RESEARCH PAPER

The Evolution Of Physicochemical Properties Of Coffee-Based Soil In Darbha Block Of Bastar District, Chhattisgarh

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Abstract

The cultivation of coffee has lately emerged as a significant sustainable livelihood alternative in the tribal-dominated bastar area of chhattisgarh. This study assesses the evolution of physicochemical parameters of coffee-based soils in the darbha block of bastar district to determine soil health and fertility under coffee plantation systems. Soil samples were obtained from designated coffee cultivation areas at two depths (0–15 cm and 15–30 cm) in accordance with established soil sampling sited villages of darbha block. The gathered samples were examined for physicochemical characteristics including soil ph, electrical conductivity, organic carbon, bulk density, moisture content, and accessible macro and micronutrients utilizing standardized laboratory techniques. The findings reveal that the soils in the research area exhibit modest to moderate acidity deemed appropriate for coffee growing. Increased organic carbon content was noted in surface soils as a result of the ongoing accumulation of organic wastes and leaf litter from coffee plants. The electrical conductivity values were minimal, signifying non-saline soil conditions. Bulk density augmented with depth, indicating natural soil compaction in subterranean strata. Nutrient analysis indicated moderate availability of nitrogen and potassium, although phosphorus concentration shown regional heterogeneity among sampling locations. The research indicates that coffee cultivation positively affects soil physicochemical qualities by increasing organic matter content and preserving soil structure. Nonetheless, balanced and site-specific nutrient management strategies are crucial for maintaining soil fertility and enhancing coffee yield in the region. The results offer foundational data for sustainable soil and land management strategies in the bastar district.

Keywords: Coffee-Based Soil, Soil Fertility, Physicochemical Properties, Villages, Darbha Block, Bastar District.

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Introduction

Coffee cultivation is expanding beyond traditional regions into central India, specifically the Bastar district of Chhattisgarh (Darbha Block), where agroforestry and coffee-centric systems have recently been promoted for livelihood diversification and carbon sequestration. Multiple regional studies have assessed soil properties and carbon dynamics in these systems, demonstrating that coffee-based agroforestry typically improves soil organic carbon and nutrient availability relative to younger or monoculture plantations. The physicochemical characteristics of the soil (SOC, bulk density, pH, and available nutrients) substantially influence coffee productivity and sustainability. Shade trees and organic inputs associated with coffee agroforestry increase litter contributions and root turnover, promoting soil organic carbon accumulation, improved aggregation, and decreased bulk density over time. However, trends may depend on specific sites (soil composition, slope, precipitation, management intensity), requiring regionally targeted studies to inform local recommendations. (Kumar K et al., 2024).

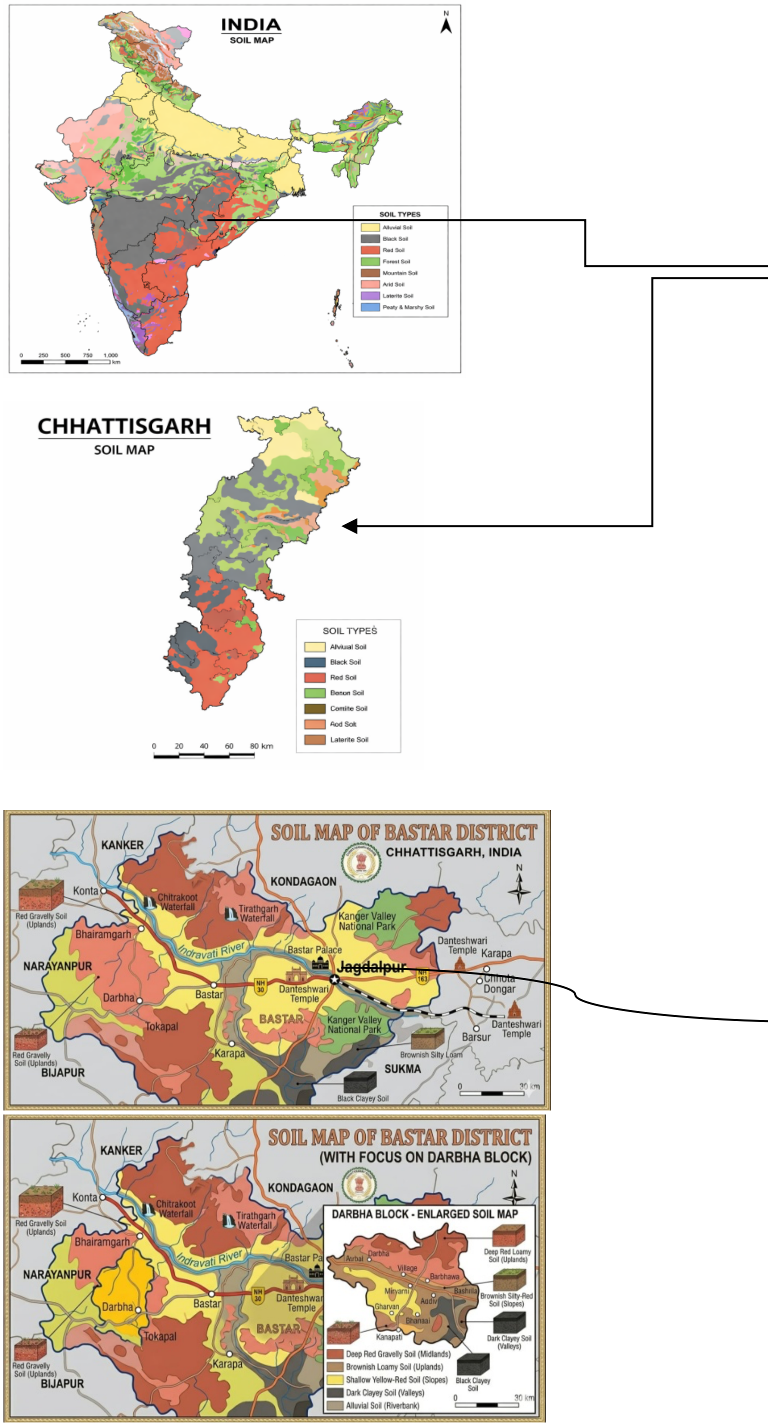
Soil is a vital natural resource that supports agricultural productivity and ecosystem resilience. The physicochemical properties of soil, including texture, structure, pH, and nutrient availability, are critical in determining soil fertility and crop yield (Brady & Weil, 2016; Hillel, 2004). Land-use patterns, climatic conditions, and vegetation cover significantly influence these characteristics in tropical regions.

Coffee-based agroforestry systems have attracted considerable attention for their ability to enhance soil organic carbon (SOC), improve nutrient cycling, and maintain soil structure. These systems improve sustainable land management by increasing litter input and microbial activity, thereby enhancing soil fertility compared to traditional agricultural systems (Velmourougane, 2016; Jose, 2009), which often lead to soil degradation and reduced crop yields. The Bastar region of Bastar District features lateritic soils that are typically acidic and prone to nutrient deficiencies due to leaching and fixation processes. Studies reveal that deficiencies in phosphorus, zinc, and boron are common in these soils, limiting agricultural productivity (Alloway, 2008; Singh, 2011). The establishment of coffee-based agroforestry systems in this area has shown considerable improvements in soil organic carbon and nutrient availability (Kumar K et al., 2024). This study aims to quantify the changes in physicochemical soil properties across various plantation ages and management systems in Darbha Block, produce spatial maps of key soil indicators, and correlate soil health with management variables to provide evidence-based recommendations for sustainable coffee expansion in Bastar.

Materials and Methods

Study Area

Darbha Block is situated in the Bastar district of Chhattisgarh, India, between latitudes 18.80°N and 19.10°N, and longitudes 81.85°E and 82.10°E. The altitude ranges from 500 to 900 meters above mean sea level. This region belongs to the southern plateau, distinguished by undulating terrain and significant forest coverage. The climate is categorized as tropical monsoon (sub-humid), with annual rainfall ranging from 1300 to 1600 mm, predominantly occurring from June to September. Summer temperatures fluctuate between 30 and 40°C, whereas winter temperatures range from 12 to 20°C. In the monsoon season, relative humidity levels are elevated, fluctuating between 60% and 85%. The soils in this region predominantly consist of sandy loam to loam, exhibiting slight acidity (pH 5.2–6.4), well-drained characteristics, and a moderate enrichment of organic carbon in the surface layer. These conditions facilitate shade-grown coffee agroforestry systems. Darbha is linked by the Jagdalpur–Sukma National Highway and functions as an administrative entity tasked with executing rural development, agricultural, and infrastructure initiatives. The region constitutes a crucial transitional agroforestry zone where the management of soil fertility is vital for sustainable coffee cultivation. Figure 1: Soil maps of the Darbha Block in Bastar District.



Soil Sampling

Soil samples were collected from multiple villages in the Darbha block using a random sampling technique. Soil samples composed of multiple layers were obtained at two depths: 0–15 centimeters (surface layer) and 15–30 centimeters (subsurface layer). Composite samples were generated by combining sub-samples collected from multiple locations. At each sampling location, five to seven subsamples were collected in a zig-zag pattern and amalgamated to create a single composite sample for each depth. The geographic coordinates of each sampling location were documented utilizing a handheld Global

Positioning System (GPS). The gathered materials were air-dried, meticulously pulverized, and subjected to a 2-mm filtration for physico-chemical analysis. The materials were dehydrated, filtered, and conserved for analysis. The study involved the application of coffee monoculture techniques and coffee-based agroforestry systems, intended to evaluate the sustainability and yield of these approaches in coffee production.

Laboratory Analysis

Standard laboratory techniques were employed to examine the physicochemical characteristics of the soil. The hydrometer technique was used to determine soil texture. Soil pH was measured in a 1:2.5 soil-to-water suspension with a digital pH meter, while electrical conductivity (EC) was assessed in the same extract using a conductivity meter. The core sampling technique was applied to measure bulk density. Soil organic carbon content was determined using the Walkley–Black wet oxidation method. The Kjeldahl digestion method was used to analyze total nitrogen content. Available phosphorus was measured through the Olsen method, and available potassium was extracted with neutral normal ammonium acetate, then evaluated using a flame photometer. Micronutrients, including iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu), were extracted using a DTPA solution and quantified by atomic absorption spectrophotometry (AAS). All analyses were carried out with appropriate quality control measures, including the use of reagent blanks and standard reference samples. The following physicochemical characteristics were examined:

Parameter	Method
pH	Digital pH meter
EC	Conductivity meter
Moisture	Oven drying method
Organic Carbon	Walkley-Black method
Bulk Density	Core method
Dielectric Properties	Microwave technique

GIS Analysis

Geographical Information System (GIS) techniques were employed to examine the spatial distribution of soil properties. The GPS coordinates of the sampling locations were documented and imported into GIS software. Interpolation methods, including Inverse Distance Weighting (IDW), were utilized to produce thematic maps that visually represent the variations in soil properties across the sampled locations.

Results

Physical Properties

Table 1.Villages wise of Darbha Block of Bastar district of Soil Physical Properties in depth size

S. No	Village	Depth (cm)	Texture	Bulk Density (g/cm³)	Porosity (%)	WHC (%)	Structure
1	Darbha	0–15	Sandy Loam	1.28	52	58	Granular
		15–30	Sandy Loam	1.34	48	54	Blocky
2	Dilmili	0–15	Loam	1.32	50	55	Granular
		15–30	Loam	1.38	46	51	Blocky
3	Urukpal	0–15	Sandy Loam	1.26	53	60	Granular
		15–30	Sandy Loam	1.33	49	56	Blocky

Chemical Properties

Table 2.Villages wise of Darbha Block of Bastar district of Soil Chemical Properties in depth size

S. No	Village	Depth (cm)	pH	EC (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	CEC (cmol/kg)
1	Darbha	0–15	6.9	0.21	0.60	163	30.00	302	18
		15–30	6.7	0.20	0.30	100	8.75	224	15
2	Dilmili	0–15	6.4	0.10	0.45	100	60.00	257	17
		15–30	6.3	0.20	0.60	237	32.76	156	14
3	Urukpal	0–15	6.1	0.10	0.45	125	41.25	324	19
		15–30	6.4	0.10	0.30	125	41.25	324	16

Macronutrients

Table 3.Villages wise of Darbha Block of Bastar district of Macro nutrient of Soils in depth size

S. No	Village	Depth (cm)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Fertility Rating
1	Darbha	0–15	163	30.00	302	High
		15–30	100	8.75	224	Medium
2	Dilmili	0–15	100	60.00	257	High
		15–30	237	32.76	156	Medium
3	Urukpal	0–15	125	41.25	350	High
		15–30	125	41.25	324	Medium

Micronutrients

Table 4.Villages wise of Darbha Block of Bastar district of Micro nutrient of Soils in depth size

S. No	Village	Depth (cm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)	S (ppm)
1	Darbha	0–15	108.39	3.480	38.39	2.086	6.00	12.54
		15–30	96.62	6.982	26.37	3.210	8.00	13.44
2	Dilmili	0–15	147.20	2.319	20.76	2.311	5.00	10.792
		15–30	168.90	2.972	31.33	3.012	7.00	10.752
3	Urukpal	0–15	78.46	2.019	31.72	2.418	6.00	3.584
		15–30	114.50	2.776	44.98	4.862	6.00	3.584

Discussion

Physical Properties:

This study assesses the physical qualities of soil in specific villages of the Darbha block, namely Darbha, Dilmili, and Urukpal, at two depth intervals (0–15 cm and 15–30 cm). The findings demonstrate significant variation in soil properties based on depth and location.

Soil Texture: The prevalent soil textures in all settlements are sandy and loam. Sandy loam is seen in Darbha and Urukpal, but Dilmili exhibits a loam texture. This signifies moderate water retention and enough aeration, conducive to crop growth.

Bulk Density: Bulk density varies between 1.26 and 1.38 g/cm³. A lower bulk density (1.26–1.32) in surface soil signifies improved soil structure and the presence of organic matter. Elevated values in deeper strata indicate compaction and less pore space.

Porosity: Porosity ranges from 46% to 53%. Surface soils exhibit increased porosity attributable to organic content and biological activity. The decline in deeper strata indicates diminished aeration and permeability.

Water Holding Capacity (WHC) ranges from 51% to 60%. Elevated water-holding capacity in sandy loam soils (Urukpal and Darbha) signifies effective moisture-retention capability. A minor reduction with depth results from diminished organic content and heightened compaction.

Soil Structure: Surface soils display a granular structure, which is optimal for plant growth. Subsurface soils exhibit a blocky structure, signifying reduced aeration and increased density.

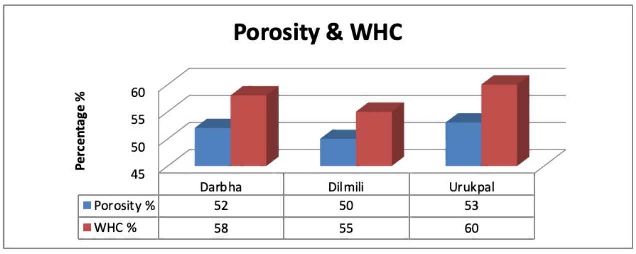


Figure.2.Villages wise of Darbha Block of Bastar district of Porosity & WHC in depth size 0-15 cm

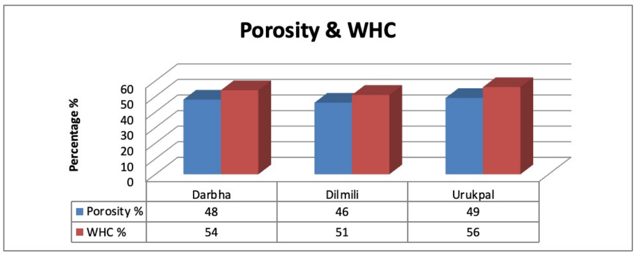


Figure.3.Villages wise of Darbha Block of Bastar district of Porosity & WHC in depth size 15-30 cm

Chemical Properties:

The chemical examination of soils from the villages of Darbha, Dilmili, and Urukpal at varying depths (0–15 cm and 15–30 cm) indicates significant differences in soil fertility and nutrient composition.

Soil Acidity (pH value): The soil pH ranges from 6.1 to 6.9, signifying slightly acidic to almost neutral soil conditions. Surface soils exhibit a marginally elevated pH relative to underlying layers. This pH range is optimal for the majority of crops, particularly rice and legumes.

Electrical Conductivity (EC): EC values vary from 0.10 to 0.21 dS/m, signifying non-saline soil.

A low electrical conductivity indicates the lack of detrimental salts, which is advantageous for plant development.

Organic Carbon (OC): OC ranges from 0.30% to 0.60%. Elevated organic carbon levels in surface soil signify enhanced organic matter accumulation. Reduced organic carbon in deeper strata indicates diminished biological activity, which may result from lower rates of decomposition and nutrient cycling compared to surface soils.

Nitrogen (N): Nitrogen concentration varies between 100 and 237 kg/ha. Surface soils typically include elevated nitrogen levels. Certain regions have moderate to low nitrogen levels, indicating a requirement for nitrogen fertilizer.

Phosphorus (P) exhibits considerable variability, ranging from 8.75 to 60 kg/ha. Reduced values in deeper strata signify inadequate phosphorus mobility. Certain communities, such as Dilmili, exhibit elevated phosphorus levels, signifying fertility discrepancies among places.

Potassium (K): Potassium levels vary from 156 to 324 kg/ha. The majority of soils exhibit medium to high potassium levels, making them conducive for agricultural cultivation. Cation Exchange Capacity (CEC) varies from 14 to 19 cmol/kg. Moderate cation exchange capacity signifies effective nutrition retention capability. The minor reduction in nutrient levels in the deeper strata is attributed to a decrease in organic matter.

Macronutrients:

The examination of macronutrients (nitrogen, phosphorus, and potassium) in the soils of Darbha, Dilmili, and Urukpal villages at two depths (0–15 cm and 15–30 cm) reveals considerable discrepancies in nutrient distribution and fertility status.

Nitrogen (N): The nitrogen content varies between 100 and 237 kg/ha. Surface soils typically have moderate nitrogen levels, whereas deeper strata display variability. In Dilmili (15–30 cm), elevated nitrogen levels (237 kg/ha) may result from leaching or buildup. Nitrogen levels are low to moderate, necessitating nitrogen supplementation.

Phosphorus (P): Phosphorus levels vary from 8.75 to 60 kg/ha. Surface soils exhibit elevated phosphorus levels, particularly in Dilmili (60 kg/ha). The reduced phosphorus concentration in a deeper layer of soil reveals its limited mobility in the soil matrix. Variation indicates inconsistent fertilizer application or disparities in soil composition, which may lead to uneven nutrient distribution and affect crop yield in the affected areas.

Potassium (K) ranges from 156 to 350 kg/ha. The majority of soils exhibit medium to high levels of potassium, especially in Urukpal. Elevated potassium levels signify favorable mineral composition and soil fertility.

Reproductive Health Status: Surface soils (0–15 cm) are typically categorized as having high fertility. Subsurface soils (15–30 cm) are classified as having medium fertility. This tendency signifies that topsoil is increasingly productive and nutrient-dense.

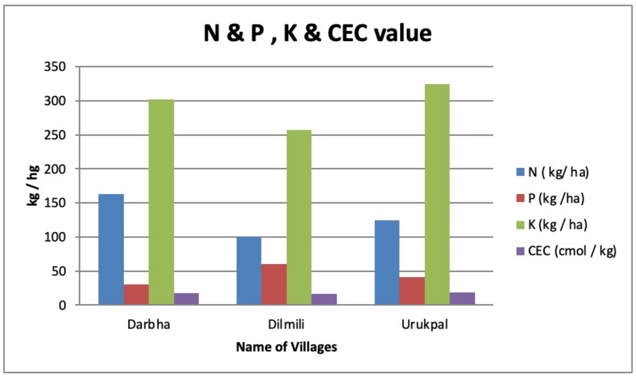


Figure.4.Villages wise of Darbha Block of Bastar district of N,P,K and CEC in depth size 0-15 cm

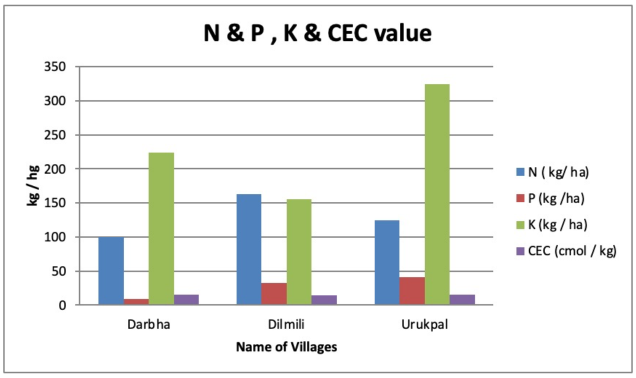


Figure.5.Villages wise of Darbha Block of Bastar district of N, P,K and CEC in depth size 15-30 cm

Micronutrient

The micronutrient analysis of soils from the villages of Darbha, Dilmili, and Urukpal at two depths (0–15 cm and 15–30 cm) reveals heterogeneity in critical elements like Fe, Zn, Mn, Cu, B, and S.

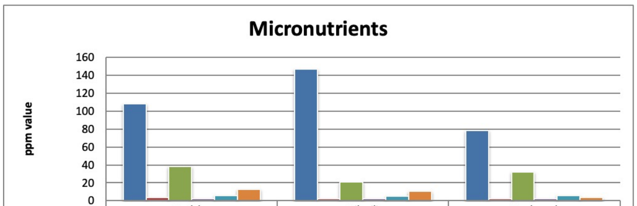
Iron (Fe) has a concentration range of 78.46 to 168.90 ppm. All samples exhibit elevated iron concentrations, particularly in Dilmili. Elevated iron levels in deeper strata in certain instances signify leaching and buildup.

Zinc (Zn) ranges from 2.019 to 6.982 ppm. The values suggest sufficient to moderately elevated zinc availability. Minor fluctuations with depth indicate that mobility and soil composition exert an influence.

Manganese (Mn) concentrations vary from 20.76 to 44.98 ppm. Elevated manganese levels detected in Urukpal (15–30 cm) demonstrate adequate manganese for agricultural development.

Copper (Cu) concentrations range from 2.086 to 4.862 ppm. All soils exhibit sufficient copper concentrations and marginal elevation in subsurface strata in certain localities.

Boron (B) concentrations range from 5.0 to 8.0 ppm. Optimal levels signify robust reproductive growth facilitation in crops.



	Darbha	Dilmili	Urukpaal
Fe (ppm)	108.39	147.2	78.46
Zn (ppm)	3.48	2.319	2.019
Mn (ppm)	38.39	20.76	31.72
Cu (ppm)	2.086	2.311	2.418
#REF!	6	5	6
Boron (ppm)	12.54	10.792	3.584

Sulfur (S) ranges from 3.584 to 13.44 ppm. Reduced results in Urukpal indicate a potential sulfur deficit in certain regions. Increased sulfur levels in surface soils attributable to the presence of organic materials. Figure.6.Villages wise of Darbha Block of Bastar district of micronutrient in depth size 0-15 cm

Conclusion

The soils of Darbha block are predominantly fertile and conducive to agriculture, primarily due to their favorable texture and water retention abilities. Surface soils (0–15 cm) are more productive because they have a lower bulk density, more porosity, and a better structure. In contrast, subsurface soils (15–30 cm) exhibit enhanced densification, decreased porosity, and reduced water-holding capacity, often displaying a blocky morphology. Soil management techniques, such as the incorporation of organic matter, appropriate tillage, and effective irrigation management, can significantly enhance soil quality.

Farmers in the Bastar region cultivate various crops, including paddy, maize, pulses, and coffee, in these soils. Darbha soils are non-saline, moderately fertile, and exhibit low acidity. Organic carbon and nitrogen levels are higher in surface soils (0–15 cm). However, nutrient availability diminishes fertility in the 15–30 cm subsurface soils, which have lower organic content and a slight decrease in cation exchange capacity. Rice, maize, and legumes thrive in these soils despite the nitrogen and organic carbon shortages in some areas, which necessitate the use of organic fertilizers and balanced fertilization.

Darbha block soils range from moderate to high fertility due to the availability of macronutrients. The topsoil is nutrient-rich, making it more suitable for farming. Nitrogen levels are low, phosphorus content varies, and potassium levels are sufficiently high. The overall quality of soil micronutrients is favorable for agriculture, with no significant deficiencies except for a regional sulfur deficit. Surface soils possess a marginally higher nutrient content compared to deeper strata.

Future Visions:

This work gives important insights into the physical properties of Darbha block soils; however, further research is necessary.

Complete

Chemical and Biological Evaluation: Future studies should include micronutrients (Zn, Fe, Mn, Cu) and biological features such as microbial activity to achieve a more comprehensive soil health assessment.

Seasonal Variation Study: The effects of summer, monsoon, and winter on soil properties need to be examined. Long-term monitoring can reveal the impacts of climate on soil dynamics, such as changes in nutrient availability and moisture retention during different seasons. Soil mapping could be enhanced using advanced Geographic Information Systems (GIS) methods, which can provide detailed spatial analysis and visualization of soil properties across different seasons.

Soil Fertility Maps: The creation of distribution maps for soil moisture will facilitate precision agriculture and improve land-use planning.

Agricultural Practice Effects: It is important to assess the impact of organic fertilizers and irrigation technologies to identify sustainable agriculture practices.

Crop Suitability and Productivity Analysis: Correlating soil parameters with agricultural output will help identify the best crops for each village and improve the coordination between soil and crops, thereby aiding scientific agricultural planning.

Soil Conservation and Management Strategies: Future efforts may focus on mitigating soil erosion and implementing organic farming techniques, along with strategies to enhance soil structure for long-term soil health.

Climate Change Impact Assessment: Assessing how changes in precipitation and temperature affect soil moisture is essential for developing adaptable agricultural strategies. Subsequent investigations should incorporate Zn, Fe, Mn, and Cu to uncover hidden deficiencies, as these micronutrients are crucial for optimal plant growth and can significantly influence soil fertility and agricultural productivity. Soil fertility mapping should utilize Geographic Information Systems (GIS) to prepare distribution maps of nutrients and health maps of soil, which will facilitate precision agriculture and informed decision-making.

Both organic and inorganic fertilizers are critical for enhancing long-term soil fertility. Analyzing seasonal changes in soil composition is also important, as soil acidity and nutritional status affect efficiency and sustainability. Chemical metrics indicate reasonable fertility in the soils of the Darbha block; however, fertilizer management is necessary to improve nitrogen levels and organic matter. The macronutrient profile of these soils shows favorable fertility, but certain constraints regarding nitrogen levels must be addressed to ensure sustainable agricultural output, particularly by implementing targeted fertilization strategies and improving organic matter content. While the micronutrient quality in the Darbha block soils is mainly adequate, there is a slight deficiency in sulfur; effective nutrient management is essential for maintaining sustainable agricultural productivity.

References

1. Alloway, B. J. (2008). Zinc in soils and crop nutrition. International Fertilizer Industry Association.
2. Bhat, R., & Sujatha, S. (2013). Soil fertility and nutrient dynamics under coffee-based agroforestry systems in India. Agroforestry Systems, 87(6), 1267–1280. https://doi.org/10.1007/s10457-013-9631-9
3. Brady, N. C., & Weil, R. R. (2017). The nature and properties of soils (15th ed.). Pearson Education, New Delhi.
4. Burrough, P. A., & McDonnell, R. A. (1998). Principles of geographical information systems. Oxford University Press.
5. Coffee Board of India. (2018). Coffee cultivation manual. Coffee Research Institute.
6. ESRI. (2020). ArcGIS Desktop: Release 10. Environmental Systems Research Institute.
7. FAO. (2006). Guidelines for soil description (4th ed.). Food and Agriculture Organization.
8. Foth, H. D. (1990). Fundamentals of soil science. Wiley.
9. Government of Chhattisgarh. (2020). Soil resource inventory of Chhattisgarh state. Department of Agriculture, Raipur, Chhattisgarh.
10. Hillel, D. (2004). Introduction to environmental soil physics. Elsevier.
11. Jackson, M. L. (1973). Soil chemical analysis. Prentice Hall.
12. Jackson, M. L. (2005). Soil chemical analysis: Advanced course. University of Wisconsin Madison, USA.
13. Jha, P., Singh, R. P., & Tiwari, A. (2018). Physicochemical characteristics of soils of Bastar plateau region of Chhattisgarh. Journal of the Indian Society of Soil Science, 66(3), 245–252.
14. Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits. Agroforestry Systems, 76, 1–10.
15. Kravchenko, A. N. (2003). Influence of spatial structure on interpolation results. Agronomy Journal, 95, 617–628.
16. Kumar, K., Pandey, A., Patel, U. K., & Sahu, J. P. (2024). The Evolution of Physico - Chemical Characteristics of Coffee - Based Soils in Bastar Division, Chhattisgarh. International Journal of Environmental Sciences, 1094-1101. https://doi.org/10.64252/54hzsp82
17. Kumar, R., Sahu, S., Tiwari, S., & Mishra, V. (2024). Soil properties and carbon dynamics under coffee-based agroforestry systems in Bastar region, India. Environment, Development and Sustainability.
18. Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304, 1623–1627.
19. Li, J., & Heap, A. D. (2011). A review of spatial interpolation methods. Environmental Modelling & Software, 26, 573–584.
20. McBratney, A. B., Mendonça Santos, M. L., & Minasny, B. (2003). On digital soil mapping. Geoderma, 117, 3–52.
21. Minasny, B., & McBratney, A. B. (2016). Digital soil mapping: A brief history. Geoderma, 264, 301–311.
22. Nair, P. K. R. (2011). Agroforestry systems and environmental sustainability. Agroforestry Systems, 83, 1–3.
23. Nelson, S. O. (1999). Dielectric properties of agricultural materials. Journal of Microwave Power and Electromagnetic Energy, 34, 231–252.
24. Singh, K. P., Verma, R. R., & Sharma, S. K. (2023). Soil properties and carbon dynamics under coffee-based agroforestry systems in Bastar region of Chhattisgarh, India. Agroforestry Systems, 97, 1123–1136.
25. Singh, M. V. (2011). Micronutrient deficiencies in soils and crops of India. Indian Journal of Fertilizers, 7, 56–64.
26. Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (1993). Soil fertility and fertilizers. Macmillan.
27. Tiwari, S., Pandey, A., Mishra, V., & Shrivastava, A. (2018). Microwave dielectric behavior of soil. Journal of Applied Physics.
28. Velmourougane, K. (2016). Impact of organic and conventional systems on soil properties under coffee cultivation. Scientifica, Article ID 1954796.
29. Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter. Soil Science, 37, 29–38.