



Comparative evaluation of soil health across forest and wasteland soils in subtropical region of Chhattisgarh, India

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Abstract

The present study was conducted to evaluate the physicochemical properties of contrasting soil categories namely the forest soil and the wasteland soil in and around the Bilaspur district of Chhattisgarh which potentially represents the subtropical zone. The aim of the study includes gathering data from contrasting locations and analyzing their physical and chemical properties to understand the soil characteristics, nutrient availability, and functioning patterns of such soil categories and to compare them based on the parameters at different depths. In this study, soil samples were taken from five distinct sites with two different sampling plots in each site and at two different depths of 0-15 cm and 15-30 cm. Findings of the study indicated that the wasteland soils had higher bulk density with highest reading of $1.89 \pm 0.508 \text{ g/cm}^3$ in Birkona at 15-30cm depth and lowest in GGVCampus ($1.33 \pm 0.332 \text{ g/cm}^3$) at 0-15cm depth in forest soil, also the wasteland soils had lower moisture content with lowest reading of $5.26 \pm 0.099\%$ at 0-15cm depth in Bilaspur City and highest in Sendri ($12.2 \pm 2.669\%$) at 15-30cm depth in forest soil. Similarly, lowest nutrient levels i.e., $3.63 \pm 0.781\%$ in Birkona, $0.371 \pm 0.012\%$ in Sendri, $0.462 \pm 0.048\%$ in Sendri and $0.025 \pm 0.00102\%$ in Lokhandi for Nitrogen, Carbon, Hydrogen and Sulfur respectively were seen in the same when compared to the forest soils which hindered the new germination and plant growth. Higher moisture content and higher bulk density were found at higher depths whereas, a decrease in nutrient content (C, H, N, and S) was observed. The outcomes of this study are expected to benefit the local environmental community and ecological researchers for the restoration of wasteland soils by understanding their characteristics, as healthy soils are essential for plant growth.

Keywords: Physio-chemical properties, forest soil, wasteland soil, soil quality assessment, nutrient status, soil health

Introduction

Soil is a fundamental natural resource, supporting terrestrial life and mediating essential biogeochemical processes. However, soil health can be compromised by natural degradation and poor land management, leading to reduced fertility and ecosystem function (Johnson, 2018) [14]. In the subtropical region of Bilaspur, Chhattisgarh, contrasting land-use patterns between forests and wastelands can influence soil quality and productivity. This study addresses the critical need to evaluate and compare the physical and chemical properties of soils in these landscapes, with the hypothesis that differences in land cover result in distinct soil health and nutrient dynamics.

Previous research has highlighted the importance of soil structure, texture, pH, organic matter content, and nutrient availability in determining soil fertility and ecosystem sustainability (Brady & Weil, 2008; Doran & Parkin, 1994) [8]. Studies have also shown that nutrient interactions within soil matrices drive microbial activity and nutrient cycling (Kogel-Knabner *et al.*, 2010; Fierer *et al.*, 2009) [11]. Wasteland soils, despite being degraded, have demonstrated potential for vegetation reestablishment and ecological restoration (Wang *et al.*, 2020) [28]. However, there is a gap in region-specific knowledge, particularly concerning how these factors differ between forest and wasteland soils in Bilaspur.

This study aimed to bridge that gap by conducting a comparative analysis of soil health in forests and wastelands of Bilaspur. Using standard soil analysis methods, we examined key physical and chemical properties such as texture, pH, organic matter content, and nutrient status to assess soil fertility and health. Our objectives included identifying differences in soil properties across land-use types, evaluating their implications for ecosystem sustainability, and providing a scientific basis for land management and ecological restoration in subtropical regions.

Material and Methods

Study site

The study was carried out in Bilaspur District of Chhattisgarh State (Figure 1) with an average elevation of 270 meters above sea level at 22.0797° N Latitude and 82.1409° E Longitude (Maitry *et al.*, 2023) [19]. The district borders Korba in the north, Raigarh in the northeast, Janjgir-Champa in the east, and Mungeli in the south. The district receives an annual rainfall of 1012 mm in which 72% of rainfall occurs during the month of June-September. The study site exhibited mean annual temperature and humidity around 31.69°C and 62% respectively.

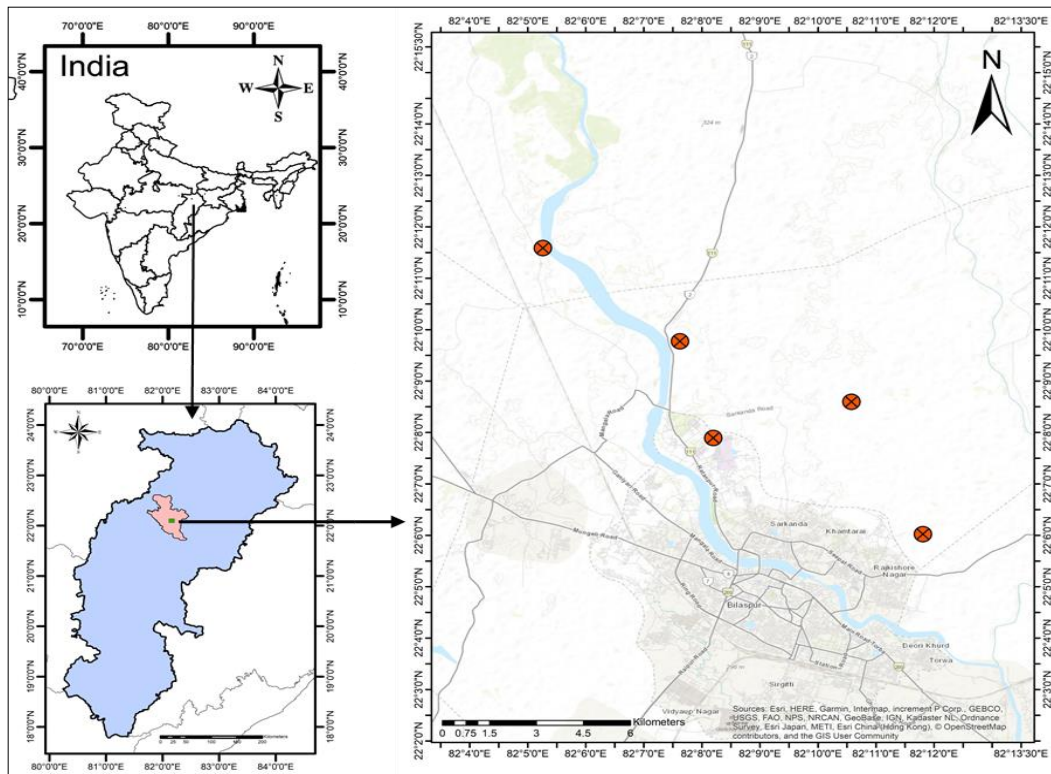


Fig 1: Geographical location of the study area in Bilaspur

Sampling plots

For the purpose of this study, soil samples were collected from five specific locations including Guru Ghasidas Vishwavidyalaya campus, Sendri (Ratanpur), Birkona, Bilaspur city, and Lokhandi with coordinates belonging at 25 kms radius around coordinate 82.1399° E and 22.0797° N (Table 1). Soil samples were collected randomly from these five sites after categorizing them into two plots namely the wasteland and forest land at each selected site. A total of 10 samples plots were formed from the selected five sites.

Table 1: Geographical coordinates of selected sampling plots

S. No.	Site Name	Coordinates	
		Latitude	Longitude
1.	Sendri	22.172487°	82.135127°
2.	GGV campus	22.129599°	82.142924°
3.	Bilaspur city	22.114647°	82.135972°
4.	Birkona	22.142354°	82.161283°
5.	Lokhandi	22.144066°	82.118134°

Sampling Method

Sampling was done in accordance with general microbiological protocol from 10 selected plots around the Bilaspur area. Each sampling plot was divided into 3 blocks, and from each block soil samples were collected randomly at 0-15 cm and 15-30 soil depths by digging pits through soil auger. Samples collected from each block were referred as ‘sub-samples’, and was thoroughly mixed to form one ‘composite sample’. Unwanted debris, forest litter, stones, and gravels were removed from the samples and then the composite sample was replicated thrice for further analysis and data collection. Similar sampling strategies was followed for all the 10 sampling plots.

Analysis of physico-chemical parameters

After collection, the samples were subjected to sieving (0.2 mm mesh size) and stored at 4°C until analyzed. Apart from soil moisture and bulk density, the other parameters were analyzed using air-dried soil samples. Soil textural analysis of particles less than 2 mm was performed by the sieve method. The bulk density was determined by the standard soil auger (T- handle) method. Other physical properties of the soil were analyzed using standard methods – Soil pH using digital pH meter (Jackson 1973) [13], soil moisture content by gravimetric method (Allen *et al.* 1998) [1], the soil colours were determined by the standard Munsell soil colour chart (Munsell, 1994) [22]. Nutrient contents such as carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) were analyzed through CHNS elemental analyzer based on the Dumas method of dynamic flash combustion and detection. The working principle involves burning the sample at high temperatures (typically around 900-1000°C) in an oxygen-rich environment. This combustion converts the sample into gaseous forms of its constituent elements: CO₂ for carbon, H₂O for hydrogen, N₂ or NO_x for nitrogen, and SO₂ for sulfur. These gases are then separated and quantified using a combination of techniques such as thermal conductivity detection (TCD) or gas chromatography (GC). The resulting data is used to calculate the percentages of each element in the original sample.

Statistical Analysis

In the present study, mean, standard deviation and correlation have been calculated using Microsoft Excel 2021 whereas the scatterplot matrix have been originated by the SPSS V25 software.

Results and Discussion

Physical Properties of Forest Soil and Wasteland Soil

The study revealed marked differences in soil texture, bulk density, and moisture content between forest and wasteland

soils across different sites (Table 2). In forested areas like Sendri and Birkona, soils were predominantly clayey, with Sendri's forest soil showing $42.91 \pm 4.63\%$ clay content and Birkona's soil exhibiting a substantial clay presence ($32.76 \pm 1.27\%$). These forest soils generally exhibited lower bulk densities (ranging from $1.33 \pm 0.33 \text{ g/cm}^3$ at GGV campus (0-15 cm) to $1.85 \pm 0.31 \text{ g/cm}^3$ at Sendri (15-30 cm)) and higher moisture contents (up to $12.2 \pm 2.669\%$

at Sendri (15-30 cm) (Table 3)), which promote better water retention and nutrient availability, critical for supporting diverse plant life (Baldrian *et al.*, 2010) [3]. For example, forest soils at the GGV campus and Bilaspur city also had moderate to high silt and clay contents, contributing to improved soil fertility and water retention (de Assis *et al.*, 2011) [7].

Table 2: Soil colour and soil texture of studied sites

S. No.	Site Name	Forest Soil		Wasteland Soil	
		Soil colour	Soil texture	Soil colour	Soil texture
1.	Sendri	Dark brown	Clay	Dark reddish	Sandy clay
2.	GGV campus	Light yellow	Sandy loam	Dark reddish	Sandy clay
3.	Bilaspur city	Dark brown	Silt loam	Dark yellow	Sandy loam
4.	Birkona	Dark grey	Clay	Brownish grey	Sandy
5.	Lokhandi	Dark grey	Loam	Light yellow	Clay

Conversely, wasteland soils had coarser textures, such as sandy loam and sandy clay, particularly noticeable at Birkona, where the soil had a high sand content of $67.64 \pm 8.96\%$, leading to low water retention and limited fertility (Yan *et al.*, 2024) [29]. Bulk densities in wasteland soils were generally higher at deeper depths, peaking at $1.89 \pm 0.508 \text{ g/cm}^3$ at Birkona (15-30 cm), indicating greater soil compaction and reduced porosity (García-Orenes *et al.*,

2005) [12]. Moisture content was consistently lower in wasteland soils compared to forest soils, with maximum moisture levels like $11.28 \pm 4.497\%$ at the GGV campus wasteland soil (15-30 cm) (Table 5). The dark reddish or brownish grey coloration of many wasteland soils also signalled limited organic content and fertility (Blazhko *et al.*, 2017; Wang *et al.*, 2020) [4, 28].

Table 3: Physico-chemical parameters of studied sampling sites in forest soil at two different depths

Site Name	Depth (in cm)	Bulk Density (g/cm^3)	Moisture Content %	Nitrogen %	Carbon %	Hydrogen %	Sulfur %
Sendri	0-15	1.66 ± 0.232	9.61 ± 1.681	5.7 ± 1.26	1.062 ± 0.023	1.192 ± 0.15	0.062 ± 0.006
	15-30	1.85 ± 0.319	12.2 ± 2.669	4.31 ± 1.002	1.045 ± 0.016	1.053 ± 0.12	0.054 ± 0.005
GGV campus	0-15	1.33 ± 0.332	7.22 ± 2.019	5.72 ± 0.95	0.494 ± 0.012	1.048 ± 0.32	0.052 ± 0.002
	15-30	1.52 ± 0.419	9.81 ± 2.999	4.33 ± 0.702	0.481 ± 0.005	0.909 ± 0.29	0.044 ± 0.001
Bilaspur city	0-15	1.62 ± 0.343	7.58 ± 2.137	5.29 ± 0.873	0.58 ± 0.033	1.202 ± 0.48	0.044 ± 0.012
	15-30	1.74 ± 0.429	10.17 ± 3.119	3.9 ± 0.672	0.491 ± 0.026	1.063 ± 0.45	0.036 ± 0.011
Birkona	0-15	1.56 ± 0.127	6.1 ± 1.875	5.15 ± 1.172	0.672 ± 0.018	1.034 ± 0.21	0.055 ± 0.003
	15-30	1.67 ± 0.209	8.69 ± 2.859	3.76 ± 0.972	0.661 ± 0.011	0.895 ± 0.18	0.047 ± 0.002
Lokhandi	0-15	1.61 ± 0.389	8.69 ± 2.116	5.41 ± 0.892	0.781 ± 0.024	1.043 ± 0.32	0.042 ± 0.011
	15-30	1.76 ± 0.469	11.28 ± 3.099	4.02 ± 0.692	0.771 ± 0.017	0.904 ± 0.29	0.034 ± 0.010

Overall, these findings underscore that forest soils in Bilaspur, with their higher clay and moisture content, provided a better environment for nutrient cycling and vegetation support, while wasteland soils are sandier and more compact in nature which showed limited moisture retention and reduced fertility, potentially constraining plant establishment and growth (Baldrian *et al.*, 2010; Blazhko *et al.*, 2017; Yan *et al.*, 2024) [3, 4, 29].

Chemical Properties of Forest Soil and Wasteland Soil

The chemical analysis revealed marked differences in soil health and fertility between forest and wasteland soils. Forest soils generally exhibited slightly acidic to neutral pH levels (6.2 ± 0.26 in Sendri to 7.2 ± 0.38 in Bilaspur city),

which are considered optimal for nutrient availability and plant growth (Msimbira and Smith, 2020) [21]. These soils also had moderate electrical conductivity (EC) values (1.32 ± 0.01 to $1.45 \pm 0.05 \text{ dS m}^{-1}$), suggesting manageable salinity levels (Zhang *et al.*, 2011) [30]. Forest soils showed higher nitrogen content ($5.15 \pm 1.17\%$ to $5.72 \pm 0.9\%$), indicating better fertility and potential for supporting plant growth (Richardson *et al.*, 2009) [24]. Organic carbon content in forest soils was also higher ($0.49 \pm 0.012\%$ to $1.06 \pm 0.023\%$), reflecting better organic matter levels and improved soil structure and health (Wade *et al.*, 2020) [27]. Hydrogen and sulfur levels showed minor variations but remained relatively consistent.

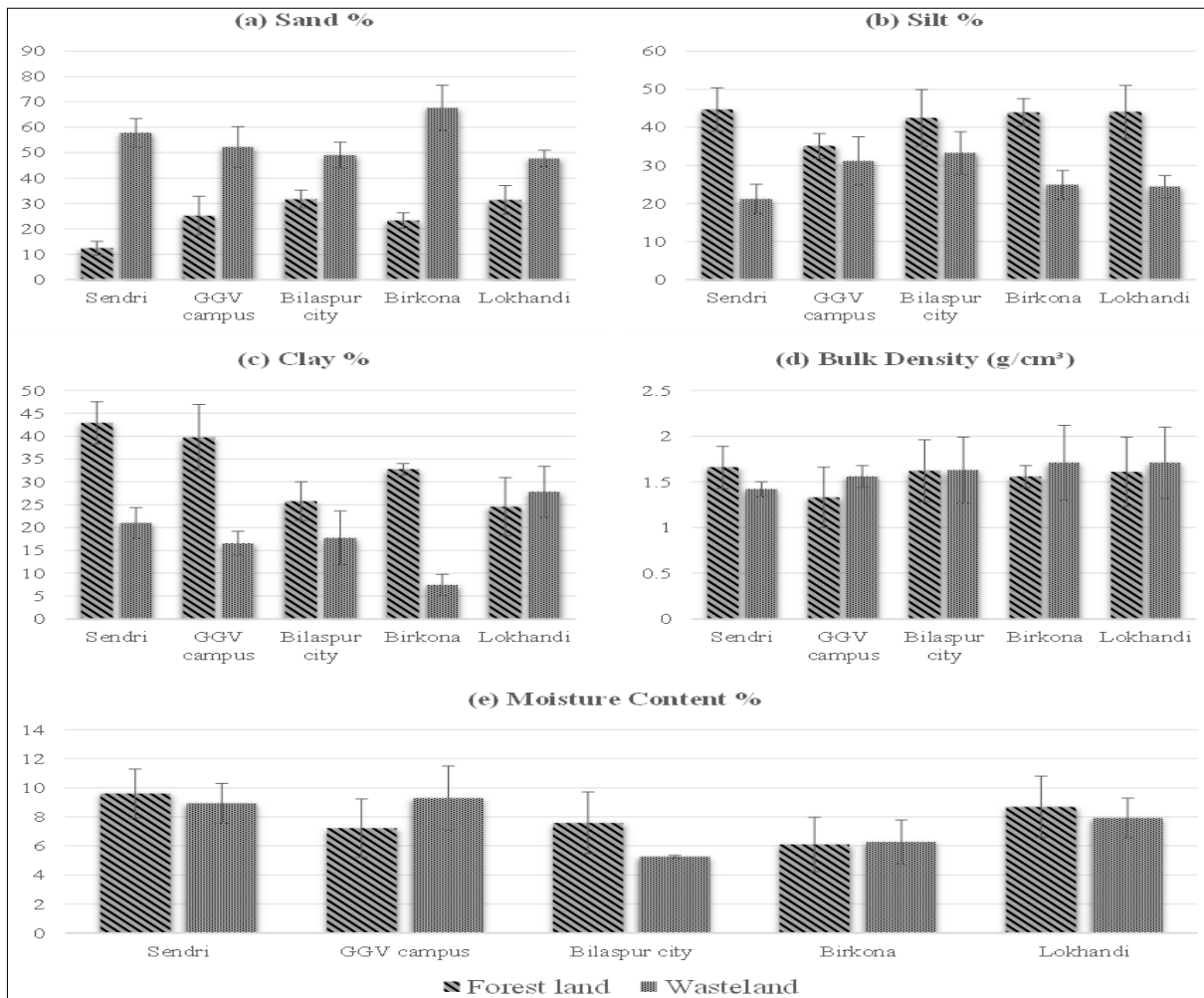


Fig 2: Different physical parameters of forest and wasteland soil (a) Sand % (b) Silt % (c) Clay %, (d) Bulk Density(g/cm³) and (e) Moisture Content % at 0-15 cm soil depth

Table 4: Physico-chemical parameters of studied sampling sites in wasteland soil at two different depths

Site Name	Depth (in cm)	Bulk Density (g/cm ³)	Moisture Content %	Nitrogen %	Carbon %	Hydrogen %	Sulfur %
Sendri	0-15	1.42 ± 0.08	8.93 ± 1.37	5.62 ± 1.57	0.38 ± 0.021	0.63 ± 0.08	0.066 ± 0.002
	15-30	1.7 ± 0.178	10.91 ± 3.667	4.23 ± 1.381	0.371 ± 0.012	0.462 ± 0.048	0.06 ± 0.001
GGV campus	0-15	1.56 ± 0.12	9.3 ± 2.2	5.25 ± 1.21	0.52 ± 0.041	1.426 ± 0.34	0.045 ± 0.001
	15-30	1.84 ± 0.218	11.28 ± 4.497	3.86 ± 1.021	0.511 ± 0.032	1.258 ± 0.308	0.039 ± 0.001
Bilaspur city	0-15	1.63 ± 0.36	5.26 ± 0.099	5.09 ± 1.34	0.41 ± 0.023	1.028 ± 0.21	0.042 ± 0.006
	15-30	1.88 ± 0.458	7.24 ± 2.396	3.7 ± 1.151	0.401 ± 0.014	0.86 ± 0.178	0.036 ± 0.005
Birkona	0-15	1.71 ± 0.41	6.27 ± 1.52	5.02 ± 0.97	0.51 ± 0.019	1.024 ± 0.23	0.061 ± 0.007
	15-30	1.89 ± 0.508	8.25 ± 3.817	3.63 ± 0.781	0.501 ± 0.01	0.856 ± 0.198	0.055 ± 0.006
Lokhandi	0-15	1.71 ± 0.39	7.92 ± 1.37	5.19 ± 0.96	0.69 ± 0.032	1.049 ± 0.18	0.031 ± 0.002
	15-30	1.86 ± 0.488	10.9 ± 3.667	3.8 ± 0.771	0.681 ± 0.023	0.881 ± 0.148	0.025 ± 0.001

Conversely, wasteland soils displayed neutral to slightly alkaline pH (7.1 ± 0.36 in Birkona to 9.2 ± 0.29 in Bilaspur city), which may hinder nutrient uptake in some plants (Zhang *et al.*, 2011) [30]. EC values were slightly lower overall (1.21 ± 0.86 to 1.33 ± 0.36 dS m⁻¹). Nitrogen content in wasteland soils was similar in range (5.02 ± 0.97% to 5.62 ± 1.57%) but showed greater variability across depths, suggesting differences in nutrient cycling (Anas *et al.*, 2020; Luo *et al.*, 2020) [2, 18]. However, wasteland soils had significantly lower carbon content (0.38 ± 0.021% to 0.69 ± 0.032%), indicating reduced organic matter and potentially poor soil structure and fertility (Topa *et al.*, 2021; Joseph *et al.*, 2020) [15, 26]. Hydrogen content showed

higher variability in wasteland soils (0.630 ± 0.08% to 1.426 ± 0.34%), possibly reflecting differences in microbial activity (Bowles *et al.*, 2014; Keeler *et al.*, 2009) [5, 16]. Sulfur content remained low across all sites. Overall, forest soils exhibited better nutrient availability, higher organic matter content, and more favourable conditions for plant growth, as compared to the more alkaline, compacted, and organic matter-depleted wasteland soils (Baldrian *et al.*, 2010; García-Orenes *et al.*, 2005) [3, 12]. These differences underscore the need for targeted management practices to improve fertility and ecosystem functioning in wasteland soils.

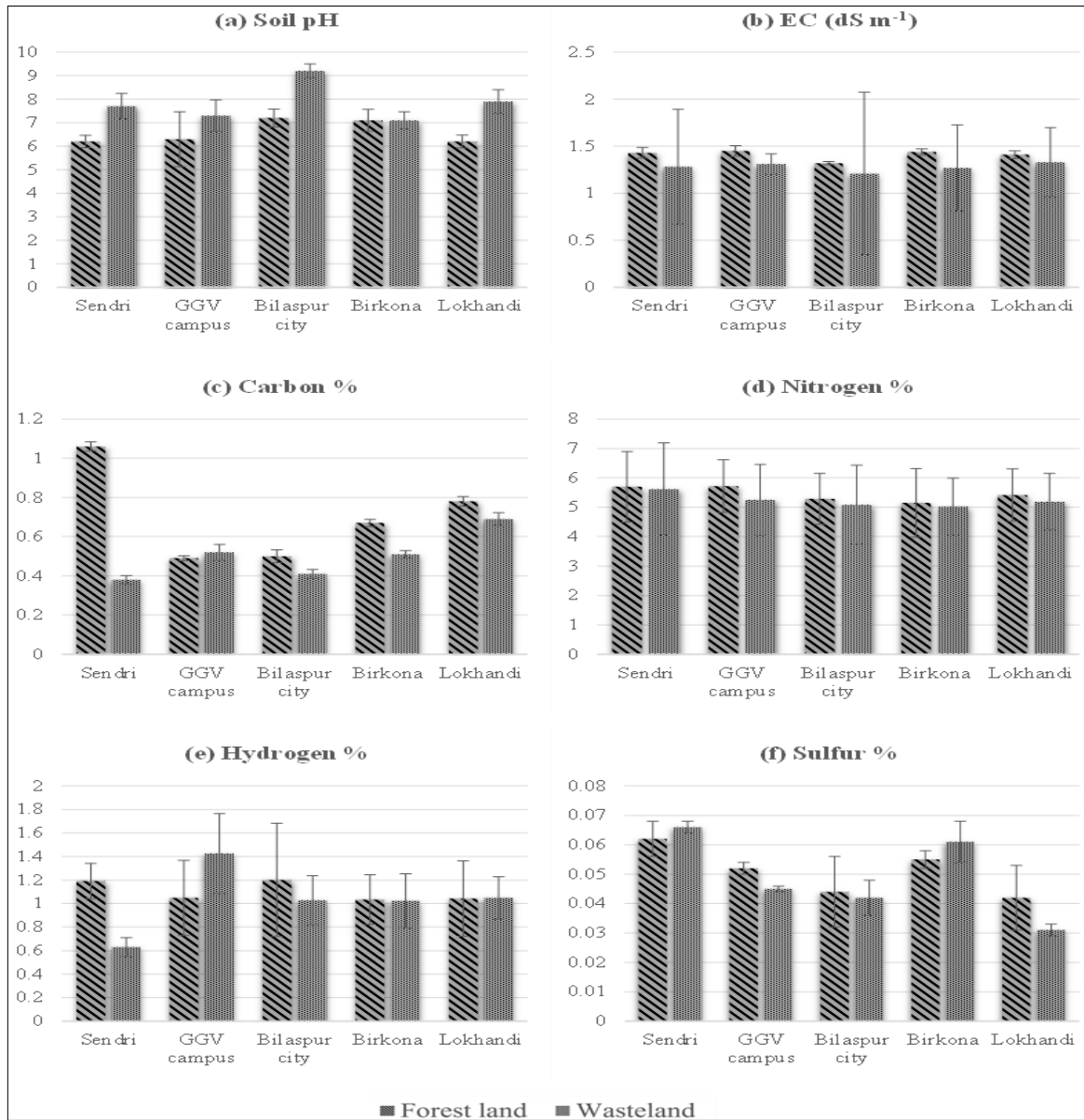


Fig 3: Different chemical parameters of forest and wasteland soil (a) Soil pH (b) Electrical Conductivity (dS m⁻¹) (c) Carbon % (d) Nitrogen % (e) Hydrogen % and (f) Sulfur % at 0-15 cm soil depth

The table 5 presents the correlation coefficients for various chemical and physical properties of forest soil at two depths (0-15 cm and 15-30 cm). It shows that bulk density has a positive correlation with carbon (0.618) and hydrogen (0.547), indicating that denser soils may retain more organic matter. Moisture content (MC) is positively correlated with

nitrogen (0.591) and carbon (0.738), highlighting the role of moisture in supporting organic matter and nutrient availability. Notably, sulfur content shows moderate positive correlations with carbon (0.560) and nitrogen (0.401), suggesting its linkage to organic matter and fertility.

Table 5: Correlation analysis of studied sampling sites in forest soil at 0-15 cm and 15-30 cm depth

FS	Bulk Density	MC	Nitrogen	Carbon	Hydrogen	Sulfur
Bulk Density	1	0.487338302	-0.368548315	0.618238101	0.547163961	-4.036363074
MC %	0.7043404	1	0.591270283	0.737983772	0.508502486	0.136680062
Nitrogen %	-0.089347921	0.591270283	1	0.300971639	0.170816382	0.401142478
Carbon %	0.77305053	0.736831241	0.297627329	1	0.26259105	0.560033152
Hydrogen %	0.610307082	0.508502486	0.170816382	0.258514727	1	0.17723745
Sulfur %	0.13142733	0.136680062	0.401142478	0.556890366	0.17723745	1
		0-15 cm			15-30 cm	

The table 6 presents the correlation coefficients of various physical and chemical properties of wasteland soils at 0-15 cm and 15-30 cm depths. It reveals strong negative correlations between bulk density and nitrogen content (-0.908), indicating that denser soils tend to have lower nitrogen. Moisture content (MC) shows a positive

correlation with nitrogen (0.711), suggesting that wetter soils have higher nitrogen levels. Carbon content has a moderate positive correlation with hydrogen (0.436), reflecting organic matter linkages. However, sulfur content is negatively correlated with most parameters, suggesting its independent behavior.

Table 6: Correlation analysis of studied sampling sites in wasteland soil at 0-15 cm and 15-30 cm depth

WLS	Bulk Density	MC	Nitrogen	Carbon	Hydrogen	Sulfur
Bulk Density	1	-0.579264002	-0.907814401	0.678644692	0.420508048	-0.541719005
MC %	-0.554671939	1	0.710719402	0.158220769	0.082257506	0.105483846
Nitrogen %	-0.989115012	0.642729944	1	-0.383900801	-0.560614869	0.42832118
Carbon %	0.467114857	0.3588817	-0.383900801	1	0.435628961	-0.687352254
Hydrogen %	0.643371057	0.085841314	-0.560614869	0.435628961	1	-0.543982464
Sulfur %	-0.545756441	-0.071340512	0.42832118	-0.687352254	-0.543982464	1
		0-15 cm			15-30 cm	

Figure 4 represents a scatter plot matrix of various soil properties at both depths i.e., 0-15 cm and 15-30 cm. The properties examined were Bulk Density (BD), Moisture Content (MC), Nitrogen (N), Carbon (C), Hydrogen (H), and Sulfur (S). Each off-diagonal cell in the matrix showed a scatter plot depicting the relationship between a pair of these properties, with green dots representing forest soil samples and yellow dots representing wasteland soil samples. Diagonal cells contain histograms showing the distribution of each property individually. In the scatter plot

matrix A, forest soils generally exhibited higher variability and content in moisture, nitrogen, carbon, and hydrogen compared to wasteland soils at 0-15 cm depth. Positive correlations among nitrogen, carbon, and hydrogen were more pronounced in forest soils, indicating a complex interdependency of these properties in healthier, more nutrient-rich soils. Wasteland soils, in contrast, were more clustered and showed less variability, reflecting their poorer condition and lower nutrient levels at 0-15 cm depth.

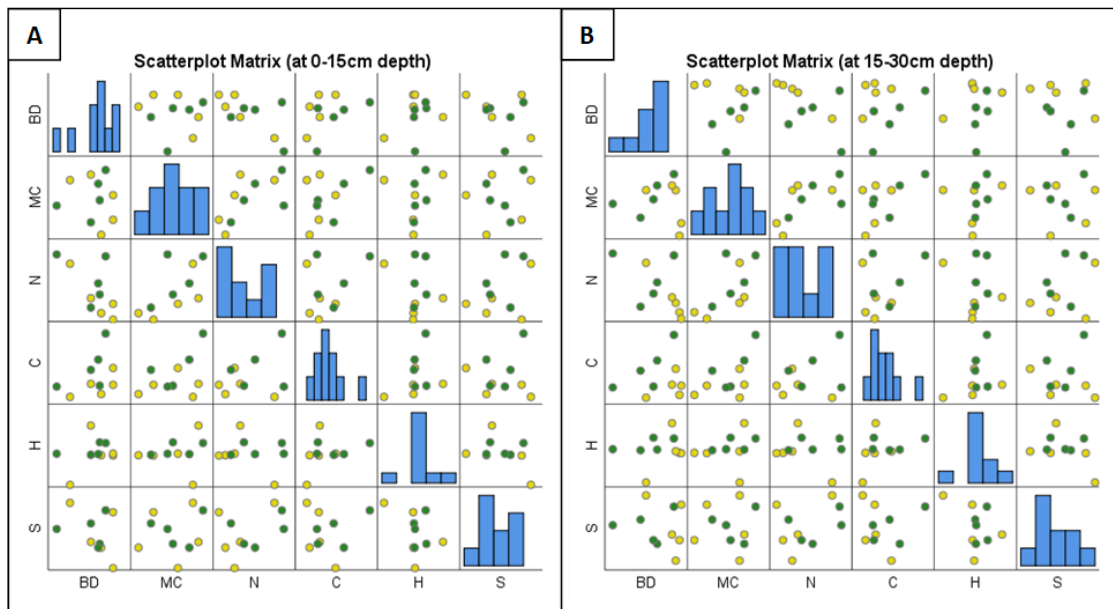


Fig 4: Scatterplot matrix of correlation between different physical and chemical parameters: Bulk Density(g/cm³), Moisture Content %, Carbon %, Nitrogen %, Hydrogen % and Sulfur % of forest soil (green dots) and wasteland soil (yellow dots); (A) At 0-15 cm depth and (B) At 15-30 cm depth. BD- Bulk Density, MC- Moisture Content, N- Nitrogen, C- Carbon, H- Hydrogen, S- Sulfur.

Similarly, the scatter plot matrix B provides a comprehensive visual summary of the interrelationships among selected soil properties and highlighted the differences between forest and wasteland soils at 15-30 cm depth. Forest soils generally exhibited higher variability and content in moisture, nitrogen, carbon, and hydrogen compared to wasteland soils similar to the scatter plot matrix A at 0-15 cm depth. Positive correlations among nitrogen, carbon, and hydrogen are more pronounced in forest soils, indicating a complex interdependency of these properties in healthier, more nutrient-rich soils. Wasteland soils, in contrast, are more clustered and show less variability, reflecting their poorer condition and lower nutrient levels. This analysis essentially helped for understanding soil health and can direct land management and conservation practices.

Conclusion

The results indicate that forest soils in the Bilaspur region generally have better physical and chemical properties

compared to wasteland soils, highlighting the impact of vegetation cover and land use practices on soil health. Forest soils showed higher organic matter content, better nutrient availability, and favorable pH and EC levels, making them more suitable for plant growth. In contrast, wasteland soils exhibited poorer physical structure, lower fertility, and higher pH values, indicating the need for soil improvement measures such as organic amendments, reforestation, and sustainable land management practices to restore soil health and enhance productivity. The variation in physico-chemical properties between forest and wasteland soils reflects different land use practices and their impact on soil health. Forest soils generally exhibit higher moisture content and nutrient levels at greater depths, suggesting better water retention and nutrient availability, which is crucial for supporting diverse plant life. In contrast, wasteland soils, with their higher bulk density and lower moisture content, indicate compaction and reduced porosity, which can hinder plant growth. Nitrogen content, a critical

nutrient for plant growth, is higher in surface soils of both forest and wasteland areas, highlighting the importance of surface soil layers in nutrient cycling. However, the lower carbon content in deeper layers of wasteland soils suggests reduced organic matter, which can affect soil structure and fertility. Due to limited information on the layered characteristics of soil physicochemical properties in the Bilaspur region, this study is expected to benefit the local environmental community and ecological researchers for the restoration of wasteland soils by understanding their characteristics, as healthy soils are essential for plant growth. Overall, the study underscores the need for targeted soil management practices to improve soil health, especially in wasteland areas, to enhance their suitability for vegetation and ecological restoration.

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