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Comparative Physico-Chemical Analysis of Surface and Subsurface Soils from Pilkha Pahad, Surajpur/Surguja District, Chhattisgarh, India

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Abstract:
The present investigation highlights a comparative assessment of the physico-chemical properties of surface (0–15 cm) and subsurface (15–30 cm) soils collected from Pilkha Pahad, Surajpur/Surguja District, Chhattisgarh, India. The study aims to examine spatial and depth-wise variations in key soil parameters, including pH, electrical conductivity (EC), organic carbon (OC), major nutrients—Nitrogen (N), Phosphorus (P), and Potassium (K)—as well as essential micronutrients such as Sulphur (S), Zinc (Zn), Iron (Fe), Manganese (Mn), Copper (Cu), and Boron (B). The results reveal noticeable variability among sampling locations and between soil horizons. Surface soils exhibited comparatively higher organic carbon and nitrogen content, indicating greater biological activity and the accumulation of organic residues in the upper layer. Conversely, subsurface soils showed slightly elevated electrical conductivity and fluctuating micronutrient levels, which may be associated with leaching processes and underlying soil composition. The pH of the soils ranged from mildly acidic to near neutral, reflecting conditions conducive to the growth of most agricultural crops. Overall, this comparative analysis provides important insights into nutrient distribution and soil fertility status in the Pilkha Pahad region. The findings serve as a useful baseline for sustainable soil management and region-specific agricultural planning.

Keywords: Physico-chemical properties; Surface soil; Subsurface soil; Pilkha Pahad; Soil fertility; Macronutrients; Micronutrients; Electrical conductivity; Organic carbon; Soil pH; Nutrient dynamics; Surajpur; Surguja District; Chhattisgarh; Agricultural soil analysis.

1. INTRODUCTION

- Soil is a fundamental natural resource that supports plant growth, regulates nutrient cycling, and maintains ecological stability. Acting as a reservoir of water, minerals, organic matter, and microorganisms, soil quality directly influences crop productivity, ecological balance, and long-term agricultural sustainability. Therefore, analysing soil physico-chemical characteristics is essential for understanding soil health and framing sustainable land-use and farming strategies.

- The present study focuses on the **Pilkha Pahad region** of **Surajpur/Surguja District**, located in the northern part of **Chhattisgarh, India**. The site is situated near the settlement of **Pilkha**, which lies at **23.138975° N latitude and 83.084066° E longitude**. Pilkha Pahad is not only agriculturally significant but is also recognised as a **local tourist attraction and popular picnic spot**, known for its natural scenic beauty and the presence of a **small lake (jhil)** that enhances the ecological value of the area. Variations in topography, land use, soil texture, and the presence of a water body influence soil moisture, nutrient distribution, and overall fertility patterns across the region.
- This research aims to conduct a **comparative physico-chemical evaluation of surface (0–15 cm) and subsurface (15–30 cm) soils** collected from selected sites in Pilkha Pahad. The analysis includes key parameters such as **pH, electrical conductivity (EC), organic carbon (OC)**, and the available concentrations of major nutrients—**Nitrogen (N), Phosphorus (P), and Potassium (K)**—along with selected micronutrients. The results will provide insights into nutrient variability and fertility status within the Pilkapahad region, supporting the development of site-specific soil management practices and promoting sustainable agriculture in the Surajpur–Surguja belt.

2. LITERATURE REVIEW

1. **Prasad, Maurya and Srivastava (2025)** reported that airborne dust and sand particles considerably influence microwave and millimetre-wave communication by enhancing signal attenuation and scattering. When particle dimensions are comparable to the wavelength, researchers frequently employ **Mie Scattering Theory** to estimate scattering and absorption behaviour. To describe the composite dielectric properties of dust-laden media, **Effective Medium Approximations** such as the **Maxwell–Garnett** and **Bruggeman** formulations are often applied. Under dense particulate conditions, the **Radiative Transfer Equation (RTE)** is used to account for multiple-scattering effects. Several empirical and semi-empirical models—based on visibility, dust density, and particle mass concentration—also provide practical estimates of signal loss in field environments. Experimental validation methods in previous studies include **Vector Network Analyzer (VNA) measurements**, **Point-to-Point Analyzer (PPA) setups**, the **Infinite Sample Technique**, and the **Two-Point Dielectric Method**. Overall, the literature consistently shows that attenuation increases with both frequency and dust concentration, with frequencies above 30 GHz being especially sensitive. Coal dust exhibits higher dielectric losses than sand, making its impact particularly relevant in mining regions such as Surguja.[1]
2. **Prasad G. and Maurya M. K. et al. (2025)** carried out an investigation on the physico-chemical characteristics of soils in the Lafri region of Surguja district, Chhattisgarh. Soil plays a vital role in agriculture, as it governs plant development, nutrient supply, and overall crop performance. Their study examined key parameters including pH, organic carbon, moisture levels, and major nutrients such as nitrogen, phosphorus, and potassium. The results revealed noticeable spatial variation in soil properties influenced by local climatic conditions and geographical features. The authors emphasized that such assessments are essential for determining soil fertility status and identifying suitable crops for the area. Overall, the study provides important guidance for sustainable land-use planning,

balanced nutrient management, and improving agricultural productivity in the region.[2]

3. **Prasad G. and Maurya M. K. et al. (2025)** carried out a comparative assessment of the physico-chemical characteristics of surface and subsurface soils from Lakhanpur, Surguja district, Chhattisgarh, to evaluate their agricultural potential. The collected soil samples were examined for texture, pH, electrical conductivity, organic carbon, major nutrients (N, P, K, and micronutrients), cation exchange capacity, and bulk density. Their findings showed noticeable differences in soil texture and structure, which influence moisture retention and drainage behaviour. The pH ranged from slightly acidic to neutral, while EC values indicated moderate salinity in certain locations. Organic carbon levels were generally satisfactory, but deficiencies of nitrogen and phosphorus were observed. The researchers emphasized the importance of site-specific soil amendments and better management strategies to improve fertility and promote sustainable agricultural development.[3]
4. **Kumar, S. and Dr. Maurya (2025)** carried out a comparative analysis of agricultural soils from Ajirma, Raghunathpur, and Mainpat in the Surguja region, reporting notable differences in their physico-chemical characteristics, especially with respect to pH, organic carbon, and nitrogen levels. Among the studied sites, soils from Mainpat displayed comparatively better nutrient balance, whereas those from Ajirma and Raghunathpur showed higher acidity and deficiencies in key nutrients. The study emphasized the importance of location-specific soil enhancement strategies, including liming to regulate soil pH, incorporation of organic matter to improve carbon content, and appropriate fertilization practices to boost soil fertility and promote sustainable agricultural growth in the region.[4]
5. **Srivastava and Mishra (2004)** conducted controlled laboratory measurements to determine the real (ε_1) and imaginary (ε_2) components of the complex dielectric constant (ε) for sand, silt, and clay at 9.967 GHz. Using the infinite sample technique, they evaluated how varying moisture levels influence the dielectric behaviour of these soil types. Their findings showed that both ε_1 and ε_2 increased gradually with rising moisture content up to a certain limit, after which a pronounced escalation occurred. This trend indicates that moisture has a significant impact on the dielectric properties of soils, with the rate of increase becoming much steeper as the soil approaches saturation.[5]

3. MATERIAL AND METHODS

3.1 Study Area Description

The present investigation was carried out in and around the Pilkha Pahad region of Surajpur/Surguja District, Chhattisgarh, India. The study area is characterized by undulating hilly terrain associated with forested patches, natural drainage channels, and limited agricultural activity in the adjoining low-lying zones. The physiography of Pilkha Pahad plays a significant role in governing soil development, erosion processes, moisture retention, and nutrient dynamics.

Climatically, the region falls under the subtropical monsoon zone, experiencing warm summers, moderate winters, and a well-defined monsoon season. Seasonal rainfall and temperature fluctuations strongly influence soil moisture availability, organic matter decomposition, and nutrient cycling across surface and subsurface layers.

To evaluate spatial and depth-wise variability in soil physico-chemical properties, five representative sampling locations were selected along a gradient extending outward from the central part of Pilkha Pahad. The approximate geographic location of the study area is around 23.138975° N latitude and 83.084066° E longitude. The selected sampling sites are as follows:

- **Sample 1:** Pilkha Pahad (Centre / Jhil area)
- **Sample 2:** Pilkha Pahad (approximately 500 m from centre)
- **Sample 3:** Pilkha Pahad (approximately 1000 m from centre)
- **Sample 4:** Pilkha Pahad (approximately 1500 m from centre)
- **Sample 5:** Pilkha Pahad (approximately 2000 m from centre)

These sites collectively represent varying micro-topographic conditions, vegetation density, and degrees of anthropogenic influence. Such a sampling design provides a reliable framework for comparing soil properties and assessing how distance from the central hill zone influences soil fertility and quality.

3.2 Soil Sample Collection

Soil sampling was carried out to examine variations in physico-chemical characteristics at different depths across the Pilkha Pahad region. At each sampling location, soil samples were collected from two distinct depth intervals:

- **Surface soil:** 0–15 cm
- **Subsurface soil:** 15–30 cm

To ensure representative sampling, five subsamples were randomly collected within a radius of approximately 10 meters at each site. These subsamples were thoroughly homogenized to form one composite sample per depth per location. Sampling was conducted using clean stainless-steel augers and spades to prevent contamination and maintain the integrity of the soil samples.

3.3 Sample Preparation

After collection, soil samples were processed following standard laboratory preparation procedures prior to analysis. The samples were first air-dried under shade at ambient temperature to avoid any alteration in chemical composition due to heat exposure. Dried samples were gently crushed using a wooden roller to break down soil aggregates without introducing metallic contamination.

Subsequently, the soils were passed through a 2 mm sieve to obtain uniform particle size and to remove coarse fragments, roots, and other extraneous materials. The prepared samples were then stored in properly labeled, airtight polyethylene containers for further physico-chemical analysis.

3.4 Physico-Chemical Analysis

All soil analyses were performed following established and widely accepted methodologies described in standard soil science literature (Pansu & Gautheyrou, 2006; Singh, 2023; Verma & Paul, 2023). The following parameters were analysed:

3.4.1 Soil Texture

Soil texture was determined by analyzing the relative proportions of sand, silt, and clay using the hydrometer and sieve method. The textural classes were assigned according to the USDA soil textural classification system.

3.4.2 Soil pH and Electrical Conductivity (EC)

- Soil pH was measured using a digital pH meter in a 1:2.5 soil–water suspension.
- Electrical conductivity (EC) was measured using a conductivity meter to evaluate the soluble salt content of the soil.

3.4.3 Organic Carbon

Soil organic carbon content was estimated using the wet oxidation method, which serves as an indicator of organic matter status, soil fertility, and biological activity.

3.4.4 Macronutrients

The available macronutrients analysed in the present study included:

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

These nutrients were determined using standard extraction procedures followed by titrimetric or spectrophotometric measurements commonly employed in soil fertility assessment.

3.4.5 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) was determined to assess the soil's capacity to retain and exchange essential nutrient cations, an important parameter influencing nutrient availability and overall soil productivity.

3.5 Data Interpretation

The obtained physico-chemical data were systematically evaluated to compare variations between surface (0–15 cm) and subsurface (15–30 cm) soil layers across the Pilkha Pahad region. Depth-wise comparisons were made to understand nutrient distribution patterns and soil profile development.

In addition, spatial comparisons among different sampling locations were carried out to assess the influence of distance from the central hill zone, micro-topography, vegetation cover, and land-use practices on soil quality. The interpretation of results provides valuable insight into soil fertility status and helps in understanding the environmental factors governing soil characteristics in the Pilkha Pahad area of Surajpur/Surguja District, Chhattisgarh.

Table-X: Comparative Physico-Chemical Parameters of Surface Soil Samples (0-15 cm) from Pilkha Pahad, Surajpur/Surguja District, Chhattisgarh

Parameters	Sample 1 Pilkha Pahad (Centre, Jhil Area)	Sample 2 Pilkha Pahad (500m)	Sample 3 Pilkha Pahad (1000m)	Sample 4 Pilkha Pahad (1500m)	Sample 5 Pilkha Pahad (1500m)
Ph	5.90	5.96	6.00	5.55	5.65
Electric Conductivity	0.34	0.19	0.30	0.18	0.12
Organic carbon	0.37	0.44	0.25	0.80	0.62
Nitrogen	140.00	153.00	115.00	277.00	231.00
Phosphorus	12.60	12.80	17.50	14.20	16.20
Potash	281.00	311.00	220.00	292.00	300.00
Zinc **Copper** **Iron** **Boron** **Manganese** **Molybdenum**	0.2 0.1 1.4 0.2 0.5 0.1	0.3 0.1 1.4 0.2 0.6 0.1	0.2 0.1 1.4 0.2 0.6 0.1	0.2 0.1 1.4 0.2 0.5 0.1	0.3 0.1 1.0 0.2 0.9 0.1

Table-Y: Comparative Physico-Chemical Parameters of Subsurface Soil Samples (15–30 cm) from Pilkha Pahad, Surajpur/Surguja District, Chhattisgarh

Parameters	Sample 1 Pilkha Pahad (Centre, Jhil Area)	Sample 2 Pilkha Pahad (500m)	Sample 3 Pilkha Pahad (1000m)	Sample 4 Pilkha Pahad (1500m)	Sample 5 Pilkha Pahad (1500m)
Ph	5.94	5.99	6.05	5.60	5.89
Electric Conductivity	0.26	0.24	0.39	0.33	0.24
Organic carbon	0.39	0.43	0.30	0.75	0.60
Nitrogen	144.00	161.00	126.00	269.00	227.00
Phosphorus	13.00	16.00	14.00	14.00	15.50
Potash	288.00	307.00	239.00	279.00	296.00
Zinc	0.3	0.2	0.2	0.1	0.2
Copper	0.2	0.2	0.1	0.1	0.1
Iron	1.4	0.9	1.2	1.5	1.4
Boron	0.2	0.2	0.2	0.2	0.2
Manganese	0.5	0.6	0.5	0.8	0.9
Molybdenum	0.1	0.1	0.1	0.1	0.1

4. RESULT AND DISCUSSION

In the present study entitled "Comparative Physico-Chemical Analysis of Surface and Subsurface Soils from Pilkha Pahad, Surajpur/Surguja District, Chhattisgarh, India," soil samples were systematically collected from five georeferenced locations across the Pilkha Pahad region. Sampling was carried out at two depths, namely surface soil (0–15 cm) and subsurface soil (15–30 cm), to examine depth-wise variations in soil characteristics. The selected sites represent increasing distances from the central hill zone of Pilkha Pahad, enabling an assessment of spatial variability in soil properties.

The investigation focused on the evaluation of major soil physico-chemical parameters, including soil reaction (pH), electrical conductivity (EC), organic carbon content, and available macronutrients such as nitrogen (N), phosphorus (P), and potassium (K). In addition, the availability of important micronutrients—zinc (Zn), iron (Fe), boron (B), manganese (Mn), and copper (Cu)—was determined to assess micronutrient status. The concentration of molybdenum (Mo) was also analyzed to understand the distribution of trace elements within the soil profile.

The results indicate pronounced spatial variability among the different sampling locations as well as distinct depth-related differences between surface and subsurface soil layers. Such variations in nutrient availability and soil chemical attributes can be attributed to differences in topography, vegetation cover, organic matter accumulation, and localized land-use or cultivation practices prevailing in the Pilkha Pahad region. These findings offer valuable insights into soil fertility status and nutrient dynamics, which are essential for sustainable land management. A comprehensive, parameter-wise comparison of soil properties across all sampling sites and depths is presented in the subsequent sections.

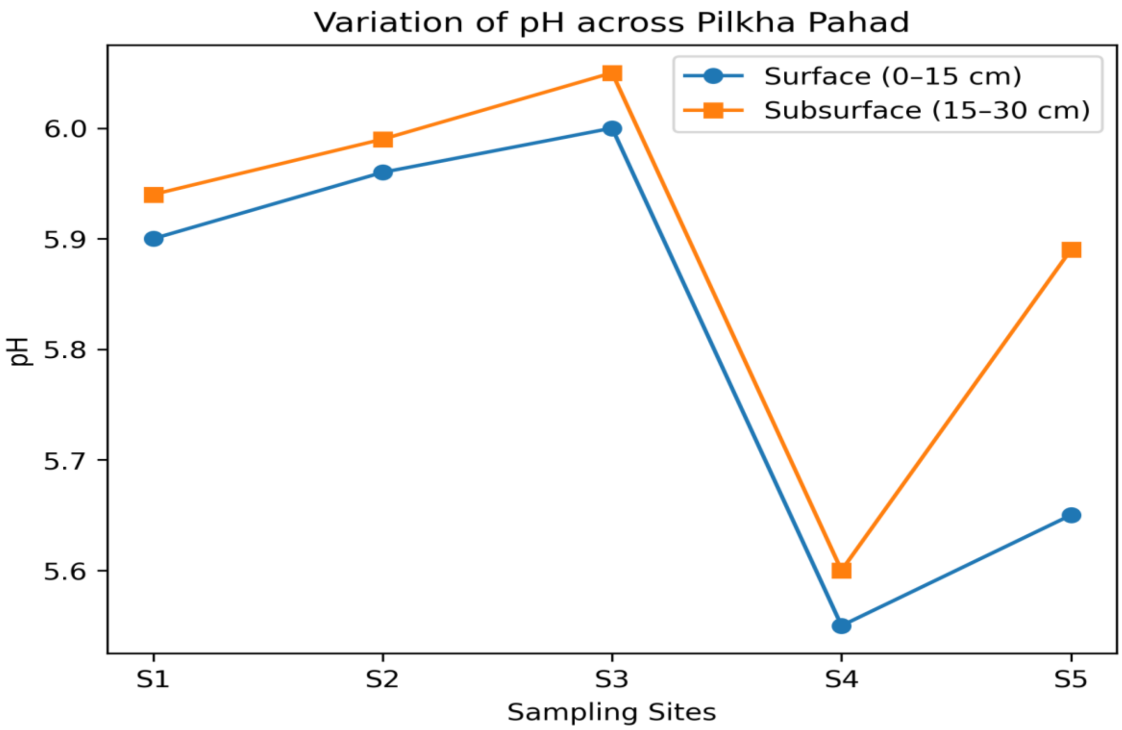
4.1 Soil pH

The soil reaction (pH) of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. The pH values of surface soils ranged from 5.55 to 6.00, indicating that the soils are predominantly slightly acidic in nature. Among the surface samples, the highest pH value (6.00) was recorded at Sample 3 (Pilkha Pahad, 1000 m), whereas the lowest value (5.55) was observed at Sample 4 (Pilkha Pahad, 1500 m). Surface soils from the central Jhil area (Sample 1) and nearby locations exhibited moderately acidic conditions, which may be attributed to organic matter accumulation and leaching under forested or semi-forested environments.

In subsurface soils, pH values varied between 5.60 and 6.05, reflecting a similar slightly acidic trend with marginal depth-wise variation. The maximum subsurface pH (6.05) was also observed at Sample 3, while the minimum value (5.60) occurred at Sample 4. In general, subsurface soils showed slightly higher pH values compared to surface layers at most sampling locations, possibly due to reduced organic matter content and lower biological activity with increasing depth.

The observed spatial and depth-wise variations in soil pH can be linked to differences in parent material, micro-topography, vegetation cover, and organic residue inputs across the Pilkha Pahad region. Slightly acidic soil conditions are favorable for the availability of several micronutrients but may influence phosphorus fixation and overall nutrient dynamics. These pH characteristics play an important role in determining soil fertility status and should be considered while formulating sustainable land-use and soil management strategies for the study area.

pH Variation: The pH values show noticeable variation between surface and subsurface soils, reflecting the influence of topography, organic matter distribution, and soil-forming processes.



4.2 Electrical Conductivity (EC)

The electrical conductivity (EC) values of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region are summarized in Tables X and Y, respectively. Electrical conductivity serves as an indicator of soluble salt concentration and overall salinity status of soils.

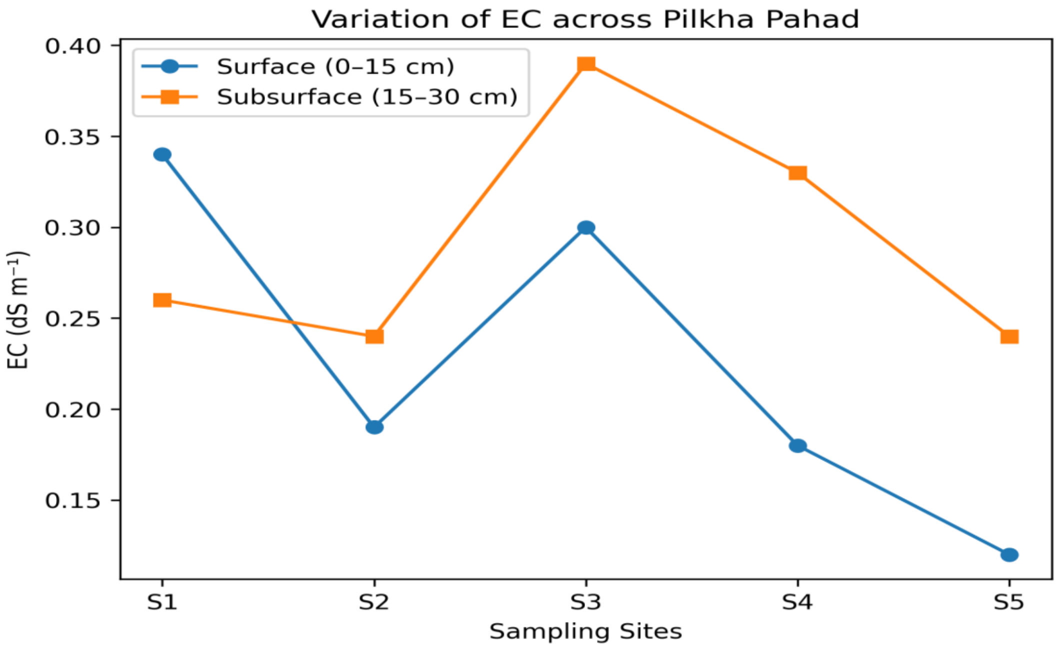
In surface soils, EC values ranged from 0.12 to 0.34 dS m^{-1}, indicating low salinity conditions across all sampling sites. The highest EC value (0.34 dS m^{-1}) was recorded at Sample 1 (Pilkha Pahad, Centre/Jhil area), which may be attributed to localized accumulation of soluble ions due to organic matter decomposition and moisture retention in low-lying zones. In contrast, the lowest EC value (0.12 dS m^{-1}) was observed at Sample 5 (1500 m), suggesting effective leaching of soluble salts under comparatively elevated terrain and better drainage conditions. Surface soils at intermediate distances (500–1000 m) exhibited moderate EC values ranging between 0.19 and 0.30 dS m^{-1}.

Subsurface soils exhibited EC values ranging from 0.24 to 0.39 dS m^{-1}, which were generally higher than those recorded in the surface layer at most locations. The maximum subsurface EC (0.39 dS m^{-1}) was observed at Sample 3 (1000 m), while the minimum value (0.24 dS m^{-1}) occurred at Samples 2 and 5. The comparatively elevated EC in subsurface layers may be associated with downward movement and accumulation of soluble salts through leaching processes, coupled with reduced evaporation losses at greater depths.

Overall, the EC values of both surface and subsurface soils fall well below the threshold for saline soils, indicating that salinity does not pose a constraint to soil productivity in the Pilkha Pahad region. The observed spatial and depth-wise variations in EC can be attributed to differences in micro-topography, soil moisture regime, vegetation cover, and natural drainage patterns. These findings highlight favorable soil conditions for sustainable agricultural and ecological management in the study area.

EC Variation

The EC values show noticeable variation between surface and subsurface soils, reflecting the influence of topography, organic matter distribution, and soil-forming processes.



4.3 Organic Carbon (%)

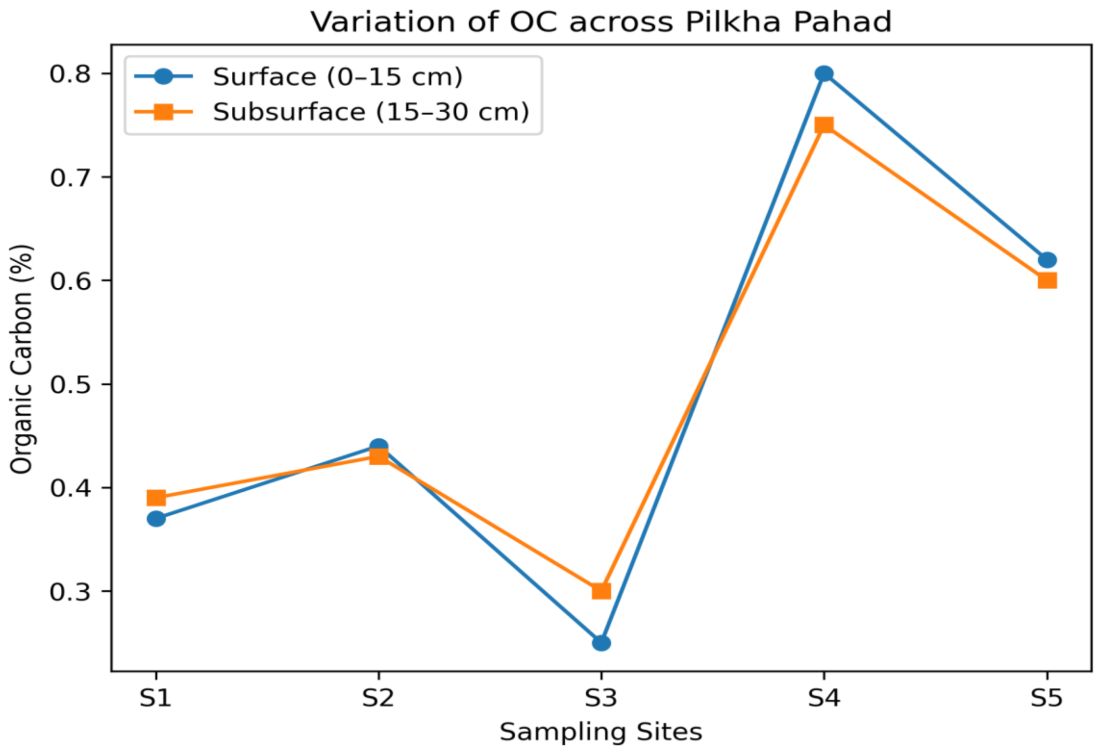
The distribution of soil organic carbon (OC) in surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from various locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Soil organic carbon is a key indicator of soil fertility, biological activity, and nutrient cycling.

In surface soils, organic carbon content varied from 0.25% to 0.80%, reflecting considerable spatial variability across the study area. The highest OC value (0.80%) was recorded at Sample 4 (Pilkha Pahad, 1500 m), followed by Sample 5 (0.62%), suggesting enhanced organic matter accumulation under relatively dense vegetation cover and minimal anthropogenic disturbance. In contrast, the lowest surface OC content (0.25%) was observed at Sample 3 (1000 m), which may be associated with comparatively lower biomass input and greater organic matter decomposition. Surface soils from the central Jhil area and 500 m location exhibited moderate OC values of 0.37% and 0.44%, respectively.

Subsurface soils showed organic carbon contents ranging from 0.30% to 0.75%, which were generally lower than or comparable to surface soil values at most locations. The maximum subsurface OC content (0.75%) was again observed at Sample 4, while the minimum value (0.30%) occurred at Sample 3. The slight reduction in organic carbon with increasing depth can be attributed to decreased organic residue input and reduced microbial activity in subsurface layers.

Overall, the observed spatial and depth-wise variations in organic carbon content are influenced by vegetation density, litter deposition, soil moisture regime, and topographic position across the Pilkha Pahad region. The relatively higher organic carbon levels at certain locations indicate favorable conditions for soil structure development and nutrient availability, contributing positively to overall soil fertility. These findings underline the importance of organic matter management for sustaining soil quality in the study area.

OC Variation: The OC values show noticeable variation between surface and subsurface soils, reflecting the influence of topography, organic matter distribution, and soil-forming processes.



4.4 Available Nitrogen (kg/ha):

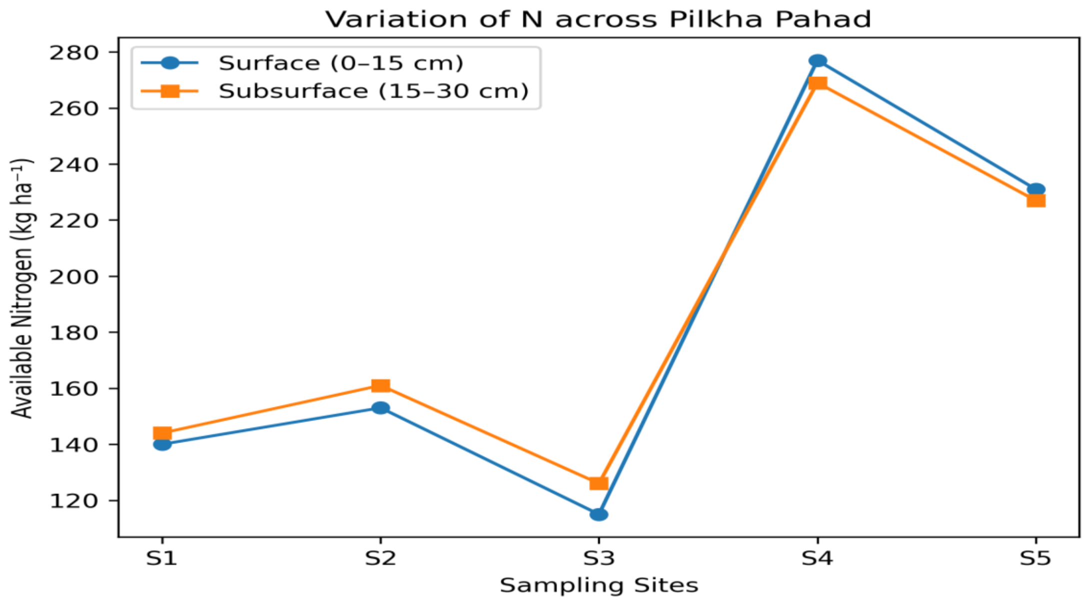
The available nitrogen content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Available nitrogen is a critical macronutrient governing plant growth and overall soil fertility.

In surface soils, available nitrogen values ranged from **115 to 277 kg ha^{-1}**, indicating considerable spatial variability across the study area. The highest nitrogen content (277 kg ha^{-1}) was recorded at Sample 4 (Pilkha Pahad, 1500 m), followed by Sample 5 (231 kg ha^{-1}), suggesting enhanced nitrogen accumulation under relatively undisturbed conditions and higher organic matter inputs. In contrast, the lowest nitrogen content (115 kg ha^{-1}) was observed at Sample 3 (1000 m), which may be attributed to reduced organic carbon levels and possible nitrogen losses through leaching or mineralization. Surface soils at the central Jhil area and the 500 m location exhibited moderate nitrogen values of 140 and 153 kg ha^{-1}, respectively.

Subsurface soils exhibited available nitrogen contents ranging from **126 to 269 kg ha^{-1}**, which were generally comparable to or slightly lower than surface soil values at most locations. The maximum subsurface nitrogen content (269 kg ha^{-1}) was again observed at Sample 4, while the minimum value (126 kg ha^{-1}) occurred at Sample 3. The marginal decrease in nitrogen content with depth may be associated with declining organic matter content and reduced microbial activity in deeper soil layers.

Overall, the observed spatial and depth-wise distribution of available nitrogen across the Pilkha Pahad region reflects the combined influence of vegetation cover, organic residue accumulation, soil moisture regime, and topographic position. Although nitrogen levels varied widely among sites, the results indicate low to medium nitrogen status in several locations, highlighting the need for appropriate nutrient management practices to sustain soil fertility and productivity in the study area.

N Variation: The N values show noticeable variation between surface and subsurface soils, reflecting the influence of topography, organic matter distribution, and soil-forming processes.



4.5 Available Phosphorus (kg/ha)

The available phosphorus content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Phosphorus is an essential macronutrient that plays a vital role in energy transfer, root development, and overall plant growth.

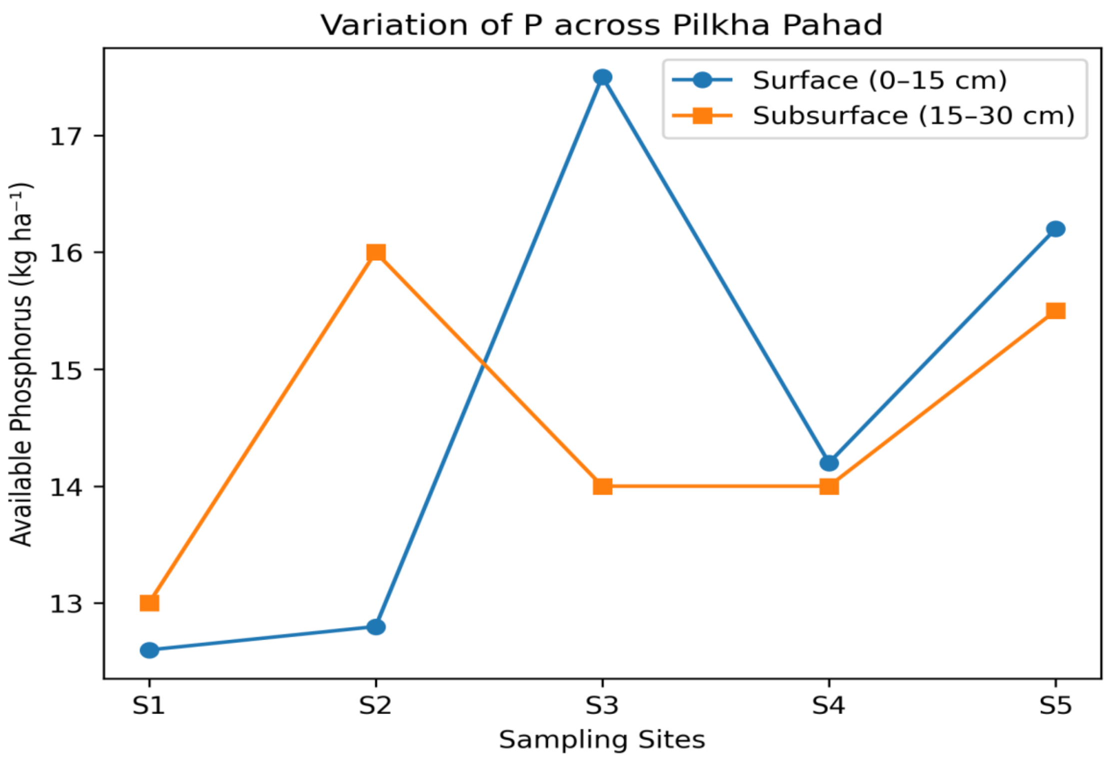
In surface soils, available phosphorus values ranged from **12.60 to 17.50 kg ha⁻¹**, indicating **low to moderate phosphorus availability** across the study area. The highest phosphorus content (17.50 kg ha⁻¹) was observed at Sample 3 (Pilkha Pahad, 1000 m), followed by Sample 5 (16.20 kg ha⁻¹). In contrast, the lowest value (12.60 kg ha⁻¹) was recorded at Sample 1 (Centre, Jhil area), which may be attributed to phosphorus fixation under acidic soil conditions and limited external phosphorus inputs. Surface soils at the remaining locations exhibited intermediate phosphorus levels.

Subsurface soils showed available phosphorus contents ranging from **13.00 to 16.00 kg ha⁻¹**, with comparatively narrower variation among the sampling sites. The maximum subsurface phosphorus value (16.00 kg ha⁻¹) was recorded at Sample 2 (500 m), while the minimum value (13.00 kg ha⁻¹) occurred at Sample 1. In general, subsurface soils exhibited slightly higher or comparable phosphorus levels relative to surface soils at certain locations, possibly due to downward movement of soluble phosphorus fractions and reduced fixation in deeper soil layers.

The spatial and depth-wise variations in available phosphorus across the Pilkha Pahad region can be attributed to differences in soil pH, organic matter content, parent material, and topographic position. The overall low to medium phosphorus status of the soils suggests a potential limitation for crop productivity, emphasizing the need for site-specific phosphorus management strategies to improve soil fertility and sustain agricultural production in the study area.

P Variation

The P values show noticeable variation between surface and subsurface soils, reflecting the influence of topography, organic matter distribution, and soil-forming processes.



4.6 Available Potash (kg/ha):

The available potassium content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Potassium is an essential macronutrient that plays a crucial role in enzyme activation, water regulation, and overall plant stress tolerance.

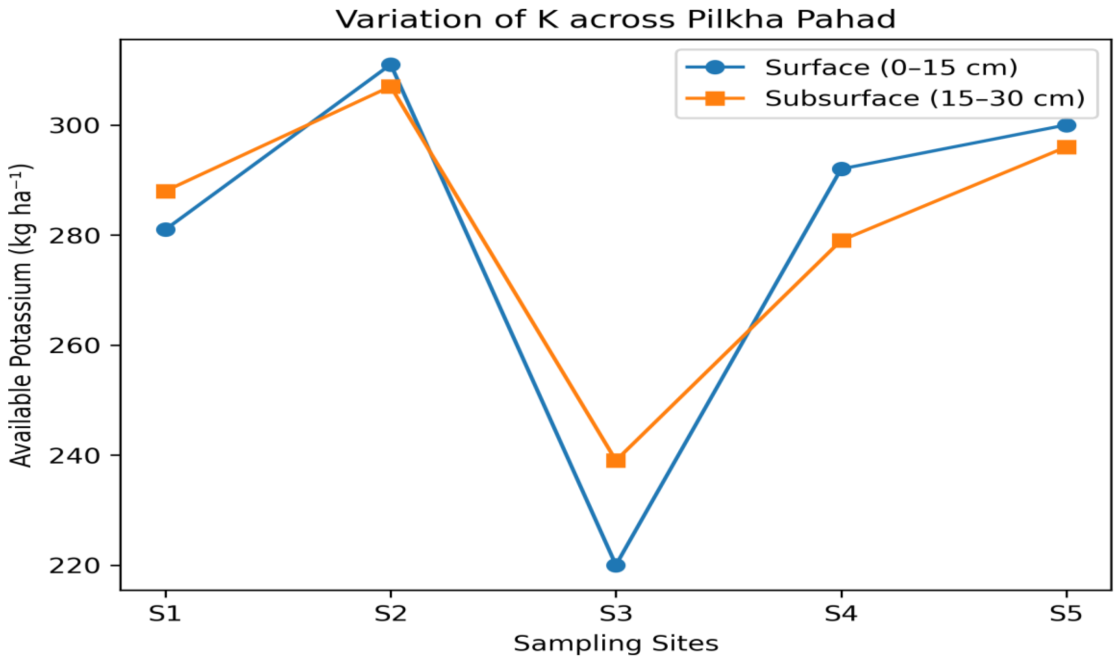
In surface soils, available potassium values ranged from 220 to 311 kg ha⁻¹, indicating medium to high potassium status across the study area. The highest potassium content (311 kg ha⁻¹) was recorded at Sample 2 (Pilkha Pahad, 500 m), followed closely by Sample 5 (300 kg ha⁻¹) and Sample 4 (292 kg ha⁻¹). In contrast, the lowest surface potassium value (220 kg ha⁻¹) was observed at Sample 3 (1000 m), which may reflect differences in parent material composition or enhanced potassium uptake by vegetation.

Subsurface soils exhibited available potassium contents ranging from 239 to 307 kg ha⁻¹, showing relatively less variability compared to surface soils. The maximum subsurface potassium content (307 kg ha⁻¹) was observed at Sample 2, while the minimum value (239 kg ha⁻¹) occurred at Sample 3. In general, subsurface potassium levels were comparable to or slightly lower than surface values, suggesting limited vertical translocation of potassium due to its relatively low mobility in soil profiles.

The spatial and depth-wise distribution of available potassium across the Pilkha Pahad region is influenced by soil mineralogy, texture, weathering intensity, and topographic position. The overall medium to high potassium availability indicates favorable soil conditions for crop growth; however, site-specific nutrient management practices may further optimize potassium use efficiency and sustain soil fertility in the study area.

K Variation

The K values show noticeable variation between surface and subsurface soils, reflecting the influence of topography, organic matter distribution, and soil-forming processes.



4.7 Boron (mg/kg):

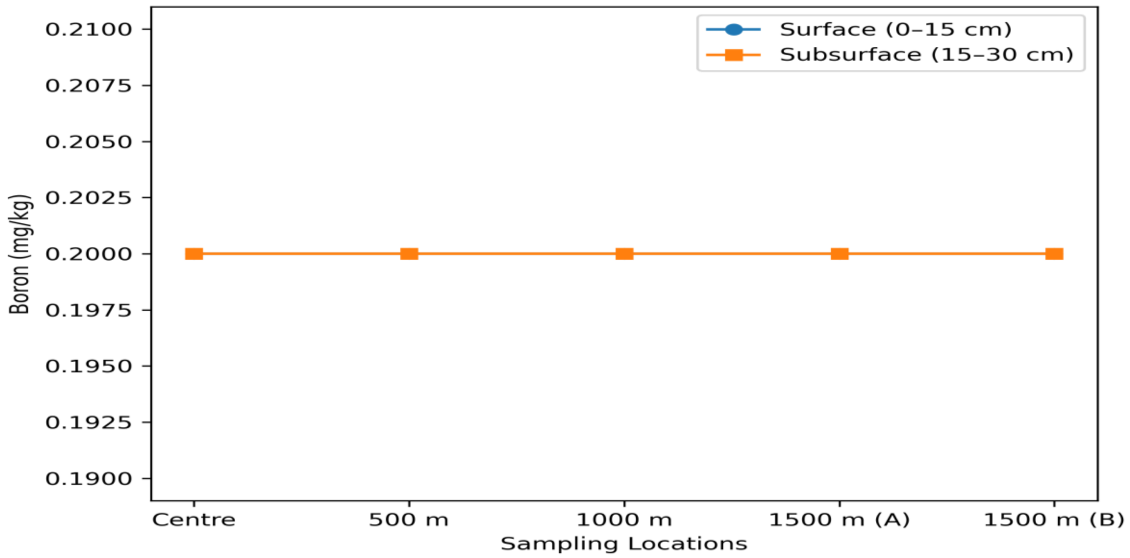
The available boron content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Boron is an essential micronutrient involved in cell wall formation, reproductive growth, and carbohydrate transport in plants.

In the present study, boron concentration in surface soils was uniform across all sampling locations, with a consistent value of **0.2 mg kg⁻¹** recorded at each site. Similarly, subsurface soils also exhibited identical boron levels (**0.2 mg kg⁻¹**) across all five locations, indicating minimal spatial as well as depth-wise variability within the study area.

The uniform distribution of boron across surface and subsurface layers suggests a homogenous parent material and limited influence of localized land-use practices on boron dynamics in the Pilkha Pahad soils. Such consistency may also reflect the relatively stable nature of boron under the prevailing acidic soil conditions and comparable organic matter status across the sites.

Although boron levels did not vary significantly, the recorded concentration indicates **low to marginal boron availability**, which may pose potential constraints for boron-sensitive crops. Therefore, periodic monitoring and balanced micronutrient management are recommended to prevent boron deficiency and to sustain soil fertility and crop productivity in the Pilkha Pahad region.

Boron Variation: The concentration of boron (mg/kg) exhibited minor spatial variation across sampling locations. Comparable values between surface and subsurface layers indicate limited vertical mobility of this micronutrient, suggesting geogenic control and stable soil chemical conditions in the Pilkha Pahad region.



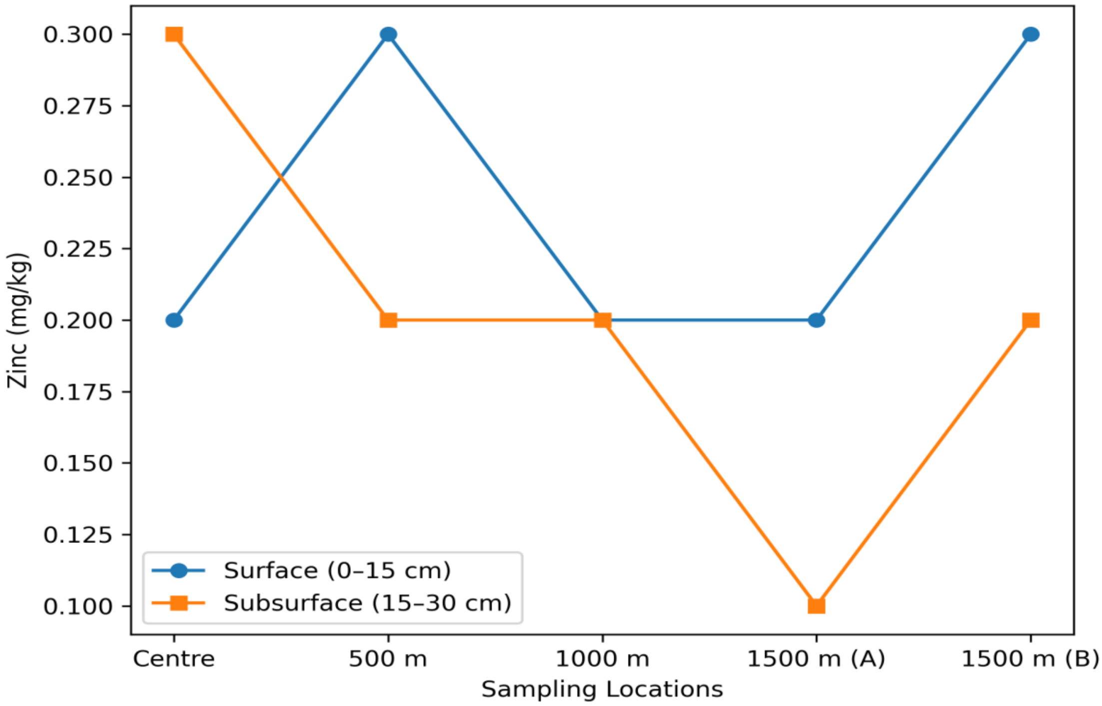
4.8 Zinc (mg/kg):

The available zinc content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Zinc is an essential micronutrient that plays a vital role in enzyme activation, protein synthesis, and growth regulation in plants.

In surface soils, zinc concentrations ranged from **0.2 to 0.3 mg kg^{-1}**, indicating **low zinc availability** across most of the sampling sites. The highest surface zinc content (0.3 mg kg^{-1}) was recorded at Sample 2 (500 m) and Sample 5 (1500 m), whereas the remaining locations exhibited uniformly lower values (0.2 mg kg^{-1}). The relatively low zinc levels in surface soils may be attributed to acidic soil conditions, low organic matter complexation, and potential zinc fixation.

Subsurface soils showed zinc concentrations ranging from **0.1 to 0.3 mg kg^{-1}**, with a slight decline in zinc availability at greater depths. The maximum subsurface zinc content (0.3 mg kg^{-1}) was observed at Sample 1 (Centre, Jhil area), while the minimum value (0.1 mg kg^{-1}) occurred at Sample 4 (1500 m). In general, subsurface soils exhibited marginally lower zinc levels compared to surface soils, which may be associated with reduced organic matter content and limited downward movement of zinc within the soil profile. +The observed spatial and depth-wise variation in zinc availability across the Pilkha Pahad region highlights a potential zinc deficiency in the soils. Such low zinc status may adversely affect crop productivity if not managed appropriately. Therefore, site-specific micronutrient management practices, including zinc supplementation, are recommended to enhance soil fertility and ensure sustainable agricultural production in the study area.

Zinc (mg/kg) Variation: The concentration of zinc (mg/kg) exhibited minor spatial variation across sampling locations. Comparable values between surface and subsurface layers indicate limited vertical mobility of this micronutrient, suggesting geogenic control and stable soil chemical conditions in the Pilkha Pahad region.



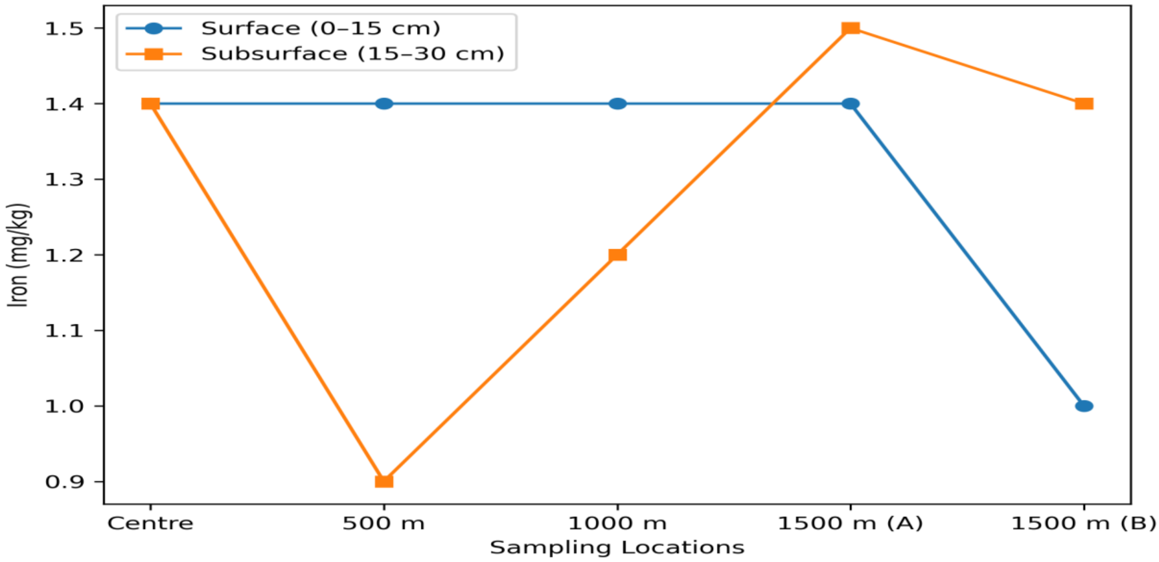
4.9. Iron (mg/kg):

The available iron content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Iron is an essential micronutrient involved in chlorophyll synthesis, electron transport, and several enzymatic reactions in plants.

In surface soils, iron concentrations ranged from **1.0 to 1.4 mg kg^{-1}**, indicating relatively uniform distribution across most of the sampling locations. Samples collected from the Centre/Jhil area, 500 m, 1000 m, and 1500 m locations exhibited similar iron levels of **1.4 mg kg^{-1}**, whereas a slightly lower value (**1.0 mg kg^{-1}**) was recorded at Sample 5. The comparatively uniform iron content in surface soils may be attributed to similar parent material and prevailing acidic soil conditions, which generally enhance iron solubility. Subsurface soils exhibited iron concentrations ranging from **0.9 to 1.5 mg kg^{-1}**, showing minor depth-wise variation among the sampling sites. The highest subsurface iron content (**1.5 mg kg^{-1}**) was observed at Sample 4 (1500 m), while the lowest value (**0.9 mg kg^{-1}**) occurred at Sample 2 (500 m). In general, subsurface iron levels were comparable to or slightly variable relative to surface soils, possibly due to differences in redox conditions, organic matter content, and leaching processes within the soil profile.

Overall, the observed spatial and depth-wise variations in available iron across the Pilkha Pahad region indicate **low to moderate iron availability**. Although iron deficiency symptoms may not be widespread under acidic soil conditions, site-specific monitoring is recommended, particularly for iron-sensitive crops. These findings contribute to a better understanding of micronutrient dynamics and soil fertility status in the study area.

Iron (mg/kg) Variation: The concentration of iron (mg/kg) exhibited minor spatial variation across sampling locations. Comparable values between surface and subsurface layers indicate limited vertical mobility of this micronutrient, suggesting geogenic control and stable soil chemical conditions in the Pilkha Pahad region.



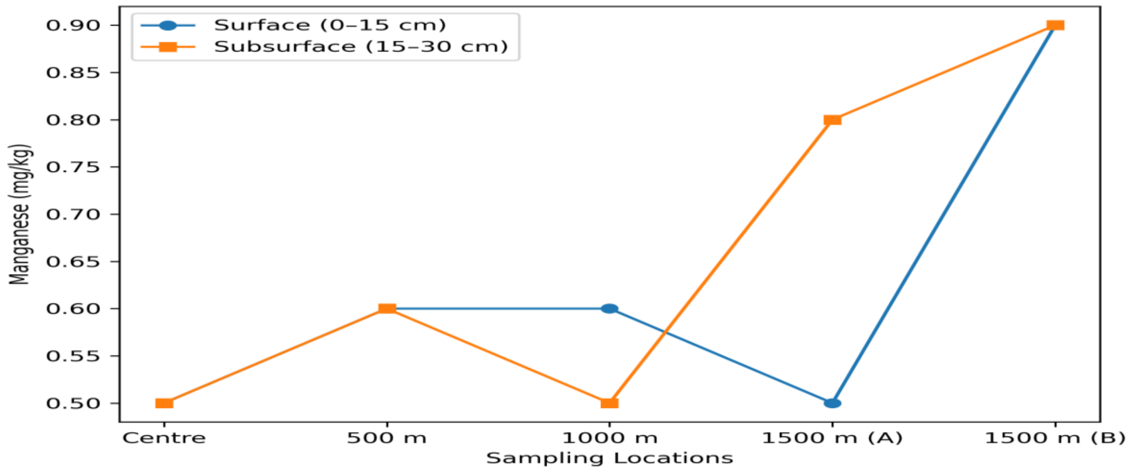
4.10 Manganese (mg/kg):

The available manganese content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Manganese is an essential micronutrient involved in photosynthesis, enzyme activation, and nitrogen metabolism in plants.

In surface soils, manganese concentrations ranged from **0.5 to 0.9 mg kg^{-1}**, indicating low to moderate manganese availability across the study area. The highest surface manganese content (**0.9 mg kg^{-1}**) was recorded at Sample 5 (1500 m), while lower but comparable values (0.5–0.6 mg kg^{-1}) were observed at the remaining locations. The relatively higher manganese concentration at Sample 5 may be associated with site-specific soil moisture conditions and organic matter influence. Subsurface soils exhibited manganese concentrations ranging from **0.5 to 0.9 mg kg^{-1}**, showing limited depth-wise variation. The maximum subsurface manganese content (**0.9 mg kg^{-1}**) was again observed at Sample 5, followed by Sample 4 (**0.8 mg kg^{-1}**). In contrast, lower values (0.5–0.6 mg kg^{-1}) were recorded at the remaining sites. The comparable manganese levels between surface and subsurface layers suggest minimal vertical translocation, possibly due to the strong adsorption of manganese oxides within the soil matrix.

Overall, the spatial and depth-wise distribution of manganese across the Pilkha Pahad region indicates generally low to moderate availability, which may be adequate for most crops under acidic soil conditions. However, continuous monitoring of manganese status is advisable to prevent potential deficiencies or toxicities, particularly under changing land-use and soil moisture regimes.

Manganese (mg/kg) Variation: The concentration of manganese (mg/kg) exhibited minor spatial variation across sampling locations. Comparable values between surface and subsurface layers indicate limited vertical mobility of this micronutrient, suggesting geogenic control and stable soil chemical conditions in the Pilkha Pahad region.



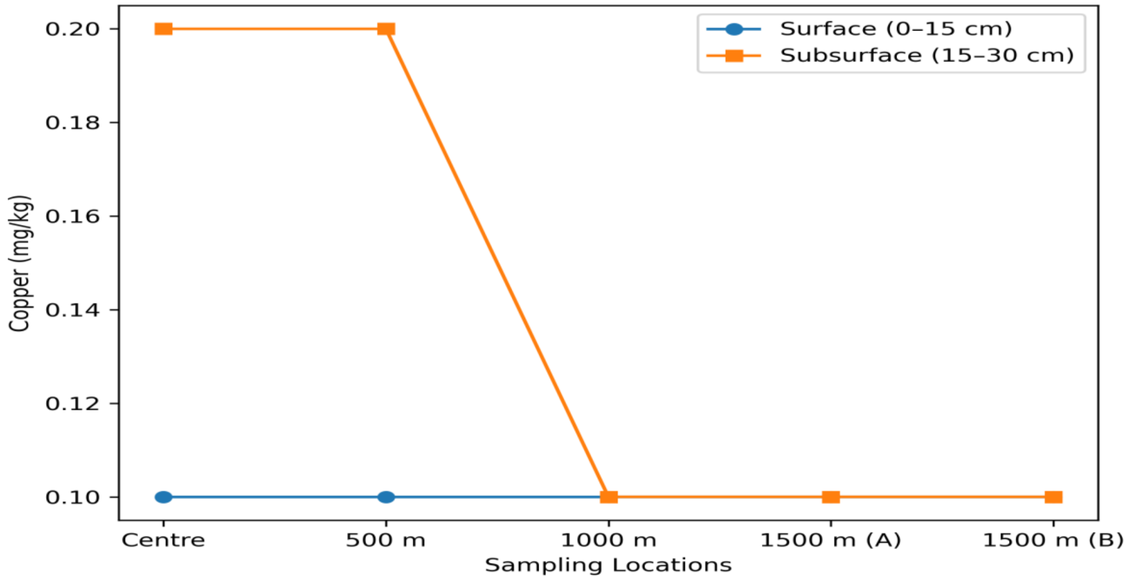
4.11 Copper (mg/kg):

The available copper content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Copper is an essential micronutrient that plays a vital role in photosynthesis, respiration, and several enzymatic processes in plants.

In surface soils, copper concentrations were uniform across all sampling locations, with a consistent value of **0.1 mg kg⁻¹** recorded at each site. This uniformity suggests a homogenous distribution of copper in the surface soil layer, likely influenced by similar parent material composition and comparable land-use conditions throughout the study area. Subsurface soils exhibited copper concentrations ranging from **0.1 to 0.2 mg kg⁻¹**, showing slight depth-wise variation. The highest subsurface copper content (**0.2 mg kg⁻¹**) was observed at Sample 1 (Centre, Jhil area) and Sample 2 (500 m), while the remaining locations recorded values comparable to surface soils (**0.1 mg kg⁻¹**). The marginal increase in copper concentration in subsurface layers at certain sites may be attributed to downward movement of copper complexes or reduced biological uptake at greater depths.

Overall, the copper levels observed in both surface and subsurface soils indicate **low copper availability** across the Pilkha Pahad region. Although deficiency symptoms may not be immediately apparent, the consistently low copper status suggests the need for periodic monitoring and balanced micronutrient management, particularly for copper-sensitive crops. These results contribute to a comprehensive understanding of micronutrient distribution and soil fertility status in the study area.

Copper (mg/kg) Variation: The concentration of copper (mg/kg) exhibited minor spatial variation across sampling locations. Comparable values between surface and subsurface layers indicate limited vertical mobility of this micronutrient, suggesting geogenic control and stable soil chemical conditions in the Pilkha Pahad region.



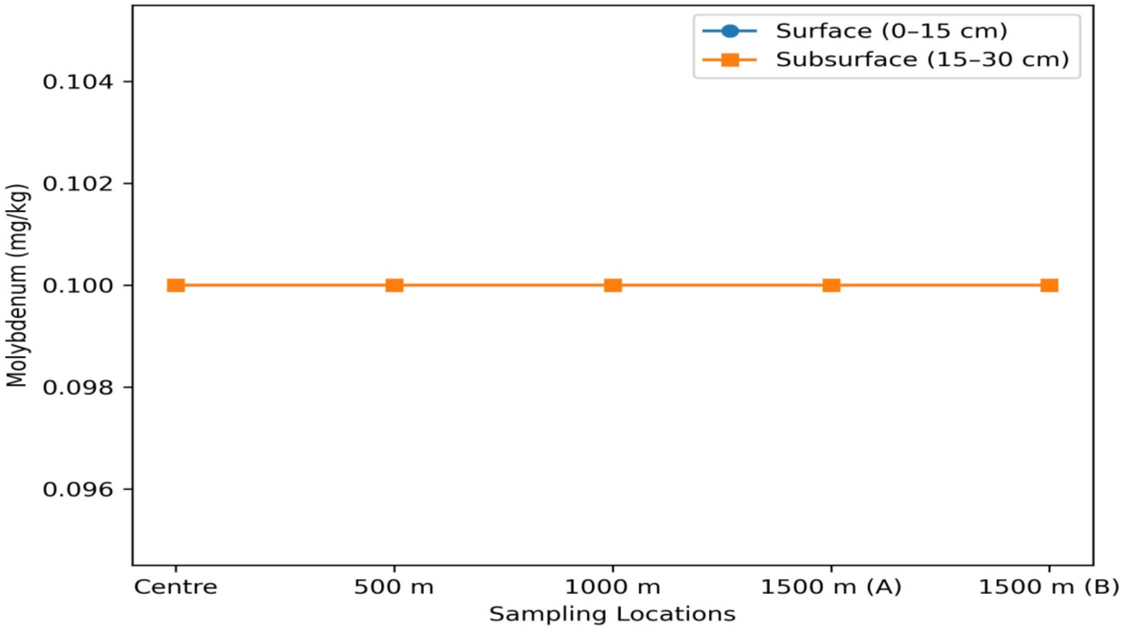
4.12 Molybdenum (mg/kg):

The available molybdenum content of surface (0–15 cm) and subsurface (15–30 cm) soil samples collected from different locations of the Pilkha Pahad region is presented in Tables X and Y, respectively. Molybdenum is a vital micronutrient involved in nitrogen metabolism, particularly in nitrate reduction and biological nitrogen fixation.

In the present study, molybdenum concentration was found to be uniform across all sampling locations and soil depths. Both surface and subsurface soils consistently recorded a molybdenum content of **0.1 mg kg^{-1}** at all five sampling sites, indicating negligible spatial and depth-wise variation within the study area. The uniform distribution of molybdenum suggests a homogeneous parent material and limited influence of topography or land-use practices on molybdenum dynamics in the Pilkha Pahad soils. Under the prevailing slightly acidic soil conditions, molybdenum availability is often constrained due to strong adsorption by iron and aluminum oxides, which may explain the consistently low values observed.

Although no significant variability was detected, the recorded molybdenum concentration indicates **low availability**, which could potentially limit nitrogen utilization efficiency in crops, particularly legumes. Therefore, regular monitoring and balanced micronutrient management should be considered to maintain optimal soil fertility and sustainable agricultural productivity in the Pilkha Pahad region.

Molybdenum (mg/kg) Variation: The concentration of molybdenum (mg/kg) exhibited minor spatial variation across sampling locations. Comparable values between surface and subsurface layers indicate limited vertical mobility of this micronutrient, suggesting geogenic control and stable soil chemical conditions in the Pilkha Pahad region.



Recommended Fertilizer Application

Based on the comparative physico-chemical analysis of surface (0–15 cm) and subsurface (15–30 cm) soils from Pilkha Pahad, Surajpur/Surguja District, Chhattisgarh, a balanced fertilizer management strategy is recommended to improve soil fertility and sustain crop productivity. The soils exhibit low to medium available nitrogen, indicating the need for a nitrogen application of about 120–150 kg ha^{-1}, preferably through urea, to support vegetative growth and yield formation. Available phosphorus levels range from low to moderate across the sampling sites; therefore, an application of 60–80 kg ha^{-1} P_2O_5 through single superphosphate (SSP) or diammonium phosphate (DAP) is suggested to enhance root development and energy transfer processes.

Potassium availability in both soil layers is generally moderate to high; hence, a maintenance dose of 40–60 kg ha^{-1} K_2O, supplied through muriate of potash (MOP), would be sufficient to maintain soil potassium balance and improve crop resistance to stress. Among micronutrients, zinc content is low to marginal, warranting the application of 20–25 kg ha^{-1} zinc sulphate to prevent deficiency symptoms and improve enzymatic activity. Iron is mostly adequate in the studied soils; however, 25–50 kg ha^{-1} ferrous sulphate may be applied only where deficiency symptoms are observed. The uniformly low boron concentration suggests the application of 1.0–1.5 kg ha^{-1} borax, while manganese levels, varying from low to medium, justify the use of 10–15 kg ha^{-1} manganese sulphate.

Copper availability is low but consistent across depths, and therefore 5–10 kg ha^{-1} copper sulphate is recommended to ensure balanced micronutrient nutrition. Although molybdenum is present only at trace levels, its importance in nitrogen metabolism and biological nitrogen fixation necessitates a small dose of about 0.5 kg ha^{-1} sodium molybdate, particularly for leguminous crops. In addition to chemical fertilizers, the incorporation of 5–10 t ha^{-1} of well-decomposed farmyard manure or compost is strongly recommended to improve organic carbon status, enhance nutrient availability, and promote overall soil health.

This integrated nutrient management approach, derived from the soil test values of both surface and subsurface layers, is expected to improve soil fertility, optimize nutrient use efficiency, and support sustainable agricultural production in the Pilkha Pahad region.

5. CONCLUSION

The present investigation entitled **"Comparative Physico-Chemical Analysis of Surface and Subsurface Soils from Pilkha Pahad, Surajpur/Surguja District, Chhattisgarh, India"** provides a comprehensive assessment of soil fertility status by integrating surface (0–15 cm) and subsurface (15–30 cm) soil characteristics across five locations of the Pilkha Pahad region. The results derived from Table X and Table Y clearly demonstrate both spatial variability among sampling sites and depth-wise variation in physico-chemical properties. Soil reaction across all sites was found to be slightly acidic in nature in both surface and subsurface layers, with marginally higher pH values observed in subsurface soils, indicating limited leaching of basic cations. Electrical conductivity values remained low at all locations, confirming non-saline conditions and suitability of soils for agricultural use. Organic carbon content was generally higher in surface soils compared to subsurface layers, reflecting the influence of surface litter accumulation, organic matter decomposition, and land-use practices. A gradual decline with depth was evident at most sites, highlighting reduced biological activity in subsurface horizons. Available nitrogen showed considerable spatial variability, with comparatively higher concentrations recorded at the 1500 m locations in both soil depths, suggesting the role of vegetation cover and organic matter inputs. Phosphorus content ranged from low to medium and exhibited slight depth-wise variation, possibly governed by fixation processes and limited downward mobility. Available potassium levels were moderate to high across all sites in both soil layers, indicating adequate reserve of exchangeable potassium derived from parent material and clay minerals. Micronutrient analysis revealed that zinc, iron, manganese, copper, boron, and molybdenum contents were generally within low to medium ranges, with relatively uniform distribution between surface and subsurface soils. Slight variations among sites may be attributed to differences in soil texture, organic carbon content, and micro-topographic conditions. The consistent presence of boron and molybdenum at low but stable levels suggests minimal risk of deficiency or toxicity under present land-use conditions.

Overall, the comparative evaluation of Table X and Table Y indicates that the soils of Pilkha Pahad possess moderate fertility with no salinity hazards, though slightly acidic reaction and relatively low availability of certain nutrients, particularly nitrogen and phosphorus at specific locations, may limit crop productivity. The findings emphasize the need for site-specific nutrient management practices, including organic matter enrichment and balanced fertilization, to enhance soil health and ensure sustainable agricultural productivity in the Pilkha Pahad region.

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