to 100, representing a continuum from oligotrophic (low productivity) to hypereutrophic (extremely high productivity) conditions. This study revealed significant spatial variation in CTSI values among the ponds, ranging from 38.31 to 68.38, reflecting a gradient from oligotrophic to eutrophic states. These variations are attributed to differences in biological activity, hydrology, and nutrient inputs across the ponds.

Ponds 17, 19, and 20 had CTSI values of 40.00, 38.31, and 39.57, respectively, indicating oligotrophic conditions. These values are characteristic of clean, well-oxygenated waters, low algal biomass, and minimal nutrient enrichment—conditions often associated with limited human impact, high biodiversity, and good ecological health.

Table 3. CTSI for the investigated ponds

Sampling area	TSI(TP)	TSI(CA)	TSI(SD)	CTSI	Trophic Status
Pond-1	49.36	42.50	68.36	53.41	Less Eutrophic
Pond-2	44.83	43.72	71.19	53.25	Less Eutrophic
Pond-3	43.95	39.72	66.89	50.19	Less Eutrophic
Pond-4	32.21	39.97	75.98	49.38	Mesotrophic
Pond-5	54.48	40.28	65.14	53.30	Less Eutrophic
Pond-6	69.32	44.90	75.13	63.12	Eutrophic
Pond-7	66.25	43.45	71.51	60.40	Eutrophic
Pond-8	72.04	51.30	81.82	68.38	Eutrophic
Pond-9	64.78	44.25	68.88	59.30	Less Eutrophic
Pond-10	64.95	35.95	70.88	57.26	Less Eutrophic
Pond-11	48.32	33.63	74.72	52.23	Less Eutrophic
Pond-12	64.61	33.44	81.82	59.96	Less Eutrophic
Pond-13	73.42	35.05	81.82	63.43	Eutrophic
Pond-14	50.45	32.00	74.33	52.26	Less Eutrophic
Pond-15	51.78	35.41	74.33	53.84	Less Eutrophic
Pond-16	51.35	36.21	74.72	54.09	Less Eutrophic
Pond-17	10.93	33.75	75.34	40.00	Oligotrophic
Pond-18	54.48	41.37	76.42	57.42	Less Eutrophic
Pond-19	23.40	24.65	66.89	38.31	Oligotrophic
Pond-20	29.50	30.98	58.24	39.57	Oligotrophic

Pond-4, with a CTSI value of 49.38, was classified as mesotrophic, reflecting moderate nutrient levels and a balanced aquatic environment. While the water remained relatively clear, this trophic state can increase the likelihood of hypolimnetic anoxia during warmer months due to seasonal productivity.
Ponds 1, 2, 3, 5, 9 to 12, 14 to 16, and 18 had CTSI values between 50 and 60, placing them in the lower eutrophic range. These ponds displayed elevated biological productivity, with occasional anoxic conditions in the hypolimnion. The increased nutrient levels may also lead to macrophyte overgrowth and shifts in species composition.
Pond-10, with a CTSI of 57.26, demonstrated notable nutrient enrichment but remained just below the threshold associated with severe eutrophic impacts. This suggests a transitionary state where nutrient loading is high but not yet causing critical ecological degradation.
In contrast, Ponds 6 to 8 and 13 had CTSI values between 60.40 and 68.38, indicating eutrophic conditions. These elevated readings point to high nutrient availability, promoting the dominance of blue-green algae (cyanobacteria) and the frequent formation of algal scums. The ecological consequences include oxygen depletion, reduced water quality, and stress on aquatic organisms.
Pond-8, with the highest CTSI value of 68.38, approached the hypereutrophic threshold, signaling very high productivity and potential ecological stress, such as increased oxygen demand, loss of biodiversity, and algal bloom dominance [44].

Statistical analysis
The correlation analysis of the water quality measures for 20 ponds was revealed some significant correlations among the parameters (Figure 11). The substantial positive association between temperature and chlorophyll-*a* (0.57, $p \leq 0.05$) indicates that higher temperatures promote algal growth, Mei *et al.* reported that for every 1°C rise in the average yearly temperature, there was a 15% increase in planktonic algae [45]. Similarly, TDS and EC exhibited a very strong connection, demonstrating that higher dissolved solids improved conductivity. Additionally, there was a strong negative correlation (-0.46) between SD and TP, suggesting that higher phosphorus levels cause algal blooms, which in turn reduce water clarity [46]. TDS and SD had an inverse connection (-0.63), resulted that higher dissolved solids cause water to become less transparent. Furthermore, the inverse relationship between temperature and DO (-0.27) suggest that higher temperatures reduce the availability of oxygen, most likely as a result of increased microbial metabolism and decreased oxygen solubility [47]. The study discovered a positive association between TP and Chlo-*a*, suggesting that phosphorus was a crucial ingredient that limits the growth of algae. In contrast, a weak negative correlation was observed between TN and Chlo-*a*, suggesting that under the conditions studied, higher nitrogen concentrations did not correspond to increased algal biomass. This finding aligns with previous research indicating that the influence of TN on Chlo-*a* can vary depending on TP levels. Specifically, TN appeared to have little effect on algal biomass under low TP conditions, while under high TP conditions, it may even exert an inhibitory influence on algal growth [48].

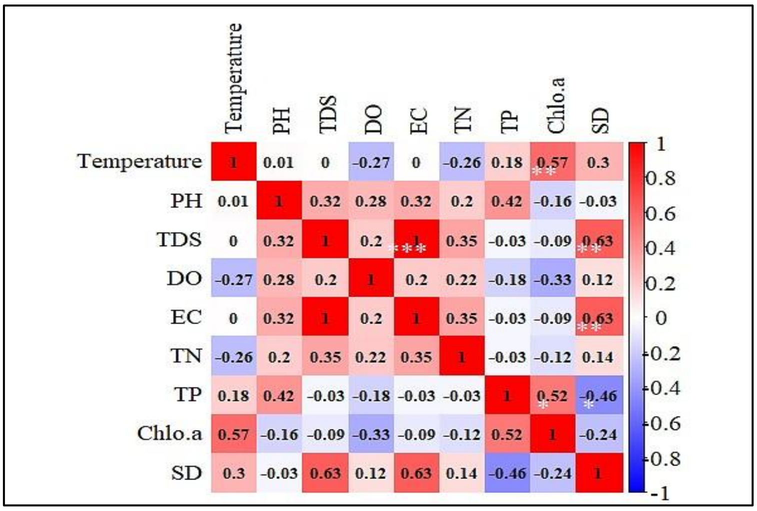

Fig. 11 Correlation matrix among 9 water quality parameters ($p \leq 0.05$*, $p \leq 0.01$**, $p \leq 0.001$***).

CONCLUSIONS

The study revealed notable variability in the physical and chemical characteristics of the 20 ponds, including temperature, pH, EC, and TDS, all of which influenced their trophic status. Parameters such as TDS, EC, dissolved oxygen, total phosphorus, chlorophyll-a, and Secchi disk depth exhibited significant variation due to both natural factors and anthropogenic influences. Based on Carlson's Trophic State Index, the ponds exhibited a wide range of trophic states—from oligotrophic to eutrophic. Notably, Ponds 17, 19, and 20 were classified as oligotrophic, characterized by low nutrient concentrations and high-water clarity. In contrast, Ponds 6, 7, 8, and 13 were categorized as eutrophic, with elevated nutrient levels and potential for algal blooms. A substantial number of ponds fell into the less eutrophic to moderately eutrophic categories. Overall, the study found that most ponds were moderately productive, with favorable correlations observed between Chlo-a and TSI values. Despite the presence of various anthropogenic pressures, the general water quality of the ponds remained relatively stable. This study provides essential baseline data on the ponds' physicochemical conditions, offering valuable insights for ecosystem management and future conservation strategies.

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