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Ecological Assessment Of Khop Taal Pond: Soil Characteristics And Aquatic Productivity In Relation To Aquatic Weeds

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Abstract

Pond soil and aquatic weeds play a vital role in maintain freshwater ecosystems and biodiversity, providing essential resources for drinking water, irrigation, and fish farming. This study was conducted at Khop Taal pond in Chhatarpur district, Madhya Pradesh, India. The objective was to examine seasonal changes in soil characteristics and aquatic weed dynamics. Five sampling sites were selected in different zones such as near the agricultural area (S1), Fort (S2), Khop village (S3), Niwari village (S4), and Pump house (S5). The study spanned two years, from November 2022 to October 2024, spanning the winter, summer, and monsoon seasons, to understand changes over time. Soil samples collected from all sites were analyzed for physicochemical parameters, including Texture, pH, Electrical Conductivity, Chloride, Total Alkalinity, Calcium, Magnesium, Nitrate, Phosphate, Sulfate, Sodium, and Potassium. Aquatic weeds were sampled using the quadrat method to determine species density and distribution. Six main species were identified such as *Alternanthera blitum*, *Cyperus rotundus*, *Ipomoea aquatica*, *Nelumbo nucifera*, *Pistia crassipes*, and *Trapa natans*. The results revealed seasonal fluctuations in soil quality and weed abundance and their impact on ecological characteristics.

Keywords: Khop Taal, Soil Texture, Physicochemical, AquaticWeeds, Ecology.

Introduction

The soil and weeds in any pond play a vital role in maintaining freshwater ecosystems, biodiversity, and ecological balance. Ponds are natural resources that provide water for drinking, irrigation, fish farming, and other activities [1, 2]. Khop Taal Pond, located in the Chhatarpur district of Madhya Pradesh, India, holds immense geographical and ecological significance. Khop Taal Pond is known for its unique blend of hills, plains, and rivers in the Bundelkhand region [3]. It supports a diverse range of landforms, supporting a wide variety of flora and fauna. The pond is surrounded by agricultural land, wetlands, and rivers, which enhance the ecological productivity of the area [4, 5]. Known locally as "Taal" (lake), it serves as a lifeline for irrigation, drinking water, and fishing for the surrounding communities, and is also home to a variety of aquatic life [6].

Freshwater soil characteristics play a significant role in determining water quality and water health. The physical and chemical properties of soil affect pond soil texture, nutrient content, and water flow. Sandy soils generally drain water quickly but have poor nutrient retention, while clay soils retain moisture and nutrients better, and are essential for plant roots [7-9]. Khop Taal pond soil is a balanced mixture of sand and clay, which promotes the exchange of nutrients between water and plants, enabling their growth. This balance between water and nutrients is crucial for maintaining the pond's ecological health [10, 11]. Organic matter formed by decomposing plant remains improves soil fertility by extracting essential nutrients such as nitrogen, phosphorus, and carbon. These nutrients support the growth of aquatic plants, which feed fish and other aquatic organisms, forming the food chain [12, 13]. Nitrogen, phosphorus, and potassium are essential for maintaining plant productivity. Nitrogen promotes plant growth, while phosphorus supports root development and reproduction [14, 15]. Excessive phosphorus accumulation can lead to eutrophication, algal blooms, and oxygen depletion. Potassium increases plant stress resistance, supporting aquatic ecosystems [16, 17].

Water weeds are an essential part of freshwater ecosystems and affect the physicochemistry of pond water. Weeds found in Khop Taal's ponds include water hyacinth, duckweed, water lettuce, and water lilies [18, 19]. These plants provide habitat, food, and breeding grounds for fish and other organisms during normal growth. They also serve as bioindicators of nutrient status. Excessive weed growth in water can impact ecosystems. They reduce light and interfere with gas exchange [1, 20]. They increase organic load. Dissolved oxygen is reduced during decomposition. The growth of aquatic weeds can obstruct fish movement. This can disrupt breeding activity, reducing fish diversity and ecosystem stability [21]. Controlled weed growth helps maintain nutrient regulation and ecological balance. Uncontrolled weed growth can create hypoxic conditions, stressing sensitive fish species. Understanding the interactions between soil characteristics, nutrient dynamics, aquatic weeds, and fish populations is crucial for the conservation of the pond [22, 23].

This study focuses on conducting an ecological assessment of the Khop Taal pond. The focus is on soil nutrients, the dynamics of aquatic weeds, and their impact on fish diversity. Sustainable strategies can be developed to maintain the ecological integrity and socio-economic value of this aquatic ecosystem.

Materials and Methods

Study Area and Sampling Sites

This study was conducted at Khop Taal pond located in Chhatarpur district, Madhya Pradesh, India. Five sampling sites were selected to represent different ecological and human activity zones of the pond: near the agricultural area (S1), near the fort (S2), near Khop village (S3), near Niwari village (S4), and near the pump house (S5). The study was conducted over two years, from November 2022 to October 2024, encompassing three main seasons: winter, summer, and monsoon, to understand the seasonal variations in soil characteristics and aquatic weed dynamics. Khop Taal pond is situated between two hills north of Chhatarpur and spans an area of approximately 54.397 hectares. The geographical coordinates of the pond range from 24.98° N, 79.65° E in the east to 24.98° N, 79.64° E in the west, and from 24.97° N, 79.64° E in the south to 24.99° N, 79.65° E in the north. The maximum depth of the pond was recorded as 50-60 feet, although a gradual decrease in depth has been observed due to siltation.

Soil Sample Collection and Preservation

Soil samples were collected from the bottom of the pond using a pre-sterilized spatula. Approximately 100 grams of soil were collected from each sampling site and transferred to sterilized Petri dishes. The samples were immediately transported to the laboratory in insulated containers and stored at 4°C until further analysis. Soil health was assessed based on its physicochemical properties, which are important indicators of soil fertility and the functioning of the aquatic ecosystem [24-26].

Physico-Chemical Analysis of Soil

Soil samples collected from all five locations were analyzed for physical and chemical parameters, including texture, pH, electrical conductivity (EC), chloride, total alkalinity, calcium, magnesium, nitrate, phosphate, sulfate, sodium, and potassium, following standard methods [24, 27, 28].

Soil Texture

Soil texture was determined using the sieve analysis method based on particle size distribution. Soil samples were sieved through a series of sieves with mesh sizes of 0-1.0 mm, 1-2.0 mm, and 2-3.0 mm. The proportion of soil retained on each sieve was recorded and used to classify the soil texture.

Soil pH

Soil pH was measured to assess the acidity or alkalinity of the soil, which directly affects nutrient availability. Ten grams of soil were mixed with 50 mL of distilled water and left for 30 minutes with intermittent stirring. Before measurement, the pH meter was calibrated using a standard buffer solution (pH 7.0). The electrode was immersed in the supernatant, and the pH values were recorded. The soil was classified as acidic (pH < 6.0), neutral (pH 6.0–8.5), or alkaline (pH > 8.5) [29, 30].

Electrical Conductivity (EC)

Electrical conductivity was measured using the same soil-water suspension prepared for pH analysis. The EC meter was calibrated with a standard potassium chloride (KCl) solution. Measurements were taken at 25°C to estimate the amount of soluble salts. The soluble salt concentration (mg/L) was calculated using the following formula [31]: Soluble salts (mg/L) = 640 × EC (dS/m).

Chloride

Chloride concentration was determined by argentometric titration using silver nitrate ($AgNO_3$) and potassium chromate as an indicator. Five grams of soil were dissolved in 100 mL of distilled water and titrated with 0.0141 N $AgNO_3$. The endpoint was indicated by a color change from yellow to pinkish-yellow [32-35]. The chloride concentration was calculated using the following formula: Chloride (mg/L) = (A-B)×N×35450 / weight of soil sample (where A = volume of titrant for the sample, B = volume for the blank, and N = normality of $AgNO_3$).

Total Alkalinity

Total alkalinity was determined by titrating a known volume of soil suspension with standard hydrochloric acid (HCl) using phenolphthalein and methyl orange indicators [36, 37]. Alkalinity was calculated as follows: Total alkalinity (mg/L) = V_1×N×50/Vs. (where V_1 = volume of acid used, N = normality of the acid, and Vs = volume of the sample).

Calcium and Magnesium

Calcium and magnesium concentrations were estimated by EDTA complexometric titration using Eriochrome Black T as an indicator [32-35]. Soil samples were pre-treated, buffered at pH 10, and titrated with 0.01 M EDTA. Total salts were calculated as follows: Total salts = 2.497[Ca^{2+}] + 4.118[Mg^{2+}]

Nitrate

Nitrate content was determined using the alkaline permanganate digestion method. Organic nitrogen was oxidized to ammonia, which was distilled and absorbed in boric acid and titrated with 0.01 N sulfuric acid [38-40]. Nitrate percentage was calculated as follows: Nitrate (%) = (X-Y)×0.01×100/Weight of soil.

Available Phosphorus

Available phosphorus was estimated using the Olsen method. Soil samples were extracted with 0.5 M sodium bicarbonate, and phosphorus concentration was determined spectrophotometrically at 660 nm after color development with ammonium molybdate and stannous chloride [41, 42]. Available P (ppm) = Q×V/A×S

Sodium

Sodium concentration was measured using a sodium analyzer after calibration with a standard sodium solution. Soil samples were dissolved in distilled water, and the amount of sodium was determined from a standard calibration curve [38-40,43].

Potassium

Available potassium was determined using the ammonium acetate extraction method and measured by spectrophotometry [42,44]. Potassium concentration was calculated using a standard curve.

Sulfate

Sulfate concentration was analyzed using the barium chloride titration method, in which sulfate ions are precipitated as barium sulfate ($BaSO_4$). The endpoint was determined by stable precipitation and color change using methyl orange indicator [36, 37, 45, 46].

Sampling and Analysis of Aquatic Weeds

Aquatic weeds were collected using a systematic sampling method. The pond was divided into five zones, and samples were collected along predetermined transects using a double-headed rake attached to a marked rope. In shallow areas, weeds were collected by hand, and quadrat sampling was used to estimate biomass [41, 47]. The collected weed samples were placed in labeled plastic bags, washed to remove debris, and transported to the laboratory. In the lab, the samples were thoroughly rinsed with distilled water, separated by species, and analyzed for fresh biomass, dry weight, and identification. Any damaged or decaying plant parts were removed before analysis [48].

Results and Discussions

Soil Analysis

Analysis of soil in zones S1 to S5 revealed a similar (winter, summer, and monsoon) seasonal trend in clay content in both years (2022-23 and 2023-24), with the highest values and the lowest compared [49].

Texture analysis

In 2022-23, clay content ranged between 4.01 and 4.05 during the winter and decreased to between 3.14 and 3.57 during the monsoon. In 2023-24, clay content decreased slightly in winter in most zones, such as in S3, where the clay content decreased from 4.01 to 3.59, and in S4 and S5, where it decreased from 4.03 to 3.87. Silt values also showed a seasonal decline from winter to monsoon. In 2022-23, winter silt ranged from 3.07 to 3.20, and monsoon values fell between 2.52 and 3.26. In 2023-24, winter silt increased slightly in some zones, such as S4, from 3.07 to 3.33. Monsoon silt increased in zones S1, S2, and S3, with S1 increasing from 2.52 to 2.64 and S2 from 2.87 to 2.92. This increase indicates a slight accumulation of fines during the 2023-24 monsoon, although S4 and S5 experienced a slight decrease in monsoon silt levels compared to the previous year. Sand content showed the opposite pattern, peaking during the monsoon season in all zones. In 2022-23, monsoon sand varied from 3.56 in S2 to 4.33 in S1, while these values decreased slightly in 2023-24, with S1 decreasing from 4.33 to 4.25 and S2 from 3.56 to 3.51. This decrease was more pronounced in zones S3, S4, and S5, where monsoon sand decreased by approximately 0.5 to 0.6 units, indicating a shift toward finer clay during the 2023-24 monsoon (Figure 1). The soil texture showed clear seasonal and annual variations. In 2022-23, the proportion of clay and silt was generally higher during the winter months and decreased during the monsoon season, indicating a seasonal redistribution of fine particles, while sand showed the opposite trend during the monsoon. In 2023-24, the clay content decreased slightly during the winter in most zones, and silt increased during the monsoon in several zones (S1-S3), suggesting a slight accumulation of fine particles compared to the previous year. In 2023-24, the sand content decreased during the monsoon in all zones, particularly in S3-S5, indicating a shift towards finer soil particles. These patterns highlight the influence of seasonal processes and year-to-year variations on the dynamics of soil texture [50-54].

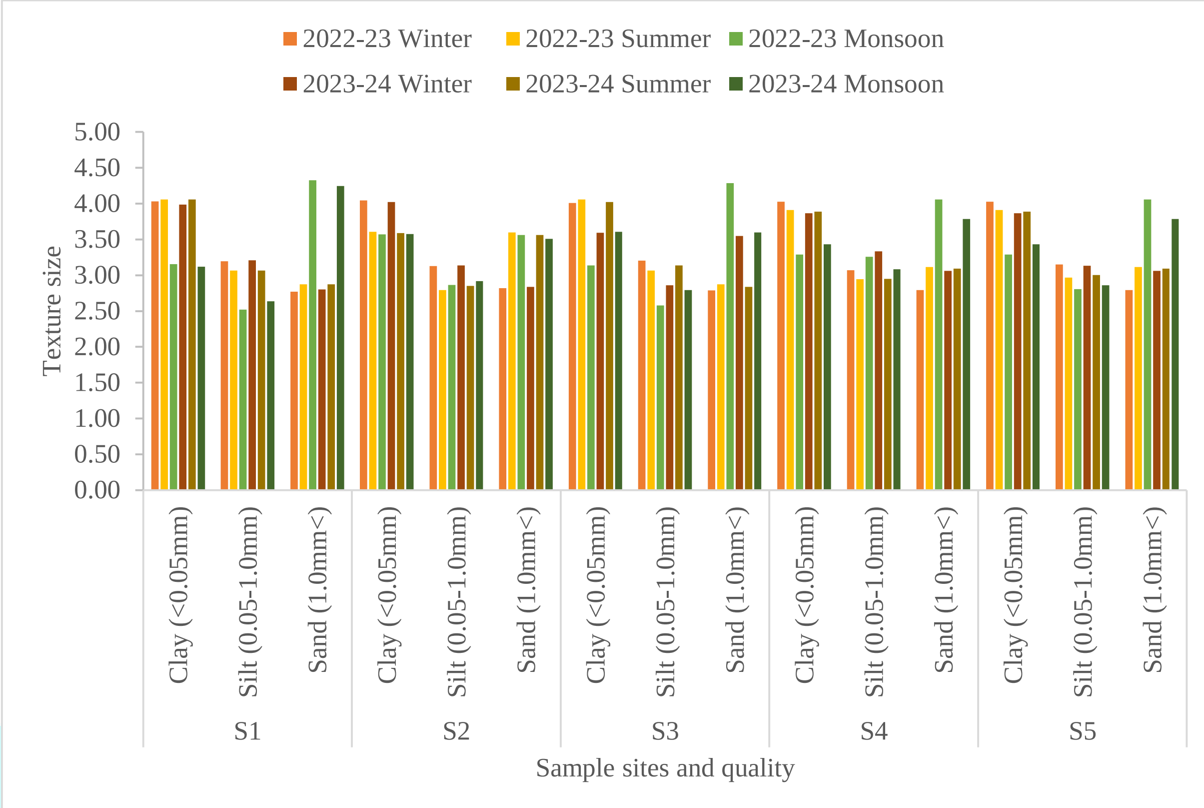

Figure 1: Texture analysis of soil samples.

Soil pH analysis

Analysis of pH values in zones S1 to S5 revealed a similar seasonal pattern of soil reaction in both 2022-23 and 2023-24, with higher pH levels in summer and lower in winter. In 2022-23, winter pH ranged from 5.89 to 6.08, indicating slightly acidic conditions, while summer pH increased significantly to between 6.93 and 7.15, leading to neutral soil conditions. Monsoon pH values remained intermediate, ranging from 6.33 to 6.40. In 2023-24, winter pH increased slightly in all zones except S1, reaching between 6.10 and 6.27, indicating a slight decrease in soil acidity. Summer pH also increased slightly, especially in zones S2 and S3, where values reached 7.30 and 7.32, respectively. In 2023-24, monsoon pH increased slightly across all zones, ranging between 6.43 and 6.75. The soils generally became slightly less acidic in 2023-24, and seasonal fluctuations in pH remained consistent, with pH highest in the summer months and lowest in the winter (Figure 2). Soil pH in zones S1-S5 showed a similar seasonal trend in both years, with the lowest values in winter and the highest in summer. In 2022-23, the soil was slightly acidic in winter and became nearly neutral in summer, while values were intermediate during the monsoon season. In 2023-24, there was a slight increase in pH across all zones and seasons, indicating a general decrease in soil acidity. Despite this year-on-year increase, the seasonal pattern remained consistent, suggesting that the higher alkalinity of the soil in summer and higher acidity in winter are persistent characteristics of the soil system [55-57].

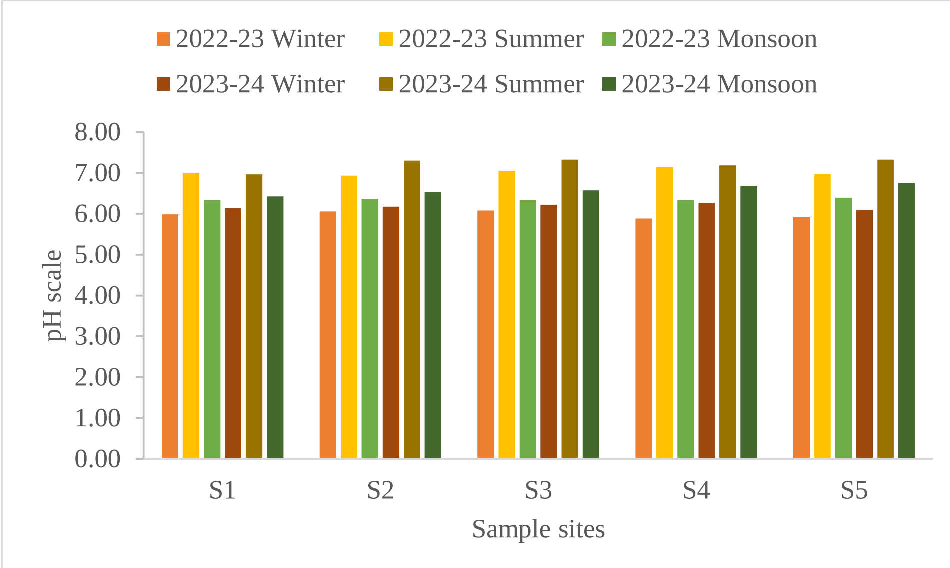

Figure 2: The pH analysis of soil samples.

Soil EC analysis

Analysis of electrical conductivity (EC) in zones S1 to S5 revealed that EC values generally followed a seasonal trend in both 2022-23 and 2023-24, with the highest readings occurring during the monsoon and the lowest during the summer. In 2022-23, EC values ranged from 352.58 to 406.86 in winter, decreased to between 310.73 and 417.25 in summer, and increased sharply to between 433.85 and 481.10 in the monsoon. In 2023-24, winter EC values showed a slight decrease in most zones, except S3, where EC increased from 352.58 to 413.03, indicating higher salt accumulation. In summer, EC values decreased significantly across all zones, with S2 dropping from 310.73 to 251.05 and S1 dropping from 342.38 to 297.50, indicating lower soluble salt concentrations during dry periods. In 2023-24, monsoon EC values remained high across all zones and even increased in several areas, with S3 increasing from 464.15 to 504.58 and S4 increasing from 481.10 to 490.25, indicating increased salt leaching and deposition during heavy rainfall (Figure 3). In zones S1-S5, electrical conductivity (EC) showed a clear seasonal pattern in both years, with the lowest values in summer and the highest during the monsoon season. In 2022-23, EC increased sharply during the monsoon, indicating increased dissolution of salts with rainfall. During 2023-24, EC decreased slightly in most zones during the winter. In summer, EC decreased significantly across all zones, suggesting a reduction in soluble salts under dry conditions, while it increased again during the monsoon, highlighting the role of rainfall in the dissolution and redistribution of salts [58-61].

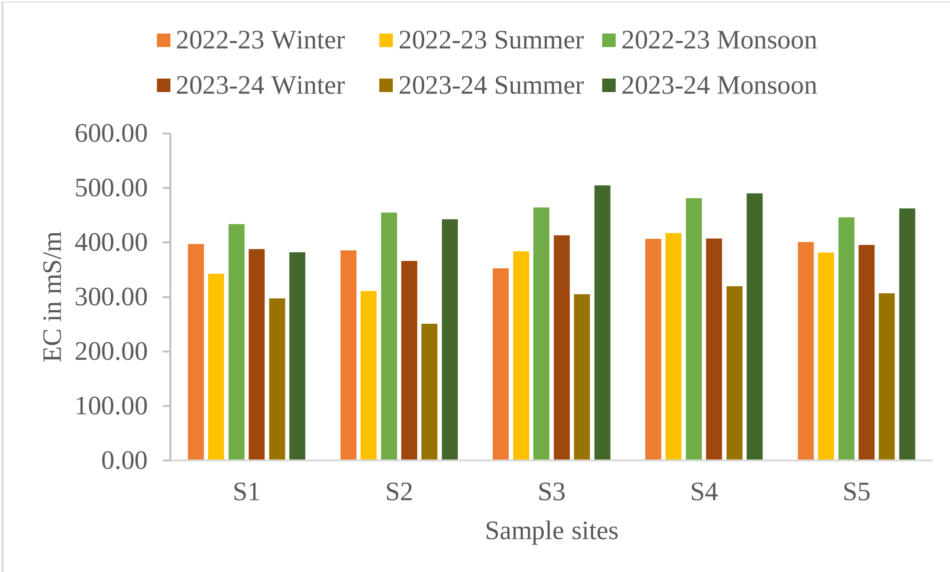

Figure 3: Electrical conductivity analysis of soil samples.

Soil chloride (Cl^-) analysis

Analysis of chloride (Cl^-) concentrations in zones S1 to S5 revealed that chloride levels varied seasonally in both years, with values consistently higher in the summer and monsoon seasons than in winter. In 2022-23, chloride values ranged from 11.24 to 17.70 mg/L in winter, increased significantly to between 27.29 and 35.01 mg/L in summer, and peaked at between 19.82 and 29.73 mg/L during the monsoon. In 2023-24, chloride values increased slightly in winter in most zones except S5, with S1 increasing from 11.24 to 16.45 mg/L and S4 increasing from 15.65 to 16.84 mg/L. However, chloride values decreased in all zones during summer, from 33.51 to 23.32 mg/L in S1 and from 33.13 to 28.22 mg/L in S3, indicating a decrease in chloride accumulation during the dry season. The 2023-24 monsoon saw a significant increase in chloride levels across all zones, with S3 increasing from 29.73 to 48.09 mg/L, S4 increasing from 27.76 to 42.28 mg/L, and S5 increasing from 24.42 to 43.54 mg/L, indicating that surface runoff and leaching processes, which carry higher chloride loads to the soil during heavy rainfall, intensified (Figure 4). In zones S1-S5, chloride levels showed a clear seasonal variation, with lower levels in winter and higher levels during the summer and monsoon seasons. In 2022-23, chloride levels increased significantly from winter to summer and remained high during the monsoon. In 2023-24, a slight increase in chloride was observed during the winter in most zones, while values decreased during the summer in all zones, indicating reduced accumulation during the dry season [62, 63].

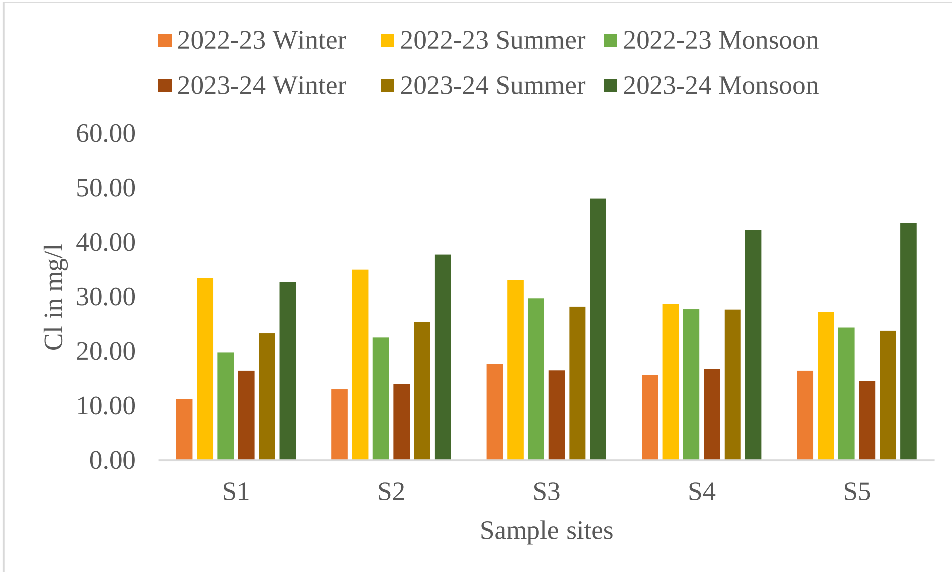

Figure 4: Chloride analysis of soil samples.

Soil total alkalinity (TA) analysis

Analysis of soil total alkalinity (TA) revealed a similar seasonal trend across all zones (S1 to S5) during 2022-23 and 2023-24, with summer values being the highest and monsoon values being the lowest. In 2022-23, S1 ranged from 118 in the monsoon to 130 in the summer, and this pattern continued in 2023-24, with winter and monsoon values decreasing slightly, but summer levels remaining roughly the same, indicating stable seasonal behavior. S2 showed the lowest overall TA values, reaching a minimum of 112 in the 2022-23 monsoon and improving slightly to 114 in the 2023-24 monsoon. While summer values increased from 124.75 to 126.5, showing a slight year-on-year increase. S3 consistently showed the highest TA values of all zones, reaching 132.25 in the summer of 2022-23 and slightly increasing to 133 in the summer of 2023-24, confirming its high-TA status. S4 showed moderate values, with a slight increase from 114.5 to 117 in the winter of the following year, while S5 remained fairly stable in both years and showed little fluctuation between seasons (Figure 5). Total alkalinity in zones S1-S5 exhibited a similar seasonal pattern in both years, with the highest values observed during the summer and the lowest during the monsoon season. Total alkalinity remained largely stable between 2022-23 and 2023-24, with minimal year-to-year variations. Zone S3 consistently recorded the highest alkalinity levels, while S2 showed the lowest values, although there was a slight improvement in 2023-24. The limited seasonal and annual fluctuations suggest that alkalinity levels in the study area are relatively stable [10].

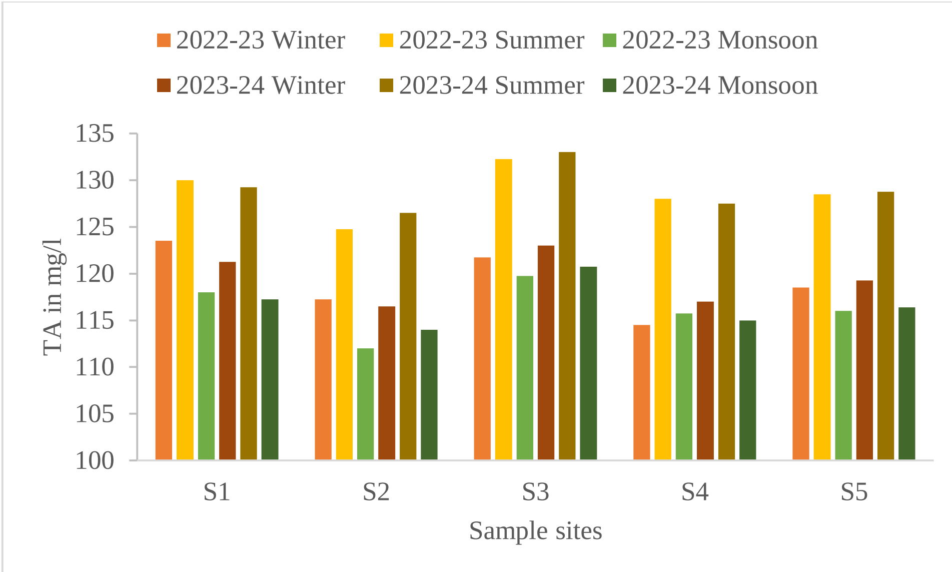

Figure 5: Total alkalinity analysis of soil samples.

Soil magnesium (Mg)

Soil magnesium (Mg) concentrations across all zones during 2022-23 and 2023-24 showed consistent seasonal variation, with the highest concentrations in summer and the lowest concentrations in monsoon. In 2022-23, Mg levels in S1 ranged from 39.33 in monsoon to 43.33 in summer, and a similar pattern was observed in 2023-24, with concentrations ranging from 39.08 to 43.08, indicating stable seasonal fluctuations. S2 recorded the lowest overall Mg concentrations, with monsoon concentrations decreasing to 37.33 in 2022-23 and slightly increasing to 38.00 in 2023-24, while summer concentrations increased from 41.58 to 42.17, indicating a slight improvement. S3 consistently showed the highest Mg values among the zones, reaching 44.08 in the summer of 2022-23 and slightly increasing to 44.33 in 2023-24, establishing its position as the zone with the highest Mg content. S4 showed fairly consistent Mg levels with minimal variation from year to year, while S5 showed fairly stable values across seasons with only minor fluctuations (Figure 6). In zones S1-S5, soil magnesium levels in both years showed a clear and consistent seasonal pattern, with the highest levels observed during the summer and the lowest during the monsoon season. Mg values remained fairly stable between 2022-23 and 2023-24, with minimal year-to-year variation. Zone S3 consistently recorded the highest magnesium levels, while S2 had the lowest, although it showed some improvement in 2023-24 [49, 50].

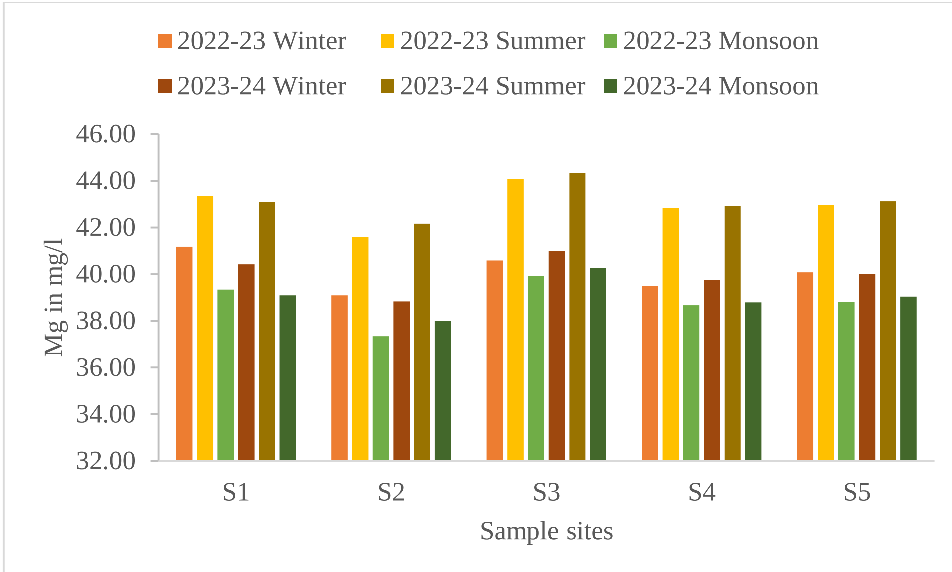

Figure 6: Magnesium analysis of soil samples.

Soil calcium (Ca) analysis

Soil calcium (Ca) concentrations showed a clear seasonal trend across all zones during 2022-23 and 2023-24, with monsoon values consistently higher than winter and summer. In 2022-23, S1 recorded Ca values ranging from 78.50 in summer to 82.50 in monsoon, and a similar pattern was observed in 2023-24, although winter and summer values decreased slightly, while monsoon values remained largely stable. S2 showed the lowest Ca concentration overall, with values increasing from 75.00 in summer 2022-23 to 79.50 in monsoon 2023-24, indicating a gradual improvement. S3 consistently recorded the highest Ca values among all zones, peaking at 85.25 in the 2022-23 monsoon and increasing slightly to 85.75 in 2023-24, confirming its status as a Ca-rich zone. S4 showed moderate Ca levels with slight fluctuations, while S5 showed very stable values across both years, with nearly identical measurements in 2022-23 and 2023-24 (Figure 7). In zones S1-S5, soil calcium levels showed a consistent seasonal pattern across both years, with the highest levels during the monsoon season and lower levels during the winter and summer months. Calcium levels remained stable between 2022-23 and 2023-24, with only minor seasonal and annual variations. Zone S3 consistently had the highest calcium levels, while S2 had the lowest, although levels in S2 gradually improved over time [51].

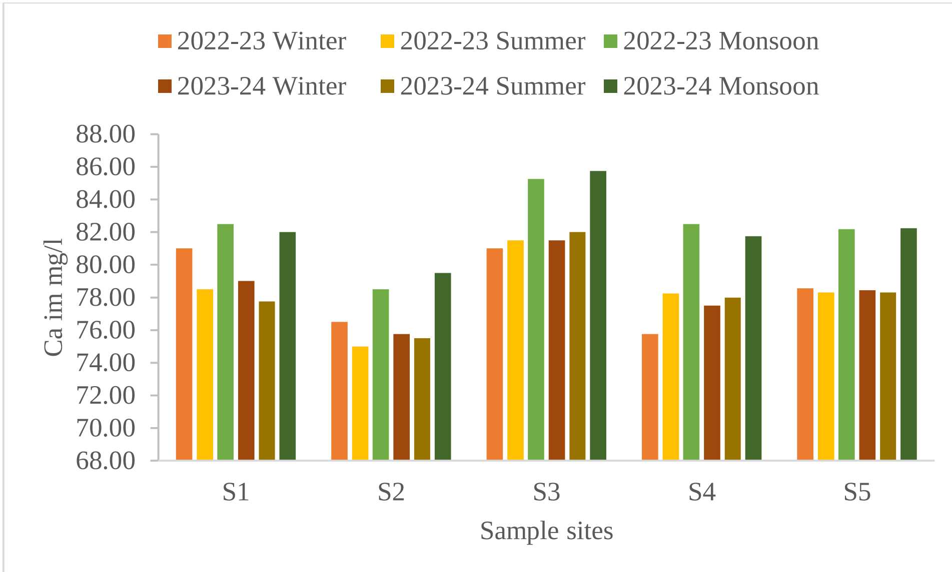

Figure 7: Calcium analysis of soil samples.

Soil nitrate (NO_3) analysis

Soil nitrate (NO_3) concentrations across all zones during 2022-23 and 2023-24 showed very small but consistent seasonal variations, generally increasing slightly during the monsoon. In 2022-23, S1 recorded values ranging from 44.89 in the monsoon to 45.93 in the summer, and a similar trend continued in 2023-24, with minor fluctuations but overall stability across seasons. S2 showed a slight increase in NO_3 during the monsoon, from 45.91 in 2022-23 to 45.85 in 2023-24, while winter and summer values remained nearly identical between the two years. S3 showed consistently lower nitrate levels than the other zones, with values ranging between 33.44 and 34.40 across seasons, with only a slight increase in 2023-24. S4 showed the lowest NO_3 values overall, but these remained stable across both years, with little seasonal variation. S5 showed the highest monsoon values across all zones, increasing from 36.49 in 2022-23 to 36.22 in 2023-24, reflecting the frequent monsoon increases despite a slight decrease from year to year (Figure 8). In zones S1-S5, soil nitrate levels remained very low in both years, but showed consistent seasonal variations, with a slight increasing trend during the monsoon season. NO_3 levels remained stable between 2022-23 and 2023-24, indicating minimal year-to-year variation. Consistently low nitrate levels were recorded in zones S3 and S4, while zone S5 showed comparatively higher concentrations during the monsoon [52-54].

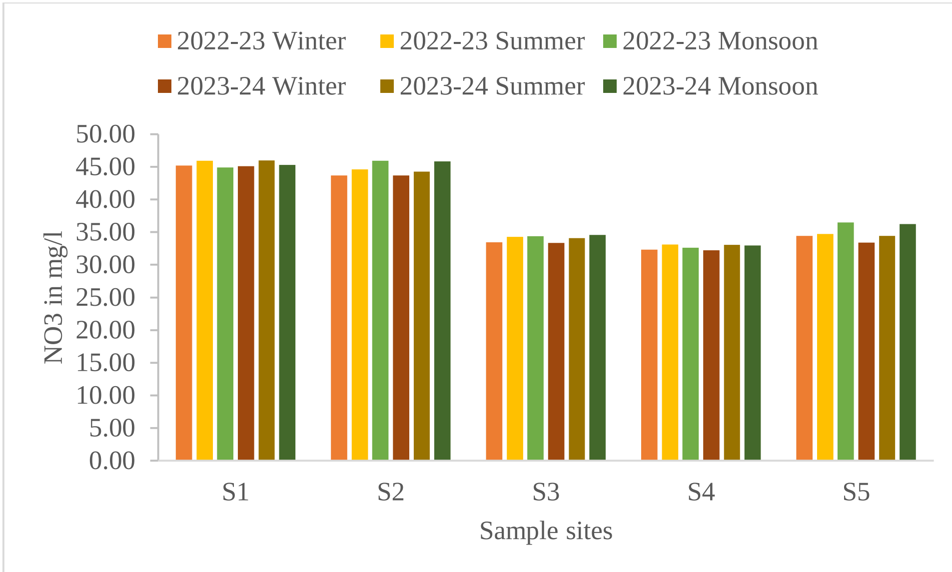

Figure 8: Nitrate analysis of soil samples.

Soil phosphate (PO_4) analysis

Soil phosphate (PO_4) concentrations across all zones during 2022-23 and 2023-24 showed very little seasonal and annual variation, indicating overall stability in phosphate levels. In S1, PO_4 values remained nearly constant across seasons, varying only slightly from 4.83 to 4.88, indicating no significant weather effect. S2 consistently showed higher PO_4 levels than S1 and S3, with a slight increase from 5.63-5.67 in 2022-23 to 5.64-5.68 in 2023-24, indicating stable but slightly improved phosphate availability. S3 showed nearly consistent values across seasons and years, remaining within a narrow range of 5.36-5.37, indicating less fluctuation. S4 recorded the highest phosphate levels of all zones, with values remaining consistent between 8.04 and 8.07 across both years, demonstrating strong stability. S5 showed the lowest PO_4 values overall, remaining stable at 3.49 across most seasons and years, and only slightly increasing to 3.52 during the 2023-24 monsoon (Figure 9). In zones S1-S5, soil phosphate levels remained very stable throughout both the 2022-23 and 2023-24 seasons, with minimal seasonal or annual variation. Only minor fluctuations were observed across all zones, indicating that seasonal conditions have a limited impact on phosphate dynamics. Zone S4 consistently recorded the highest PO_4 levels, while S5 had the lowest, yet still stable, levels. The results suggest that phosphate levels are well-balanced and stable across the entire study area [55-57].

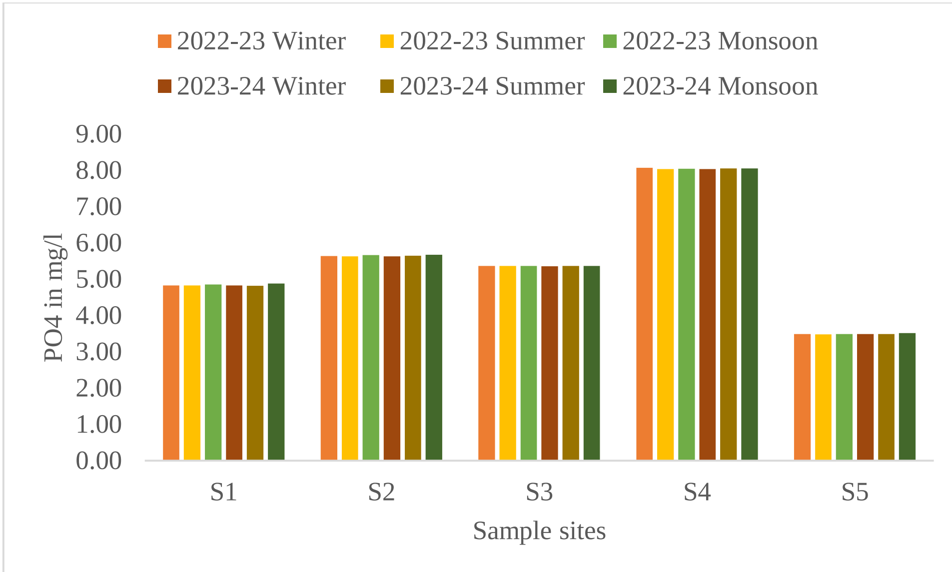

Figure 9: Phosphate analysis of soil samples.

Soil sodium (Na) analysis

During 2022-23 and 2023-24, seasonal and annual variations in soil sodium (Na) concentrations were observed in all zones, with most zones experiencing higher sodium levels during the summer or monsoon seasons. In 2022-23, Na values in S1 ranged from 9.35 in winter to 11.73 in summer, while in 2023-24, overall values increased, especially during the monsoon season, reaching 11.55, indicating a general increase in sodium concentration. S2 showed irregular fluctuations, with the highest value of 12.53 recorded during the monsoon season of 2022-23, while levels declined during the winter season of 2023-24, reflecting seasonal variations in sodium accumulation. In S3, the highest value was recorded in the summer of 2022-23 at 14.43, which decreased slightly in 2023-24. However, values increased slightly during the winter and monsoon seasons, indicating minor year-to-year variations. S4 showed an increase in sodium levels in 2023-24, especially during the monsoon season, where the value increased to 13.28 compared to 11.50 the previous year, indicating increased Na mobility or input. S5 showed consistently higher Na concentrations in most zones, with significant increases during the winter and monsoon seasons of 2023-24, reaching 12.68 and 13.13, respectively (Figure 10). In zones S1-S5, soil sodium levels showed clear seasonal and annual variations, with generally higher values observed during the summer and monsoon seasons. Sodium levels increased slightly in 2023-24 compared to 2022-23, particularly during the monsoon season, indicating increased sodium mobility or accumulation. The most significant increases were observed in zones S4 and S5, while zones S2 and S3 showed irregular but moderate fluctuations [58].

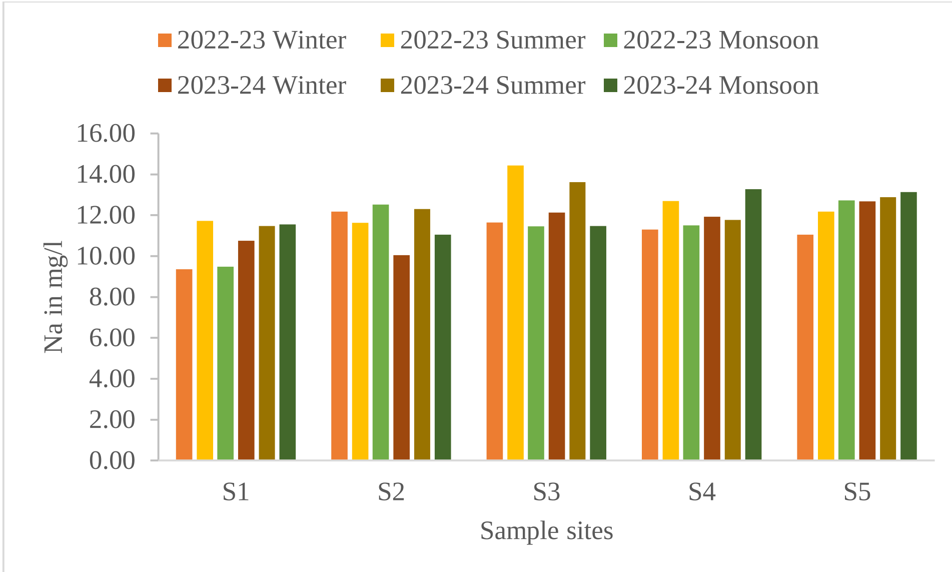

Figure 10: Sodium analysis of soil samples.

Soil potassium (K) analysis

The potassium (K) content in the soil exhibited clear seasonal and slight inter-annual variations across all zones during 2022-23 and 2023-24, with summer and winter values generally higher than those in the monsoon. In 2022-23, S1 showed K values ranging from 43.49 in the monsoon to 46.22 in winter, and in 2023-24, winter values decreased slightly to 43.82 while summer and monsoon values remained relatively stable, indicating minor year-to-year variation. S2 recorded moderately high K levels, with minimal fluctuations between 49.15 and 50.96 across both years and seasons, reflecting overall stability. S3 displayed higher K concentrations, peaking at 67.11 in the 2022-23 summer and remaining nearly constant in 2023-24, suggesting a consistently rich potassium zone. S4 had the highest K levels among all zones, ranging from 69.45 to 71.49, with slight increases in summer 2023-24, indicating stable but elevated potassium content. S5 showed moderately high K values with minimal seasonal changes, maintaining consistency across both years (Figure 11). In zones S1-S5, soil potassium levels showed a clear seasonal pattern and minor annual variations, with levels generally higher during the summer and winter months and slightly lower during the monsoon season. Zones S4 and S3 consistently exhibited the highest K content, indicating potassium-rich soil, while S1 and S5 had moderate levels with stable seasonal trends. Potassium levels remained largely consistent between 2022-23 and 2023-24, with only minor year-to-year fluctuations [59, 60].

Figure 11: Potassium analysis of soil samples.

Soil sulfate (SO_4) analysis

During the 2022-23 and 2023-24 monsoon seasons, significant seasonal and interannual variations in soil sulfate (SO_4) concentrations were observed across all zones, with summer and monsoon levels generally higher than winter levels. In 2022-23, S1 showed SO_4 concentrations ranging from 11.10 in winter to 17.43 in summer. In 2023-24, winter and summer levels decreased slightly to 11.03 and 11.90, respectively, and monsoon levels decreased slightly to 13.58, indicating a slight decrease in overall sulfate concentrations. S2 recorded a moderate level with a peak of 17.38 in the 2022-23 monsoon season, followed by an increase to 18.45 in the 2023-24 monsoon season, indicating increased sulfate accumulation during that period. S3 showed a steady increase from winter to monsoon in both years, with slightly higher values in 2023-24, especially in summer at 16.30, indicating better sulfate availability. S4 showed a peak value of 19.00 in summer in 2022-23, which decreased in 2023-24, indicating minor year-to-year fluctuations across seasons. S5 showed moderate sulfate levels with a summer peak in both years and relatively stable monsoon values (Figure 12). In zones S1-S5, soil sulfate levels showed a clear seasonal pattern in both years, with generally higher levels during the summer and monsoon seasons and lower levels during the winter. While most zones showed only minor year-to-year fluctuations, zones S2 and S3 recorded a slight increase in sulfate levels during the 2023-24 monsoon and summer seasons, indicating greater sulfate accumulation and availability [52, 57].

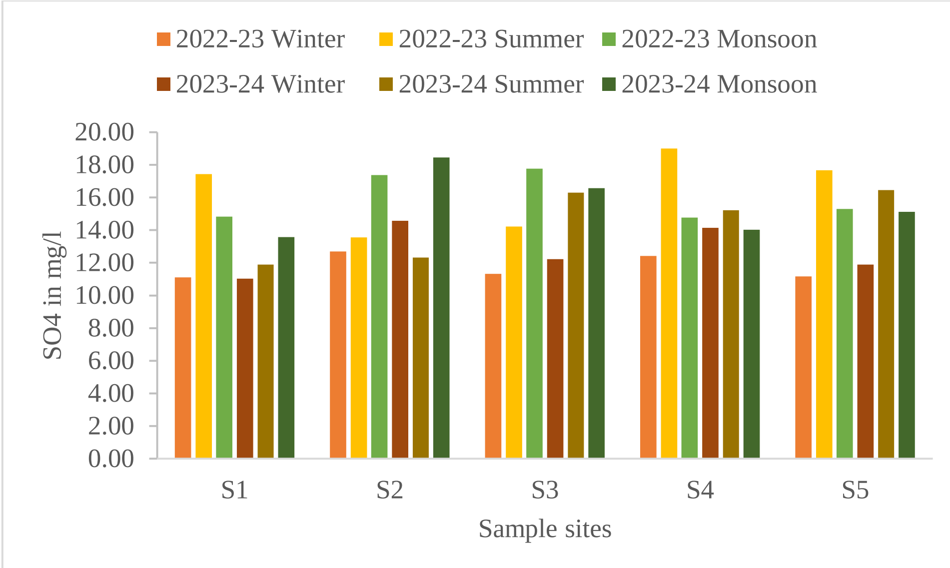

Figure 12: Sulfate analysis of soil samples.

Weeds analysis

In this study, weeds collected through quadrat methods from five sites (S1-S5) in three seasons, winter, summer, and monsoon during 2022-23 and 2023-24 of Khop Taal Pond were analyzed for their density, and six dominant species were identified, such as *A. blitum* (Ab), *C. rotundus* (Cr), *I. aquatica* (Ia), *N. nucifera* (Nn), *P. crassipeus* (Pc), and *T. natans* (Tn) (Table 1). The results indicated various weed in which, mainly six species available in the pond, and their characteristics were discussed in this manner [64-67]. The *A. blitum* plant can grow in wet conditions and is often found in disturbed areas. It can serve as a food source for herbivorous fish and other wildlife. The *C. rotundus*, known as nutgrass, can thrive in wetland areas and contributes to overall biodiversity by providing habitat and stabilizing soil. The *I. aquatica* species semi-aquatic plant that thrives in shallow water and is often used in culinary dishes. The *N. nucifera* species iconic plant is not only aesthetically pleasing but also plays an important role in providing habitat and food for various aquatic organisms. The *P. crassipes* species, known as water hyacinth, this floating plant that can quickly cover the water surface, affecting light penetration and oxygen levels. Although it can be invasive, it also provides a habitat for fish and invertebrates. The *T. natans* species, known as water chestnut, this submerged plant that provides shelter for fish and other aquatic life. Its edible seeds are also a source of food for both wildlife and humans.

Table 1: ***Analysis of aquatic weeds from five sites in Khop Taal Pond over two years***

Aquatic Weeds	Seasons	2022-23						2023-24						
		(S1)	(S2)	(S3)	(S4)	(S5)	Sum	(S1)	(S2)	(S3)	(S4)	(S5)	Sum	Aveg.
Amaranthus blitum (Ab)	Winter	++	+	-	+	+	5	+	-	+	+	+	4	4.5
	Summer	-	++	+	+	+	5	+	+	-	+	-	3	4.0
	Monsoon	-	+	+	-	-	2	-	+	-	-	+	2	2.0
Cyperus rotundus (Cr)	Winter	++	+	-	+	++	6	++	-	+	++	-	5	5.5
	Summer	-	+	+	+	+	4	+	-	-	+	+	3	3.5
	Monsoon	-	+	+	-	-	2	-	+	-	-	+	2	2.0
Ipomoea aquatic (Ia)	Winter	+	+	+	+	+	5	+	++	-	+	-	4	4.5
	Summer	+	++	+	-	++	6	+	++	+	-	-	4	5.0
	Monsoon	-	++	+	-	-	3	-	++	-	-	+	3	3.0
Nelumbo nucifera (Nn)	Winter	-	+	-	++	+	4	-	+	-	++	-	3	3.5
	Summer	++	+	-	++	+	6	-	+	-	++	+	4	5.0
	Monsoon	-	+	-	+	+	3	-	-	-	+	+	2	2.5
Pontederia crassipes (Pc)	Winter	-	++	-	+	+	4	-	++	+	+	++	6	5.0
	Summer	+	++	+	++	-	6	+	++	+	++	+	7	6.5
	Monsoon	+	++	-	+	+	5	-	++	-	+	+	4	4.5
Trapa natans (Tn)	Winter	+	-	+	++	++	6	+	+	-	++	++	5	5.5
	Summer	-	++	+	++	+	6	-	++	+	+	-	3	4.5
	Monsoon	+	++	-	+	-	4	-	++	-	+	+	4	4.0
6	18	12	25	10	19	16		9	22	6	19	13		

Seasonal Weeds Analysis

Analysis of the average number of weeds over both years revealed clear seasonal variations in aquatic weeds. *Amaranthus blitum* (Ab) and *Cyperus rotundus* (Cr) were most abundant during the monsoon season, with average numbers of 4.5 and 5.5, respectively, and least abundant during the summer. *Ipomoea aquatica* (Ia) and *Nelumbo nucifera* (Nn) were more prevalent during the winter, with an average number of 5.0, while their numbers were comparatively lower during the summer. *Pontederia crassipes* (Pc) was most abundant during the winter, with a count of 6.5, and *Trapa natans* (Tn) had the highest average numbers during the monsoon and summer seasons, at 5.5 and 4.0, respectively (Figure 13).

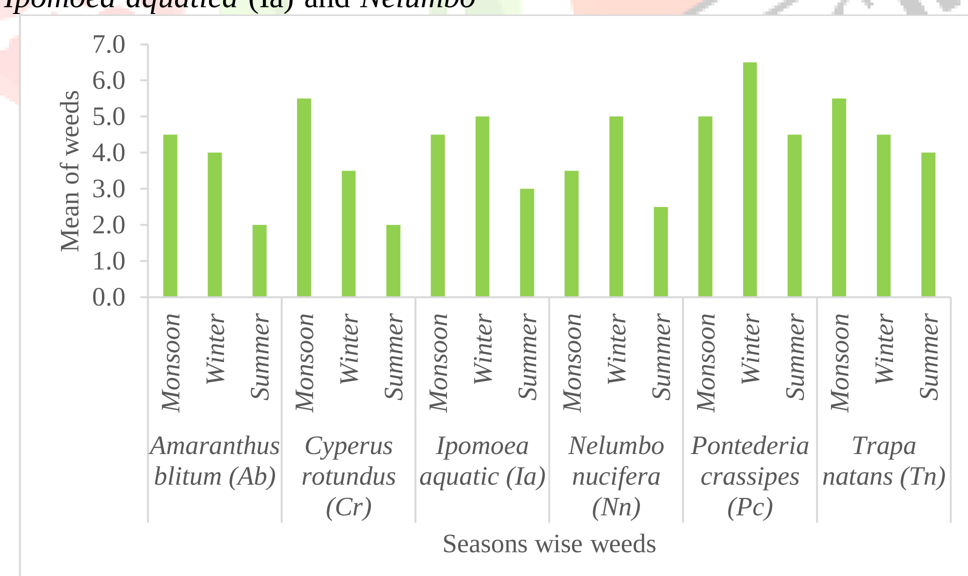

Figure 13: Average analysis of seasonal weeds in both years.

Site-wise weed analysis

Analysis of weed counts at different locations revealed differences between the two years. In 2022-23, the highest number of weeds was found at S2 (25), followed by S4 (19) and S5 (16), while S3 (10) and S1 (12) had fewer weeds [65]. In 2023-24, the number of weeds decreased at most locations, with the lowest number at S3 (6) and a comparatively higher number at S2 (22). The overall reduction in weed numbers in 2023-24 compared to the previous year indicates a decrease in weed infestation at most locations (Figure 14).

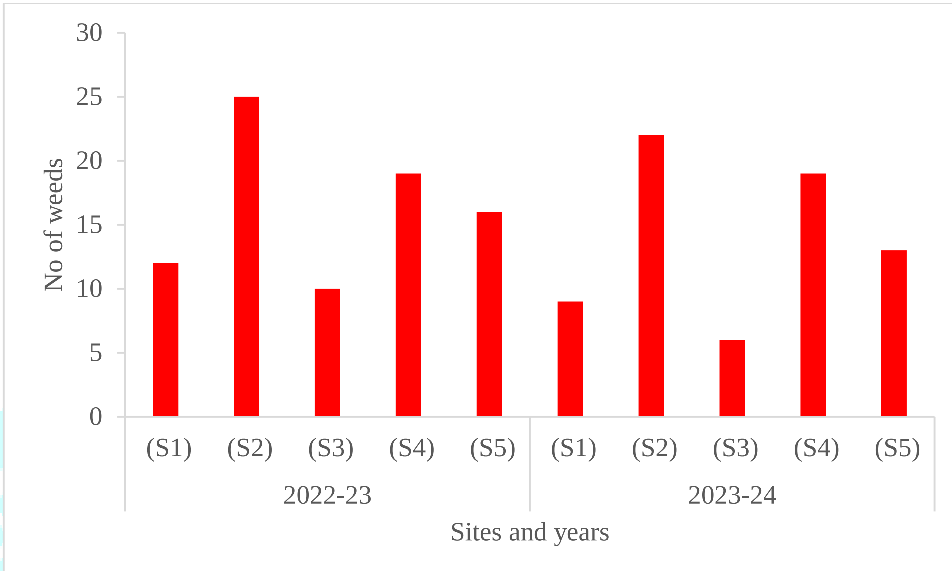

Figure 14: Analysis of weed numbers based on site in both years.

Comparative analysis of weeds

An analysis of weed frequency over two years revealed a decrease from 4.56 in 2022-23 to 3.78 in 2023-24. This indicates a reduction in the total number of weeds in the second year, which could be attributed to seasonal factors (Figure 15).

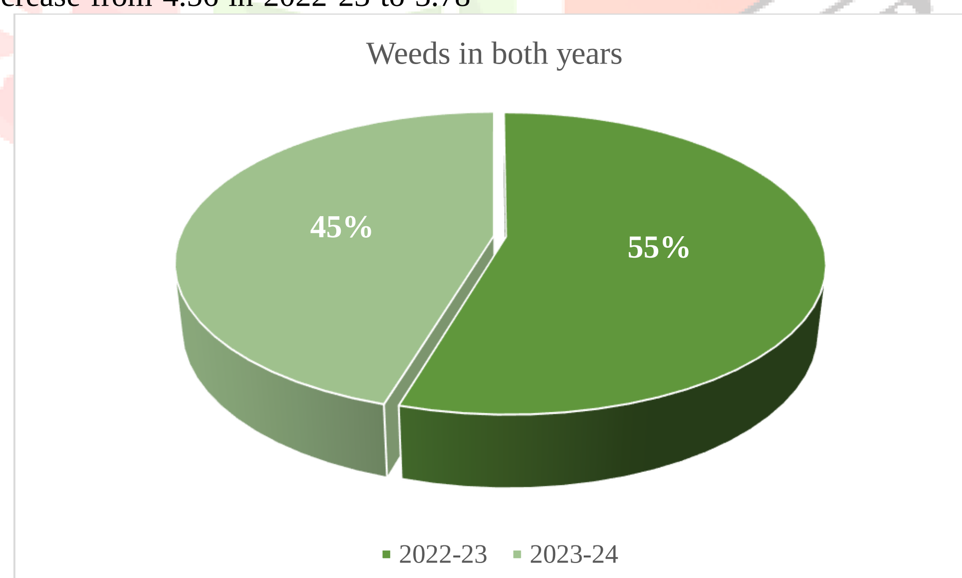

Figure 15: Analysis of weed frequency in both years.

Conclusion

This study highlights the complex interactions between soil nutrient dynamics, aquatic weed growth, and fish diversity in shaping the ecological health of Khop Taal pond. Sustainable management practices, including regular monitoring of soil and water quality, controlled management of aquatic weeds, and community-based fisheries regulation, are essential for maintaining ecological balance. Protecting and managing Khop Taal pond through scientifically informed strategies will help preserve its ecological integrity and ensure its continued socio-economic benefits for present and future generations.

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