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THE PHYSICOCHEMICAL ANALYSIS OF WATER AND SOIL OF SOOR-SAROVAR BIRD SANCTUARY IN RELATION TO EURASIAN SPOONBILL

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ABSTRACT

The study examines the physicochemical properties of water and soil in the Soor-Sarovar Bird Sanctuary (SSBS), a vital wetland ecosystem in Agra, India, and their implications for the habitat of the Eurasian Spoonbill and other avian species. Conducted over two years (2021–2023), the research analysed seasonal variations in water quality parameters including pH, alkalinity, turbidity, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Results exposed fluctuations in pH from neutral (6.95 during monsoon) to alkaline (up to 9.44 in summer), while turbidity and nutrient levels varied with seasonal inputs. High BOD and COD values indicated organic pollution, particularly in summer, likely due to anthropogenic activities like tourism and agricultural runoff.

Soil analysis highlighted spatial differences, with littoral zones exhibiting higher organic carbon (1.2–2.7%) and nitrogen (190–295 kg/ha) compared to upland areas. Bulk density and porosity also varied, reflecting the wetland's dynamic hydrology. The study underscores the sanctuary's ecological significance as a habitat for resident and migratory birds, while identifying threats from pollution and human disturbance.

Findings emphasise the need for sustainable management practices to mitigate water quality degradation and preserve biodiversity. The research contributes to broader wetland conservation efforts, aligning with global initiatives like the Ramsar Convention, and provides a baseline for future monitoring of SSBS. By integrating water and soil data, the study offers actionable insights for policymakers and conservationists to safeguard this critical ecosystem.

Keywords: *COD, BOD, wetland, sustainable, ecosystem, parameters, density, porosity*

INTRODUCTION

Inland freshwater bodies support diverse ecosystems, classified as lentic (still water) or lotic (flowing water), and may be perennial or seasonal. Wetlands are amongst the most energetic and productive ecosystems, covering around 6% surface of Earth [1]. They serve key hydrological, biogeochemical, and biological roles [2]. As defined by the Ramsar Convention [3], wetlands include natural or artificial areas with static or flowing water, fresh to saline, up to six meters deep. These habitats support rich biodiversity, including phytoplankton, zooplankton, aquatic plants, insects, molluscs, fish, and numerous bird species. India's varied topography and climate support a wide range of wetland habitats. Estimates suggest the presence of around 555–557 small wetlands (less than 2.25 ha) across the country, mainly in the form of tanks and ponds [4]. These inland wetland ecosystems are directly or indirectly sustained by key river systems such as the Ganga, Brahmaputra, Narmada, Krishna, Kaveri, Tapti, and Godavari, which play a crucial role in maintenance of their ecological balance and productivity.

Our country is home to 1340 bird species [5-6], with approximately 23% of these species relying on wetlands in India [7]. The wetlands in India span about 58.2 million hectares [8], which constitutes roughly 4.7% of the total geographical area. In addition to being productive and sensitive, wetlands provide a variety of services such as flood control, carbon sequestration, maintaining river flow, bird watching, supplying water for irrigation, domestic and industrial uses, and facilitating nutrient removal and water purification; hence, they are also referred to as the 'Kidneys of landscapes' [9].

Wetland ecosystems are among the most threatened ecosystems (WWF, 2016). Their restoration has multiple objectives, including improving water quality, habitats, species enhancement, and environmental protection [10]. Keeping this in mind, the Ramsar Convention was signed in 1971 by 169 parties to protect and conserve wetlands [11-12]). Protected areas or Bird Sanctuaries are the main attraction centres for visitors, resulting in human disturbance to the resident and migratory birds, which is becoming a serious concern for conservation

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due to the growing population and fast-expanding tourism as a source of revenue [12].

The World Bank estimates that India's overall environmental damage costs 4.5%, of which 59% is due to the negative health effects of water pollution [13]. The current water demand has doubled because of growing industrial and home requirements. There are a lot of noteworthy studies and papers on limn-biotic investigations of water pollution and its decrease.

However, none detailed study on water quality and soil analysis of the Soor Sarovar Bird Sanctuary (Keetham Lake) (SSBS) is accessible. Studies on diverse physicochemical parameters of various ground and surface water generated beneficial data for understanding the water quality and changes brought by various human interferences. So, studies on the effects of anthropogenic factors on freshwater resources are authoritative. Such studies provide information on our limits in nature.

Various research studies have been done on the ecology of wetlands around the world. Hart reported that rainwater has a great impact on the water quality in the Magela Creek Wetland System in Australia [14]. According to Tomiyama (1995), the development activities in its catchment basin resulted in eutrophication, algal blooms, high COD, and a decline in fish population, all of which worsened the water quality. Bhatt studied the physicochemical characteristics and phytoplankton dynamics in Taudaha Lake in the high altitudes of Nepal [15]. Becht and Harper observed the water steadiness of Lake Naivasha, Kenya ‘s second Ramsar site, and found that the Lake is declining in its water quality due to overexploitation [16]. Vestergaard and Sand-Jensen identified that alkalinity controls aquatic plant distribution in Danish lakes [17]. Murugavel and Pandian documented that a decrease in temperature increases the solubility of oxygen in the water [18. Klug investigated planktonic community responses to pH perturbations [19]. Adak described that diverse physicochemical parameters of water are very important for effective care of water quality [20]. Gulati and Donk described that phosphorus content in water Cyanobacteria can produce significantly higher biomass and generate greater turbidity compared to green algae [21]. Romero reported that phosphorus limits algal growth and, occasionally, nitrogen [22]. Owen studied that pH, conductivity, temperature and nitrates appear to be strictly correlated to Diatom growth [23].

In India, foundational research on the limnology of rivers and lakes began with several pioneering studies. Chakrabarty conducted early work on the Jamuna River in Allahabad [24], followed by David on the Tungabhadra Reservoir [25]. Subsequent studies included Lal on Pushkar Sarovar [26], Gambhir on Maithon Reservoir [27], and Patel on Pitamahal Dam [28]. Further contributions were made by Sinha on the Ram Ganga River [29], Singh on the Yamuna River [30], and Prasad and Narayana on the Sarada River basin, enriching India's limnological knowledge [31]. Deviation in physicochemical characteristics has been observed by Das and Jain surface water systems like ponds, lakes, rivers and groundwater of various parts of India [32-33].

In India, numerous studies have been conducted in past few years on lentic water bodies, highlighting their ecological importance and diverse biodiversity [34-38].

Ramakrishna stated that Season data of the various parameters noticeably shows that the thermal stratification was not very significant, though, during summer months the thermal variance was in the range of 1.5 - 1.8 degrees Celsius in the samples collected, pH in the range of 7.5 - 8.6, a steady rise in the bicarbonate and carbon dioxide in deeper layers are revealing of higher values for the lake during to summer months in Fox Sagar lake [39].

Das and Sayantan reviewed a study on the diverse physicochemical constraints of water such as electrical conductivity (EC), temperature, total suspended solids (TSS), turbidity, total dissolved substance (TDS), pH, hardness, alkalinity, chloride, nitrate, sulphate, fluoride, COD, dissolved oxygen (DO), BOD, phosphate and nitrate of various ponds in Bihar [40].

Nag examined the physicochemical parameters of Surya Kund Pond in Gaya of Bihar and revealed that there was major seasonal (cyclic) variation in some physicochemical parameters, and the water was reasonably polluted [41]. A primary study was performed and showed that total suspended solids and total dissolved solids were higher in the summer season, due to sewage water and suspended matter, high phosphate suggests a high degree of pollution, and assessment of BOD suggests that the pond is eutrophic, increase in COD during the summer season is correlated with the breakdown of suspended organic matter which produces the soluble organic matter in the water [41-43]

Rashmi analyzed the seasonal variations in physico-chemical parameters, i.e summer, winter and monsoon seasons and discovered that the pond water sample was somewhat rich in nutrients, concerning phosphate, chloride and nitrate, due to the high organic burden BOD of this pond was slightly high in Moti Lake, Motihari [44]. The aquatic bodies of the Samastipur district suffered from eutrophication, higher BOD, lower dissolved oxygen, and higher nitrate concentrations specified the eutrophicated ponds as unsuitable for domestic use Sinha [45].

Patel studied the physicochemical parameters of water, the value of water temperature- 26.30ºC, depth of visibility- 240.65 cm, pH- 8.45, EC- 0.42mS/cm^{-1}, bicarbonates- 50.53 mg l-1, total alkalinity- 61.4 mg l-1, Nitrate-N- 0.20 mg l-1, orthophosphates- 0.33 mg l-1 [37]. Total dissolved solids- 273.86, dissolved oxygen- 10.21 mg l-1, free CO_2- absent, carbonates- 10.86 mg l-1. A study on physicochemical parameters was done, and the results stated that high water temperature, BOD, PH, and total hardness were found. K. Anuradha observed water analysis, seasonal variations of some physicochemical calibrations and factors such as Temperature, pH, Turbidity, DO, BOD, etc., for Narsapur Lake in Siddipet of Telangana state [46].

A.K. Verma investigate several physicochemical factors such as transparency, temperature, pH, free CO_2, DO, total alkalinity, hardness, phosphate and, nitrates alter within a range beneficial to high biological production [47].

Study Area

SSBS, Keetham, Agra, is one of the most significant bird sanctuaries in Uttar Pradesh. It consists of an artificial freshwater wetland or Jeel, with the river Yamuna bordering its northern edge, creating a mosaic of ecological niches. In 1991, the Government of Uttar Pradesh designated it as a Bird Sanctuary under the Wildlife Protection Act of 1972. SSBS is recognised as an Important Bird and Biodiversity Area (IBA) and was declared a Ramsar site in November 2020.

SSBS is located between N27°14' 38" and N27° 31'51" latitude, E77° 49'38" and E77°52'40" longitude, 20 km away from Agra district headquarters on Agra-Delhi highway (NH 2) (Fig. 1.2; 1.3). Its entire catchment area is 7.97 km^2, while the lake is spread over 2.25 km^2 with a depth ranging from 4 to 8 meters.

The region receives heavy monsoon rainfall (June to mid-September), with annual temperatures ranging between 4°C and 48°C. SSBS is surrounded by dry deciduous forests and supports a rich biodiversity. It gives shelter to 165 species of migratory and resident birds. It is a good tourist attraction providing fruitful bird-watching from October to April. SSBS has the biggest Bear Rescue centre for rescued dancing bears.

Though it has been known as a paradise for both migratory and non-migratory birds, it is threatened by various anthropogenic activities, including poaching, overgrazing, and fishing within its premises.

MATERIALS AND METHODS

Water Analysis

Samples of water were collected from several sites across the study area to assess water quality parameters. These included measurements of salinity, temperature, alkalinity, water depth, turbidity, pH, COD, and BOD providing a comprehensive understanding of the physicochemical characteristics of the aquatic environment. These parameters were analysed by using standard methods and with the help of laboratory equipment.

To analyse all the parameters, standard methods (APHA, 2005) were adopted.

1. pH

Method: Electrometric Method.

Introduction: The pH is scaled as a negative logarithm of hydrogen ion (H+) concentration. At a specified temperature pH values from 0 - 7 are weakening acidic, 7 to 14 are progressively alkaline, and 7 are neutral.

Principle: pH is measured by determining the electromotive force (EMF) of a cell consisting of two electrodes: an indicator electrode, typically a glass electrode sensitive to hydrogen ions, and a reference electrode, commonly a calomel electrode. Both electrodes are immersed in the test solution. The resulting EMF generated by the cell is then measured using a pH meter, which accurately reflects the hydrogen ion (H+) concentration and thus the pH of the solution.

So, the pH is defined operationally on a potentiometric scale; the measuring instrument is also calibrated potentiometrically with an indicating (glass) electrode using a standard buffer so that.

PHB = - log10 (H+)

Calibration Technique:

- A portable digital pH meter (Elico pH-Meter, Model LI 120; Electrode type-CL-51B) was used.
- The pH meter is standardised by three standard buffer solutions (pH 4.0, 7.0, & 10.0) by pH tablets dissolved in 100 ml of distilled water (DW).
- The electrode is washed with double-distilled water.
- The electrode is inserted into the beaker & the pH values of three standard buffer solutions (4.0, 7.0, &10.0) are determined one by one.

Procedure:

- Turn on the pH meter and make sure that the meter reads 7 pH.
- Rinse the electrode with double-distilled water & blot dry.
- Set the temperature from the temperature knob.
- Set the knob to check the range.
- Calibrated using standard buffer solutions of pH 4, 7, 10.
- Set middle knob 000.
- Set the knob to the pH range, move the knob to the pH range of 0-7 and record the pH value of the sample. If exceed 7, move the knob switch to a pH range of 7-14 and record the pH value.
- After completing the measurement, clean properly, turn off the pH meter and keep the electrode dipped in distilled water.

2. Turbidity

Method: Nephelometric method.

Introduction: Turbidity in water results from suspended and colloidal particles like silt, clay, inorganic and organic matter, and micro-organisms. It reflects the optical property causing light to scatter and absorb.

Principle: The nephelometric method is based on the comparing of the intensity of light dispersed by the sample under specific conditions with the intensity of light scattered by a standard reference suspension under similar situations. Turbidity is directly proportional to the intensity of scattered light. Formazin polymer is used as the reference turbidity suspension. The turbidity of a specified concentration of formazine suspension is defined as 40 NTU.

Reagent:

A) Stock Turbidity Suspension:

- Dissolved 1 gm hydrazine sulfate $(NH_2)_2\ H_2SO_4$ in double-distilled water and diluted to 100 mL in a volumetric flask.
- Dissolve 10 g of hexamethylenetetramine $(CH_2)6N_4$ in double-distilled water and dilute to 100 mL in a volumetric flask.
- In a 100 mL volumetric flask, mix 5 mL of solution 1 and 5 mL of solution 2, allowing them to stand for 24 hrs at 25 ± 3°C. Dilute up to the 100 ml mark with distilled water.
- This 400 NTU suspension remains stable for one month.

B) Standard Turbidity Suspension: To prepare a 40 NTU turbidity suspension, dilute 10 ml of a 400 NTU stock solution with DW to a final volume of 100 ml. This diluted suspension can be stored and used for approximately one week.

Procedure:

- Turn on the turbidity meter, and allow it to heat up for 15 minutes.
- Take the test tube which have double DW.
- Select the requisite range for measurement.
- Adjust the display to 000 by adjusting the set zero knob.
- Eliminate the test tube containing double distilled water and insert another test tube of standard solution (40 NTU) & adjust the calibrated knob & the display read the selected standard solution value (0.4 NTU).
- Again, check the display of zero with the test tube contains double-distilled water.
- Take the turbidity of an unknown sample.
- If the sample has a turbidity of more than 40 NTU, dilute it so turbidity can be read on the same scale.
- After completing the measurement, clean properly and turn off the turbidity meter.

Turbidity (NTU) = Nephelometer reading x 0.4 x dilution factor

3. Total Alkalinity

Method: Titration Method

Reference: American Public Health Association

(APHA) 2320 B (2-30)

Introduction: The alkalinity of the water is its acid-neutralising capacity. Alkalinity exceeding alkaline earth metal concentrations plays a crucial role in assessing water suitability for irrigation. It also aids in interpreting and controlling water and wastewater treatment processes, ensuring optimal chemical balance and overall treatment efficiency.

Principle: Alkalinity of the water is its capability to neutralise a strong acid and is characterised by the presence of OH- ions capable of combining with H+ ions.

The alkalinity of samples can be predicted by titrating them with standard H_2SO_4 (0.02 N) at room temperature using phenolphthalein and methyl orange indicator. Titration to decolourisation of phenolphthalein indicator will indicate complete neutralisation of OH- and ½ CO3--, while the sharp change from yellow to orange of methyl orange indicator will indicate total alkalinity (complete neutralisation of OH-, CO_3--, HCO_3--).

Reagents (Reagent quantity as per the requirement to avoid wastage):

- **Sodium Carbonate Solution (0.05 N):** Dry 3-5 g primary standard Na2CO3 at 250°C for 4 hrs and cool in a desiccator. Weight 2.5 ± 0.2g (to the nearest mg) and transfer to the mark with D.W.
- **Standard sulfuric acid or Hydrochloric acid 0.02 N:** Dilute 200 ml of 0.1 N standard acid with distilled water to make a final volume of 1000 ml.
- **Phenolphthalein Indicator:**
- **Methyl Orange Indicator:** Dissolve 0.5 g methyl orange in 100 ml of water and dilute to 1000 ml with CO2-free DW (pH 4.3-4.5)

Procedure-

- A 100 ml of sample is taken in a 250 ml conical flask is taken, and 2-3 drops of phenolphthalein indicator are added.
- If no colour is produced, phenolphthalein alkalinity is zero.
- If a pink cooler develops, titrate it with 0.02 N H_2SO_4 taken in a burette until the solution becomes colorless or pH is 8.3.
- Note the reading of the burette and then calculate as in (1).
- In case the pink colour does not appear, continue as above.
- Add 2-3 drops of methyl orange to the same flask, then the solution turns yellow, and continue to titrate till the yellow colour changes to orange-red.
- Note the volume of H_2SO_4 required or reading and calculate as (2).

Calculation:

PA (as $CaCO_3$, mg/l) = A × Normality H_2SO_4×50 ×1000 ml of Sample

1. TA (as $CaCO_3$, mg/l) = B × Normality H_2SO_4×50 ×1000 ml of Sample

Where A = Volume of H_2SO_4 (ml) used with the only phenolphthalein

B = Volume of total H_2SO_4 (ml) used with phenolphthalein and methyl orange

PA = phenolphthalein alkalinity

TA = Total alkalinity

4. BOD

Method: 3-day B.O.D. test at 27°C

Reference: American Public Health Association 5210 A (5-4)

Introduction: Micro-organisms such as break down of bacteria, carbohydrates and use the energy thus released, but the aquatic system is depleted of its oxygen content. The amount of oxygen used by microorganisms in the aerobic oxidation of organic matter is termed BOD.

Principle: The method consists of filling samples to overflowing an airtight bottle of the specified size and incubating it at a specified temperature for 3 days. DO is measured initially and after incubation, and the BOD is computed from the difference between the initial and final DO. Because the initial DO is determined immediately after the dilution is made, all oxygen uptake, including that occurring during the first 15 minutes, is included in the BOD measurement.

Reagents:

- **Phosphate buffer solution:** Dissolve 8.5 gm KH_2PO_4, 21.75gm K_2HPO_4, 33.4gm $Na_2HPO_4.7H_2O$ and 1.7gm NH_4Cl in about 500ml distilled water and dilute to 1 litre. Adjust pH to 7.2 by adding acid or base.
- **Magnesium Sulphate Solution:** Dissolve 22.5 g $MgSO_4.7H_2O$ in about 700 ml of distilled water and dilute to 1 litre.
- **Calcium Chloride Solution:** Dissolve 27.5g of CaCl2 in distilled water and dilute to 1 litre.
- **Ferric Chloride Solution:** Dissolve 0.25g $FeCl_3.6H_2O$ in distilled water and dilute to 1 litre.

Procedure:

Preparation of Dilution Water:

- Water is saturated in a glass container by bubbling compressed air into distilled water.
- Add 1 mL each of Phosphate buffer, MgSO4, $CaCl_2$ and $FeCl_3$ solution for each litre of dilution water and mix thoroughly.
- B.O.D. seed is added 1mg/l to the BOD mixture.
- The pH of the sample is kept at 7.
- Sample is added in the B.O.D. bottles 2 for incubation and 1 for DO.
- One bottle out of three is fixed for the determination of DO, and its initial DO is calculated.
- The other 2 bottles are kept in BOD incubation for three days at 270 °C.
- After 72 hrs. DO is determined.
- Simultaneously suitable blank using dilution water is also treated in the above manner.

Calculation:

(a) When dilution water is not seeded

B.O.D. as O2 mg/L**= (D**1 - D2**)** ×100

% dilution of a sample

(b) When dilution water is seeded

B.O.D. as O2 mg/L= (D1 - D2) - (B1 -B2) ×100

% dilution of a sample

Where,

D1: DO of the sample immediately after preparation, mg/l

D2: DO of the sample after the incubation period, mg/l

B1: DO of blank (Seeded dilution water) before incubation, mg/l

B2: DO of blank (Seeded dilution water) after incubation. mg/l

5. Chemical Oxygen Demand

Method: Open Reflux Method

Reference: American Public Health Association (APHA) 5220 B (5-12)

Introduction: The COD test determines the oxygen necessary equivalent to the oxidation of organic matter with the help of a strong chemical oxidant. The test can be related empirically to BOD, organic carbon or organic matter in samples from a specific source.

Principle: Mostly organic matters are oxidised by a boiling mixture of chromic and sulphuric acids to produce CO_2 and water. A sample is refluxed in a strongly acidic solution with a known excess of potassium dichromate. After digestion, the remaining unreduced $K_2Cr_2O_7$ is titrated with ferrous ammonium sulphate using a ferroin indicator to determine the amount of $K_2Cr_2O_7$ consumed and the oxidisable organic matter is calculated in terms of oxygen equivalent.

Reagents (Reagents Quantity as Per Requirement):

Standard Potassium dichromate solution, 0.0417M (0.25N): Dissolve 12.259 g $K_2Cr_2O_7$, Primary grade, previously dried at 103°C for 2 hrs., in D.W. and dilute to 1 L. Add about 120 mg of sulphamic acid to take care of 6 mg/L of NO_2-N.

Sulphuric Acid Reagent: Add 10 gm Ag_2SO_4 to 1000 mL conc. H_2SO_4 and keep overnight for dissolution.

Ferroin Indicator Solution: Dissolve 1.485 g 1,10-Phenanthroline monohydrate and 695 mg $FeSO_4.7H_2O$ in distilled water and dilute to 100 ml.

Mercuric Sulphate: HgSO4, crystals analytical grade

Standard Ferrous Ammonium Sulphate (FAS), titrant 0.25N: Dissolve 98gm $Fe(NH_4)_2(SO_4)_2.6H_2O$ in D.W, add 20 ml conc. H_2SO_4, cool and dilute to 1 L, standardise daily as follows.

Standardizations: Dilute 10 ml standard $K_2Cr_2O_7$ to about 100 ml, add 30 ml conc. H_2SO_4, Cool. Add 2 drops of Ferroin indicator and titrate with FAS (Ferrous Ammonium Sulphate).

Normality of FAS = ml $K_2Cr_2O_7$ × 0.25

ml sample required

The deterioration of FAS can be decreased if it is stored in a dark bottle.

Procedure:

- A 20 ml sample is taken in a 250 ml refluxing flask.
- Add 0.4 g mercuric sulphate ($HgSO_4$) and several glass beads.
- 10 ml $K_2Cr_2O_7$ solution (0.25N) is added.
- Add slowly slowly 30 ml concentrated H_2SO_4 with dissolved $HgSO_4$.
- Reflux for 2 hrs. and cooled.
- It is titrated against standard ferrous ammonium sulphate (FAS) (0.025N) using the Ferroin indicator.
- The change of colour from blue-green to wine-red is the endpoint.

- Simultaneously blank is run.
- Standardise FAS solution against standard $K_2Cr_2O_7$ solution.

Calculation:

C.O.D. as mg/l = (A - B) × N × 8000
Volume of sample in ml
Where,
A = Volume of F.A.S. used for blank
B = Volume of F.A.S. used for the Sample
N = Normality of F.A.S.
8000 = mille eq. wt. of O_2 ×1000

Soil Analysis

Soil analysis is essential for assessing the health and fertility of ecosystems, particularly in wetland areas like Keetham Lake, SSBS, Agra. This methodology outlines the systematic collection and analysis of soil samples for various physicochemical and biological parameters, including pH, bulk density, organic carbon, and nutrient availability. The procedures adhere to standard soil science protocols while incorporating site-specific considerations for accuracy and reproducibility. The area was divided into zones based on proximity to the lake (littoral, riparian, and upland) to ensure representative sampling. Surface soil (0–15 cm) was collected for most analyses. Three composite samples per zone were collected to account for spatial variability.

Sample Collection Procedure

1. **Site Preparation**: Surface litter and debris were removed before sampling.
2. **Core Sampling**: The auger was vertically inserted to the desired depth, and the soil core was extracted.
3. **Composite Sampling**: The 5–6 subsamples from each zone were mixed to form a homogenised composite sample.
4. **Sample Labelling**: Each sample was labelled with location ID, date, and depth.
5. **Storage**: The samples were stored in an airtight bag at 4°C for biological analyses, while air-dried samples were used for physicochemical tests.

Sample Preparation

- **Air-Drying**: The samples were spread on clean trays and dried at room temperature (25–30°C) for 48 hours.
- **Sieving**: The soil was sieved through a 2-mm sieve to remove gravel and organic debris.

pH Measurement

- **pH (as received)**: Prepared a 1:2.5 soil-water suspension, stirred for 30 min, and measured pH at 27°C using a calibrated pH meter (Jackson, 1973).
- **pH (air-dried)**: The procedure was repeated using air-dried soil.

Bulk Density (BD) and Porosity

- **BD**: Oven-dry (105°C, 24h) a known volume of undisturbed core sample and weigh [48].

Bulk Density (g/cm³) = Oven-dry weight (g) Soil volume (cm³) Bulk Density (g/cm³) = Soil volume (cm³) Oven-dry weight (g)

- **Porosity**: Calculated using BD and particle density (assumed as 2.65 g/cm³ for mineral soils).

Porosity (%) = (1−BDParticle Density) ×100Porosity (%) = (1−Particle Density BD) ×100

Water Holding Capacity (WHC)

- Soil saturated in a funnel, allowed drainage for 2h, and measured retained water (Gardner, 1986).

Organic Carbon (Walkley-Black Method)

- Oxidised soil with potassium dichromate ($K_2Cr_2O_7$) and titrate with ferrous ammonium sulfate [49].

Nitrogen Analysis

- **Total Nitrogen**: Kjeldahl digestion followed by distillation [50].
- **Available Nitrogen (Alkaline Permanganate Method)**: Extract with $KMnO_4$ + NaOH and quantify (Subbiah & Asija, 1956).

Available Phosphorus (Olsen's Method)

- Extract with $NaHCO_3$ (pH 8.5) and measure via spectrophotometry [51].

Water-Soluble Sulphate & Chloride

- **Sulphate**: Turbidimetric method using $BaCl_2$ (Richards, 1954).
- **Chloride**: Argentometric titration (Mohr's method).

Magnesium (Atomic Absorption Spectroscopy, AAS)

- Extract with ammonium acetate (NH_4OAc) and analyse via AAS [52]

RESULTS

Water Analysis

The important physico-chemical parameters such as Turbidity, pH, EC, TDS, Alkalinity, DO, BOD and COD etc., are openly linked with the quality of water and the distribution and plenty of biological biota (micro-organism). These several parameters affect the organism and water- quality of the wetland ecosystem, as temperature does not show much discrepancy due to the exclusive thermal properties of water, turbidity affects the penetration of light, and phosphorus and Nitrogen from the domestic litter and fertilisers speed up the practice of eutrophication. Thus, the study of physicochemical parameters laterally will indicate the status of a specific water body. Each element plays its specific role, but the interaction of such factors results in the final result.

pH: pH is defined as the negative logarithm of the hydrogen ion concentration (-log10 of H+ +). Water holds both H+ (Hydrogen) and OH- (Hydroxyl) ions. Water that has more H+ ions than OH- ions is measured as acidic, and if H+ ions are less than OH- ions, it is basic or alkaline.

***Turbidity*:** Turbidity in water is due to suspended particles of clay, silt, organic matter, phytoplankton, and other microscopic living organisms, defined as the expression of optical properties (Tyndall effect).

BOD: BOD is referred to as the amount of oxygen needed for the biochemical degradation of organic material. The BOD assessment of any water body determines the pollution level.

COD: COD measures the oxygen essential to decompose both organic as well as inorganic constituents present in the water by chemical reaction.

Total Alkalinity: The alkalinity is the buffering capacity of water and the quantity of carbonates and bicarbonates present in the water due to the occurrence of salts of weak acids and strong bases. It is directly proportional to the productivity of freshwater.

The degrading quality of water in the country has started affecting the lives of people as well as the environment. Pollution of surface and groundwater from agrochemicals (fertilisers and Pesticides) and industry caused a major environmental health risk. The study site is currently subjected to anthropogenic pressures such as tourism and developmental activities in and around it. No serious studies have been found so far on the water analysis of this site.

Water analyses of samples were carried out for a period of two repeated years from early March 2021 to February 2023. The water samples were collected in different periods in summer, monsoon, post-monsoon and winter seasons of respective years.

pH, BOD, COD, Total alkalinity, turbidity, temperature and salinity were analysed in the water samples. For suitability and ease, the different seasons of the study period were given a unique identity. The identities of the seasons are as follows: year 2021 summer-S1, 2022 summer-S2, 2021 monsoon-M1, 2022 monsoon-M2, 2021 post-monsoon PM1, 2022 post-monsoon PM2, 2021-22 winter-W1, 2022-23 winter-W2.

The study was performed to understand the overall status of the water quality and pinpoint the factors responsible for the fluctuating water quality of the wetland. Wetlands are one of the potential sites in terms of biodiversity conservation and sustenance of a range of aquatic flora and fauna, and are the feeding and breeding pulverized for resident and migratory birds. On the other hand, local people rely on these wetlands for their livelihood in terms of agricultural and fishery products as well as uses for various purposes, such as for the irrigation of the agricultural fields, for various household purposes, etc. But an abrupt increase in population burden has altered these natural ecosystems.

Assessment of seasonal changes in Physico-chemical parameters of water

pH

In the season S1, the documented lowest mean values of pH of the water were 7.41, and the highest mean values of pH were 9.04. Likewise, in S2, the lowest mean value of pH was 7.62, and the highest mean value was 9.44. In the M1, the lowest mean value of pH was 6.97, and the highest mean value was 8.12. In the M2, the lowest mean value was 7.27, and the highest mean value was 8.52. In the PM1, the lowest mean value was 6.95, and the highest mean value was 8.10. In the PM2, the lowest mean value of pH was 7.25 in and the highest mean value was 8.50. In the W1, the documented lowest mean values of pH of the water were 7.40, and the highest mean values of pH were 8.55. Likewise, in the W2, the lowest mean value of pH was 7.70, and the highest mean value was 8.95 (Table 1; Fig. 1).

Table 1: Mean variations of pH in the summer, monsoon, post-monsoon and winter seasons

Season	Parameter	Stats		
S1	pH	Mean	7.94	9.04
		SD	0.21	0.28
		SEM	0.15	0.2
S2	pH	Mean	7.62	9.44
		SD	0.14	0.28
		SEM	0.1	0.2
M1	pH	Mean	6.97	8.12
		SD	0.14	0.14
		SEM	0.1	0.1
M2	pH	Mean	7.27	8.52
		SD	0.14	0.14
		SEM	0.1	0.1
PM1	pH	Mean	6.95	8.1
		SD	0.14	0.14
		SEM	0.1	0.1
PM2	pH	Mean	7.25	8.5
		SD	0.14	0.14
		SEM	0.1	0.1
W1	pH	Mean	7.4	8.55
		SD	0.07	0.07
		SEM	0.05	0.05
W2	pH	Mean	7.7	8.95
		SD	0.07	0.07
		SEM	0.05	0.05

ABBREVIATION: SD- Standard Deviation**; SEM-** Standard Error of Mean

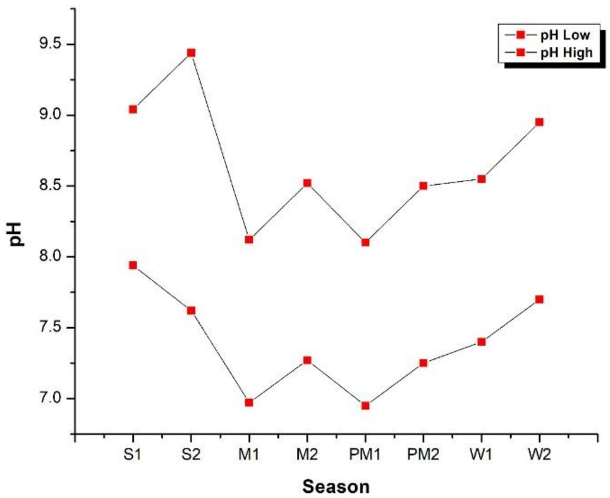

Fig. 1: Mean variations of pH in the summer, monsoon, post-monsoon and winter seasons

Turbidity

In the present study, during the S1, the documented lowest mean values of conductivity of water were 5.00 NTU, and the highest mean values of conductivity were 14.00 NTU. Likewise, in the S2, the lowest mean value of conductivity was 5.20 NTU, and the highest mean value was 15.00 NTU. In the M1, the lowest mean value of conductivity was 7.50

NTU, and the highest mean value was 12.45 NTU. In M2, the lowest mean value was 7.70 NTU, and the highest mean value was 15.40 NTU. In the PM1, the lowest mean value was 4.90 NTU, and the highest mean value was 12.50 NTU. In the PM2, the lowest mean value of conductivity was 5.65 NTU, and the highest mean value was 13.50 NTU. In the W1, the documented lowest mean values of conductivity of water were 5.00 NTU, and the highest mean values of conductivity were 10.20 NTU. Likewise, in the W2, the lowest mean value of conductivity was 5.75 NTU, and the highest mean value was 10.40 NTU. (Table 2; Fig. 2).

Table 2: Mean variations of Turbidity in the summer, monsoon, post-monsoon and winter seasons

Season	Parameter	Stats		
S1	Turbidity (NTU)	Mean	5	14
		SD	0	2.83
		SEM	0	2
S2	Turbidity (NTU)	Mean	5.2	15
		SD	0	2.83
		SEM	0	2
M1	Turbidity (NTU)	Mean	7.5	12.5
		SD	3.54	0.07
		SEM	2.5	0.05
M2	Turbidity (NTU)	Mean	7.7	15.4
		SD	3.54	0.14
		SEM	2.5	0.1
PM1	Turbidity (NTU)	Mean	4.95	12.5
		SD	0.13	3.54
		SEM	0.09	2.5
PM2	Turbidity (NTU)	Mean	5.65	13.5
		SD	0.21	3.54
		SEM	0.15	2.5
W1	Turbidity (NTU)	Mean	5	10.2
		SD	0	0
		SEM	0	0
W2	Turbidity (NTU)	Mean	5.75	10.4
		SD	0.07	0
		SEM	0.05	0

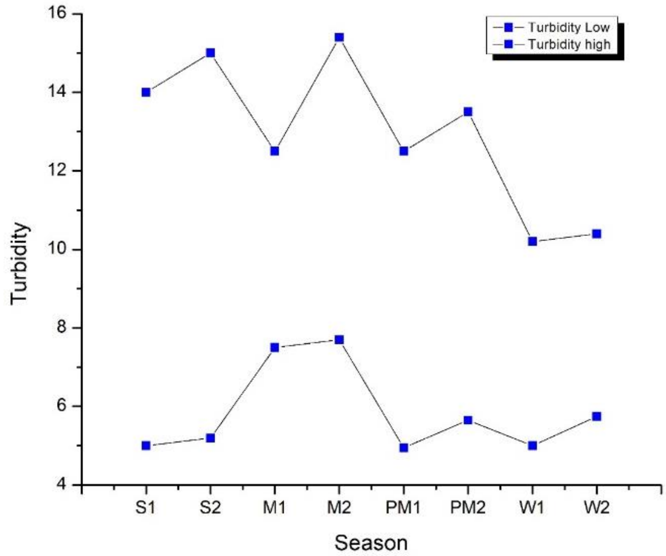

Fig. 2: Mean variations of Turbidity in the summer, monsoon, post-monsoon and winter seasons

Total Alkalinity

In the present study, during S1, the documented lowest mean value of water alkalinity was 131.00 mg/L, and the highest mean value of alkalinity was 171.24 mg/L. Likewise, in the S2, the lowest mean value of alkalinity was 132.00 mg/l, and the highest mean value was 175.32 mg/l. In the M1, the lowest mean value of alkalinity was 116.10 mg/l, and the highest mean value was 147.50 mg/l. In the M2, the lowest mean value was 116.80 mg/l, and the highest mean value was 147.70 mg/l. In the PM1, the lowest mean value was 132.00 mg/l, and the highest mean value was 198.60 mg/l. In the PM2, the lowest mean value of alkalinity was 133.00 mg/l, and the highest mean value was 202.68 mg/l. In the W1, the documented lowest mean values of alkalinity of water were 129.00 mg/l, and the highest mean values of alkalinity were 156.78 mg/l. Likewise, in the W2, the lowest mean value of alkalinity was 130.00 mg/l, and the highest mean value was 160.86 mg/l (Table 3; Fig. 3).

Table 3: Mean variations of Alkalinity in the summer, monsoon, post-monsoon and winter seasons

Season	Parameter	Stats		
S1	Alkalinity (mg/l)	Mean	131	171
		SD	9.9	0.34
		SEM	7	0.24
S2	Alkalinity (mg/l)	Mean	132	175
		SD	9.9	0.34
		SEM	7	0.24
M1	Alkalinity (mg/l)	Mean	116	148
		SD	0.14	12
		SEM	0.1	8.5
M2	Alkalinity (mg/l)	Mean	117	148
		SD	0.14	12
		SEM	0.1	8.5
PM1	Alkalinity (mg/l)	Mean	101	199
		SD	0.21	0.17
		SEM	0.15	0.12
PM2	Alkalinity (mg/l)	Mean	118	203
		SD	0.14	0.17

		SEM	0.1	0.12
W1	Alkalinity (mg/l)	Mean	130	157
		SD	0.07	0.08
		SEM	0.05	0.06
W2	Alkalinity (mg/l)	Mean	130	161
		SD	4.24	0.08
		SEM	3	0.06

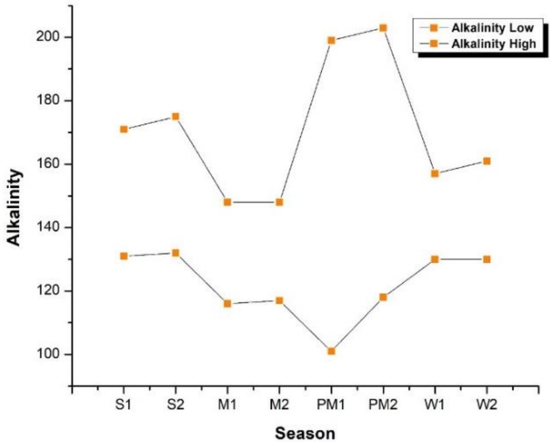

Fig. 3: Mean variations of Alkalinity in the summer, monsoon, post-monsoon and winter seasons

BOD

During the study period, S1, the BOD documented the lowest mean value of BOD of water was 10.80 mg/l, and the highest mean value of BOD was 34.44 mg/l. Likewise, in the S2, the lowest mean value of BOD was 11.00 mg/l, and the highest mean value was 38.52 mg/l. In the M1, the lowest mean value of BOD was 4.10 mg/l, and the highest mean value was 11.16 mg/l. In the M2, the lowest mean value was 4.80 mg/l, and the highest mean value was 11.50 mg/l. In the PM1, the lowest mean value of BOD was 4.30 mg/l, and the highest mean value was 10.89 mg/l. In the PM2, the lowest mean value of BOD was 5.00 mg/l, and the highest mean value was 11.89 mg/l. In the W1, the BOD documented the lowest mean value of BOD of water was 4.05 mg/l, and the highest mean value of BOD was 13.20 mg/l. Likewise, in the W2, the lowest mean value of BOD was 4.75 mg/l, and the highest mean value was 14.20 mg/l (Table 4; Fig. 4).

Table 4: Mean variations of BOD in the summer, monsoon, post-monsoon and winter seasons

Season	Parameter	Stats		
S1	BOD (mg/l)	Mean	10.8	34.4
		SD	1.41	0.34
		SEM	1	0.24
S2	BOD (mg/l)	Mean	11	38.5
		SD	1.41	0.34
		SEM	1	0.24
M1	BOD (mg/l)	Mean	4.1	11.2
		SD	0.14	0.51
		SEM	0.1	0.36
M2	BOD (mg/l)	Mean	4.8	11.5
		SD	0.14	0.42
		SEM	0.1	0.3
PM1	BOD (mg/l)	Mean	4.3	10.9

		SD	0.14	1
		SEM	0.1	0.71
PM2	BOD (mg/l)	Mean	5	11.9
		SD	0.14	1
		SEM	0.1	0.71
W1	BOD (mg/l)	Mean	4.05	13.2
		SD	0.07	0.85
		SEM	0.05	0.6
W2	BOD (mg/l)	Mean	4.75	14.2
		SD	0.07	0.85
		SEM	0.05	0.6

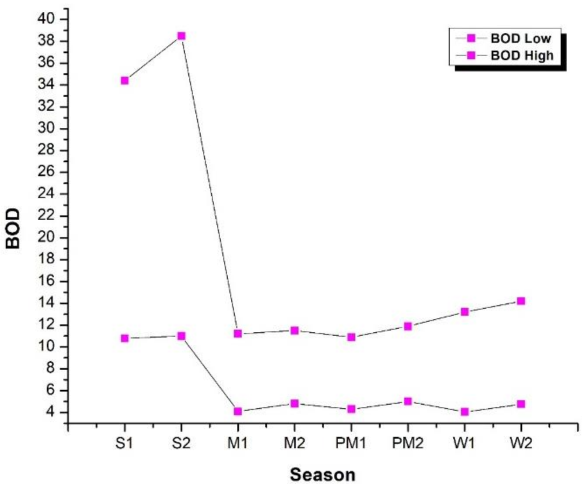

Fig. 4: Mean variations of BOD in the summer, monsoon, post-monsoon and winter seasons

COD

During the study period, S1, the COD documented the lowest mean value of COD of water was 19.30 mg/l, and the highest mean value of COD was 48.54 mg/l. Likewise, in the S2, the lowest mean value of COD was 19.50 mg/l, and the highest mean value was 49.02 mg/l. In the M1, the lowest mean value of COD was 12.46 mg/l, and the highest mean value was 25.35 mg/l. In the M2, the lowest mean value was 15.36 mg/l, and the highest mean value was 25.60 mg/l. In the PM1, the lowest mean value of COD was 19.06 mg/l, and the highest mean value was 30.75 mg/l. In the PM2, the lowest mean value of COD was 22.45 mg/l, and the highest mean value was 31.28 mg/l. In the W1, the COD documented the lowest mean value of water was 12.93 mg/l, and the highest mean value of COD was 29.80 mg/l. Likewise, in the W2, the lowest mean value of COD was 15.90 mg/l, and the highest mean value was 30.80 mg/l (Table 5; Fig. 5).

Table 5: Mean variations of BOD in the summer, monsoon, post-monsoon and winter seasons

Season	Parameter	Stats		
S1	COD (mg/l)	Mean	19.3	48.5
		SD	1.27	0.25
		SEM	0.9	0.18
S2	COD (mg/l)	Mean	19.5	49
		SD	1.27	0.25
		SEM	0.9	0.18
M1	COD (mg/l)	Mean	12.5	24.6
		SD	0.15	2.55

		SEM	0.1	1.8
M2	COD (mg/l)	Mean	15.4	25.6
		SD	0.17	2.55
		SEM	0.12	1.8
PM1	COD (mg/l)	Mean	19.1	30.8
		SD	0.14	11
		SEM	0.1	7.75
PM2	COD (mg/l)	Mean	22.5	31
		SD	0.15	11
		SEM	0.1	7.75
W1	COD (mg/l)	Mean	12.9	29.8
		SD	0.07	3.39
		SEM	0.05	2.4
W2	COD (mg/l)	Mean	15.9	30.8
		SD	0.08	3.39
		SEM	0.06	2.4

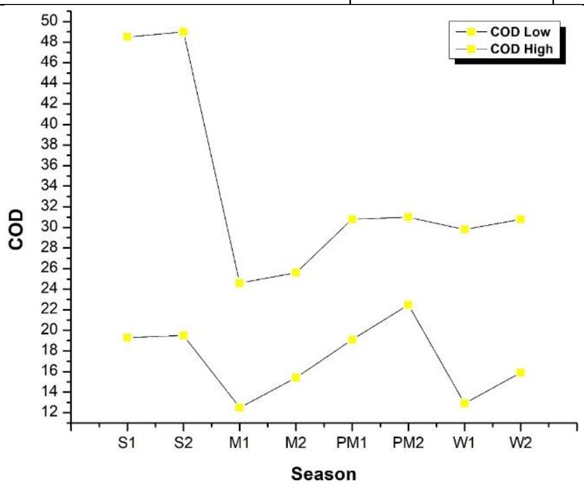

Fig. 5: Mean variations of BOD in the summer, monsoon, post-monsoon and winter seasons

Spatial and temporal correlations between the various physicochemical parameters

Physicochemical parameters of water

The bivariate Pearson correlation coefficients are calculated in ORIGIN 8.5 between the season-wise documented values of all the physicochemical parameters of water in order to detect the degree of relatedness among the variables. The level of significance is calculated either at the 0.01 level (highly significant) or at the 0.05 level (significant).

Bivariate Pearson correlation

Various variables show the degree of association with others as accepted with few exceptions during the study period (Table 6; Fig. 6). The variables which revealed a highly significant positive relationship (α = 0.01 level) include BOD with COD (r = 0.979), indicating they increase together. The positive correlation is observed between pH and BOD (r = 0.922) and between pH and COD (r = 0.907)

Table 6: Pearson Correlation coefficient of physicochemical parameters of water during the study period

	pH	**Turbidity**	**Total Alkalinity**	**BOD**	**COD**
pH	1	0.98252	0.92798	0.078044	0.093267
Turbidity	-0.017481	1	0.95684	0.66343	0.76438
Total Alkalinity	-0.072021	-0.04316	1	0.92274	0.7392
BOD	0.92196	0.33657	0.077256	1	0.021187
COD	0.90673	0.23562	0.2608	0.97881	1

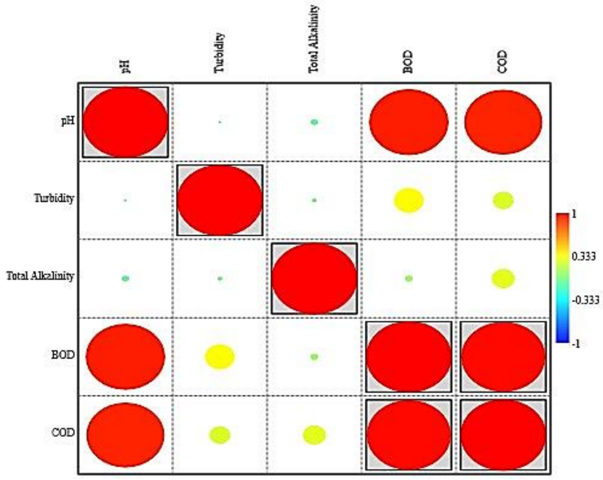

Fig. 6: Pearson Correlation coefficient of physicochemical parameters of water during the study period

Soil Analysis

Soil analyses of samples were conducted over a period of two consecutive years from 2021 to 2022. The study aimed to comprehend the overall condition of soil quality in the wetland and its margins. Wetlands are significant sites for biodiversity conservation and the support of a variety of aquatic flora and fauna.

Several factors affecting soil quality were analysed, including pH value at 27°C as received, pH value at 27°C air dried, bulk density, porosity, water-holding capacity, organic carbon, available nitrogen, total nitrogen, available phosphorus, water-soluble sulphate, chloride, and magnesium. The results are that the pH of soil samples, tested both as received and air-dried at 27°C, revealed slight variations- littoral zones exhibited mildly acidic conditions (6.5–6.8 when fresh, rising to 6.9–7.1 upon drying), while upland soils were more neutral (7.3–7.6). Bulk density and porosity showed distinct spatial trends. Littoral soils had lower bulk density (1.18–1.22 g/cm³) and higher porosity (54–56%), reflecting their loose, organic-rich composition. In contrast, upland soils were denser (1.42–1.45 g/cm³) with reduced pore space (45–47%). The water holding capacity was highest in littoral zones (42–45%). Organic carbon (1.2–2.7%) and available nitrogen (190–295 kg/ha) peaked near the lake. Total nitrogen was (0.12–0.20%) near the wetland. Available phosphorus (8.5–13.8 kg/ha), though relatively low, was more accessible in littoral areas. Water-soluble sulphate (30–50 ppm) and chloride (40–70 ppm), remained within safe thresholds. Magnesium levels (75–130 ppm) were sufficient for plant growth, with slight elevations in littoral soils (Table 7).

Table 7: Physico-chemical analysis of Soil

Year	**2021**			**2022**		
Zone	**Littoral**	**Riparian**	**Upland**	**Littoral**	**Riparian**	**Upland**
pH (as received)	6.8 ± 0.2	7.2 ± 0.1	7.5 ± 0.3	6.5 ± 0.3	7.0 ± 0.2	7.3 ± 0.2
pH (air-dried)	7.1 ± 0.1	7.4 ± 0.2	7.6 ± 0.2	6.9 ± 0.2	7.3 ± 0.1	7.5 ± 0.3
Bulk Density (g/cm³)	1.22 ± 0.05	1.35 ± 0.03	1.45 ± 0.04	1.18 ± 0.06	1.32 ± 0.05	1.42 ± 0.03
Porosity (%)	54 ± 2	49 ± 3	45 ± 2	56 ± 3	50 ± 2	47 ± 3
WHC (%)	42 ± 3	38 ± 2	32 ± 4	45 ± 2	40 ± 3	35 ± 3
Organic Carbon (%)	2.5 ± 0.3	1.8 ± 0.2	1.2 ± 0.1	2.7 ± 0.2	2.0 ± 0.3	1.4 ± 0.2
Available N (kg/ha)	280 ± 15	240 ± 20	190 ± 10	295 ± 18	255 ± 22	205 ± 15

Total N (%)	0.18 ± 0.02	0.15 ± 0.01	0.12 ± 0.01	0.20 ± 0.02	0.16 ± 0.02	0.13 ± 0.01
Available P (kg/ha)	12.5 ± 1.2	10.2 ± 0.8	8.5 ± 0.7	13.8 ± 1.5	11.0 ± 1.0	9.2 ± 0.9
SO_4^{2-} (ppm)	45 ± 4	38 ± 3	30 ± 2	50 ± 5	42 ± 4	35 ± 3
Cl^- (ppm)	65 ± 6	55 ± 5	40 ± 4	70 ± 7	60 ± 6	45 ± 5
Mg^{2+} (ppm)	120 ± 10	95 ± 8	75 ± 6	130 ± 12	105 ± 9	85 ± 7

DISCUSSION

Water quality is a main driver of habitat suitability for wetland birds. In this study, a number of important parameters were measured, such as pH, turbidity, total alkalinity, BOD, and COD. The pH varied seasonally, from nearly neutral during monsoon (around 6.95) to slightly alkaline during summer and winter (up to 9.44). These variations influence nutrient cycling and overall aquatic ecosystem health [53-54].

The soil analysis from Keetham Lake, Agra, provides critical insights into the wetland's ecological health and fertility. Among the key parameters measured, pH serves as a fundamental indicator of soil chemistry. The pH of soil samples, tested both *as received* and *air-dried* at 27°C, revealed slight variations—littoral zones exhibited mildly acidic conditions (6.5–6.8 when fresh, rising to 6.9–7.1 upon drying), while upland soils were more neutral (7.3–7.6). This shift occurs because air-drying reduces moisture-driven acidity and microbial CO_2 production 56. The lower pH in waterlogged areas aligns with typical wetland biogeochemistry, where organic matter decomposition releases organic acids [55].

Bulk density and porosity, closely linked to soil structure, showed distinct spatial trends. Littoral soils had lower bulk density (1.18–1.22 g/cm³) and higher porosity (54–56%), reflecting their loose, organic-rich composition. In contrast, upland soils were denser (1.42–1.45 g/cm³) with reduced pore space (45–47%), likely due to compaction and lower organic inputs [56]. These physical properties directly influence water holding capacity (WHC), which was highest in littoral zones (42–45%) owing to their porous structure and abundant organic carbon [57]. The strong correlation (r = +0.92) between WHC and organic carbon underscores the role of organic matter in moisture retention—a critical factor for sustaining wetland vegetation.

Nutrient dynamics further highlighted the littoral zone's ecological significance. Organic carbon (1.2–2.7%) and available nitrogen (190–295 kg/ha) peaked near the lake, driven by decaying aquatic plants and sediment deposition. Total nitrogen (0.12–0.20%) followed a similar trend, with higher values in waterlogged soils where anaerobic conditions slow nitrogen loss [58]. Available phosphorus (8.5–13.8 kg/ha), though relatively low, was more accessible in littoral areas, likely due to organic acid interactions that solubilise phosphorus [59-63].

The analysis also tracked essential ions like water-soluble sulphate (30–50 ppm) and chloride (40–70 ppm), which remained within safe thresholds, indicating no saline intrusion (WHO, 2006). Magnesium levels (75–130 ppm) were sufficient for plant growth, with slight elevations in littoral soils from mineral weathering [59].

Impact on Avifaunal Diversity

Water quality is one of the key drivers of habitat suitability for wetland birds. For this study, some of the key parameters were quantified, including pH, turbidity, total alkalinity, BOD, and COD. The pH was seasonally variable—almost neutral in monsoon (approximately 6.95) and slightly alkaline in summer and winter (up to 9.44). These fluctuations affect nutrient cycling and general aquatic ecosystem health [53-54].

Spatial and Temporal Correlations

The study also examined the associations between water quality indices and bird diversity indices in spatial and temporal perspectives. Deterioration in water quality (e.g., rising BOD/COD) was significantly and positively correlated with reduced bird evenness, demonstrating that degraded habitats support few opportunistic species and exclude more sensitive species simultaneously [61-63]. The findings emphasize the imperative need to maintain high water quality in wetland ecosystem biodiversity conservation.

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