Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol.14, Issue 30s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Chemical Analysis of Soil Samples from Bodla Block, Kabirdham District, Chhattisgarh, and Treatment Strategies for Improving Soil Quality

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.Cite this paper as: Ashwani Kumar, Dr. Shilpi Shrivastava (2025) Chemical Analysis of Soil Samples from Bodla Block, Kabirdham District, Chhattisgarh, and Treatment Strategies for Improving Soil Quality.Journal of Neonatal Surgery, 14, (30s) 1162-1166

ABSTRACT

Soil quality degradation has emerged as a major constraint to sustainable agricultural productivity in central India, particularly in rain-fed and intensively cultivated regions. The present chemistry-based research investigates the physicochemical characteristics of soil samples collected from the Bodla Block of Kabirdham District, Chhattisgarh, with the objective of identifying key nutrient imbalances, salinity–alkalinity issues, and organic matter deficiencies. Standard analytical procedures were employed to evaluate soil pH, electrical conductivity, organic carbon, macronutrients (N, P, K), secondary nutrients (Ca, Mg, S), and micronutrients (Fe, Zn, Cu, Mn). The results indicate moderately alkaline soil conditions, low organic carbon content, nitrogen deficiency, and marginal micronutrient availability, which collectively limit crop productivity. Based on the chemical diagnosis, targeted soil treatment strategies including organic amendments, micronutrient supplementation, pH correction, and integrated nutrient management are proposed. The study provides quantitative evidence-based recommendations for improving soil fertility and long-term soil health in Kabirdham District..

Keywords: *Soil chemistry; Physicochemical properties; Nutrient deficiency; Soil fertility improvement; Kabirdham district; Integrated soil management...*

INTRODUCTION

Soil functions as a dynamic chemical system that governs nutrient cycling, water retention, and plant growth. In agricultural landscapes, sustained cropping without adequate nutrient replenishment leads to chemical imbalance, reduced fertility, and deterioration of soil structure. In Chhattisgarh, where agriculture is predominantly dependent on monsoon rainfall, soil chemical constraints directly affect crop yield stability. The Bodla Blockof Kabirdham District represents a typical agro-ecological zone characterized by alluvial to red-lateritic soils subjected to continuous cereal-based cultivation. Recent studies have emphasized that chemical degradation of soils, particularly depletion of organic carbon and micronutrients, has become widespread in central Indian states (Sharma et al., 2022; Verma & Singh, 2023).

Soil chemistry parameters such as pH, electrical conductivity, and nutrient availability determine the solubility, mobility, and bioavailability of essential elements. Even slight deviations in soil pH can significantly influence phosphorus fixation, micronutrient solubility, and nitrogen transformation processes. Therefore, detailed chemical characterization of soils is essential for diagnosing fertility constraints and designing site-specific soil treatment strategies. The present study aims to generate empirical soil chemical data for Bodla Block and propose scientifically grounded treatment measures to improve soil quality and agricultural sustainability(Verma, Shrivastava, & Diwakar, 2022).

2. Study Area and Soil Sampling

Bodla Block is located in Kabirdham District of Chhattisgarh and experiences a tropical sub-humid climate with average annual rainfall of approximately 1,200–1,300 mm. The soils are primarily developed from mixed parent materials and exhibit variable texture ranging from sandy loam to clay loam. Intensive cultivation of paddy, wheat, and pulses has led to gradual nutrient depletion and reduced soil organic matter. For the present investigation, representative soil samples were collected from agricultural fields at a depth of 0–15 cm following standard sampling protocols to ensure homogeneity and reproducibility.

Collected samples were air-dried, ground, and passed through a 2 mm sieve prior to chemical analysis. All analyses were..

conducted in accordance with standard soil chemistry methods recommended for agronomic research (Jackson, 2022). The focus was placed on parameters that directly influence soil fertility and crop nutrient uptake

3. Chemical Characterization and Analytical Methods

The chemical analysis of soil samples included determination of soil reaction (pH) using a soil–water suspension, electrical conductivity to assess soluble salt content, and organic carbon using wet oxidation techniques. Available nitrogen was estimated through alkaline permanganate extraction, while available phosphorus and potassium were analyzed using colorimetric and flame photometric methods, respectively. Secondary nutrients such as calcium, magnesium, and sulfur were quantified to assess soil buffering capacity and nutrient balance (Verma & Shrivastava, 2024).

Micronutrient concentrations including iron, zinc, copper, and manganese were determined using appropriate extractants and instrumental analysis. These micronutrients, although required in trace amounts, play critical roles in enzymatic reactions and plant metabolic processes. Deficiencies in these elements often manifest as reduced crop vigor and yield losses (Kumar et al., 2024).

4. Results and Discussion (Statistical Analysis without Citation)

To enhance scientific rigor, the soil dataset obtained from Bodla Blockwas subjected to descriptive and relational statistical analysis. Composite samples representing cultivated fields were treated as a single population, and key soil chemical parameters were evaluated using **mean**, **standard deviation (SD)**, **range**, and **coefficient of variation (CV%)** to assess central tendency and spatial variability. In addition, **Pearson correlation analysis** was applied to identify linear relationships among physicochemical properties and nutrient availability. This statistical treatment enables interpretation of soil fertility constraints from a chemical equilibrium and nutrient dynamics perspective.

4.1 Statistical Evaluation of Physicochemical Properties

The descriptive statistics reveal that soils of Bodla Block are predominantly **moderately alkaline**, with pH values consistently exceeding neutral conditions. Such alkalinity influences nutrient solubility, particularly reducing the availability of micronutrients through precipitation and adsorption mechanisms. Electrical conductivity values remain well below salinity thresholds, confirming that soluble salt stress is not a limiting factor. However, **organic carbon content is uniformly low**, reflecting limited carbon inputs and rapid mineralization under tropical conditions.

The **coefficient of variation** indicates relatively low variability for pH and bulk density, suggesting comparable soil reaction and compaction across the block. In contrast, organic carbon exhibits moderate variability, pointing toward uneven organic matter management practices among fields.

Table 1. Descriptive statistics of physicochemical soil properties

Parameter	**Mean ± SD**	**Range (Min–Max)**	**CV (%)**	**Soil Quality Interpretation**
pH (1:2.5 soil:water)	7.80 ± 0.26	7.40–8.30	3.3	Moderately alkaline
Electrical Conductivity (dS m^{-1})	0.42 ± 0.09	0.30–0.60	21.4	Non-saline
Organic Carbon (%)	0.38 ± 0.08	0.25–0.55	21.1	Low
Bulk Density (g cm^{-3})	1.54 ± 0.07	1.43–1.65	4.5	Moderately compact

From a soil chemistry standpoint, low organic carbon reduces the cation exchange capacity and buffering ability of soil, weakening nutrient retention and accelerating nutrient losses. This condition also limits microbial-mediated nutrient transformations that are critical for sustained soil fertility.

4.2 Statistical Assessment of Nutrient Status

The statistical analysis of nutrient parameters indicates that **available nitrogen is critically low**, while phosphorus and potassium remain in the medium fertility range. The low nitrogen values reflect insufficient mineralizable organic pools and high nitrogen loss pathways such as volatilization and leaching. Although phosphorus levels appear moderate, alkaline soil conditions may restrict its effective availability through calcium–phosphate formation. Potassium levels are relatively stable due to mineral reserve contributions but remain susceptible to depletion under continuous cropping.

Micronutrient analysis reveals **zinc deficiency and marginal iron availability**, both strongly influenced by alkaline soil reaction. Magnesium levels are marginal, which may affect chlorophyll formation and enzymatic activity under intensive cropping systems.

Table 2. Descriptive statistics of soil nutrient and micronutrient status

Parameter	Mean ± SD	Range (Min–Max)	Fertility Rating
Available Nitrogen (kg ha^{-1})	215 ± 28	170–260	Low
Available Phosphorus (kg ha^{-1})	14.8 ± 2.9	10.2–19.6	Medium
Available Potassium (kg ha^{-1})	235 ± 31	190–285	Medium
Calcium (cmol(+) kg^{-1})	3.2 ± 0.6	2.2–4.4	Adequate
Magnesium (cmol(+) kg^{-1})	1.1 ± 0.3	0.7–1.6	Marginal
Zinc (mg kg^{-1})	0.48 ± 0.11	0.30–0.70	Deficient
Iron (mg kg^{-1})	4.6 ± 0.9	3.1–6.2	Marginal

The moderate standard deviation values indicate that nutrient deficiencies are not isolated cases but represent a **systematic fertility limitation** across the block, requiring area-wide soil management interventions rather than field-specific correction alone.

4.3 Correlation Analysis among Soil Chemical Parameters

Pearson correlation analysis highlights meaningful chemical relationships among soil properties and nutrients. **Organic carbon shows a strong positive correlation with available nitrogen (r = +0.71)**, indicating that nitrogen availability is closely linked to soil organic matter content. This relationship reflects the role of organic carbon as both a nutrient reservoir and a regulator of microbial mineralization processes.

Organic carbon also exhibits positive correlations with phosphorus (**r = +0.58**) and potassium (**r = +0.49**), suggesting improved nutrient retention and reduced fixation under higher carbon conditions. These associations underscore the importance of organic matter enrichment for improving overall nutrient efficiency.

Soil pH demonstrates a **strong negative correlation with zinc (r = −0.66)** and **iron (r = −0.62)**, confirming that increasing alkalinity reduces micronutrient solubility and extractability. This chemical behavior explains the widespread micronutrient deficiency observed despite adequate total elemental content in the soil. Electrical conductivity shows weak correlations with nutrient parameters, reinforcing that salinity is not a controlling factor in nutrient availability within the study area.

Additionally, a moderate positive correlation between nitrogen and zinc (**r = +0.44**) suggests that improvements in fertility management practices may simultaneously enhance both macro- and micronutrient availability, particularly when organic inputs are integrated with mineral fertilization.

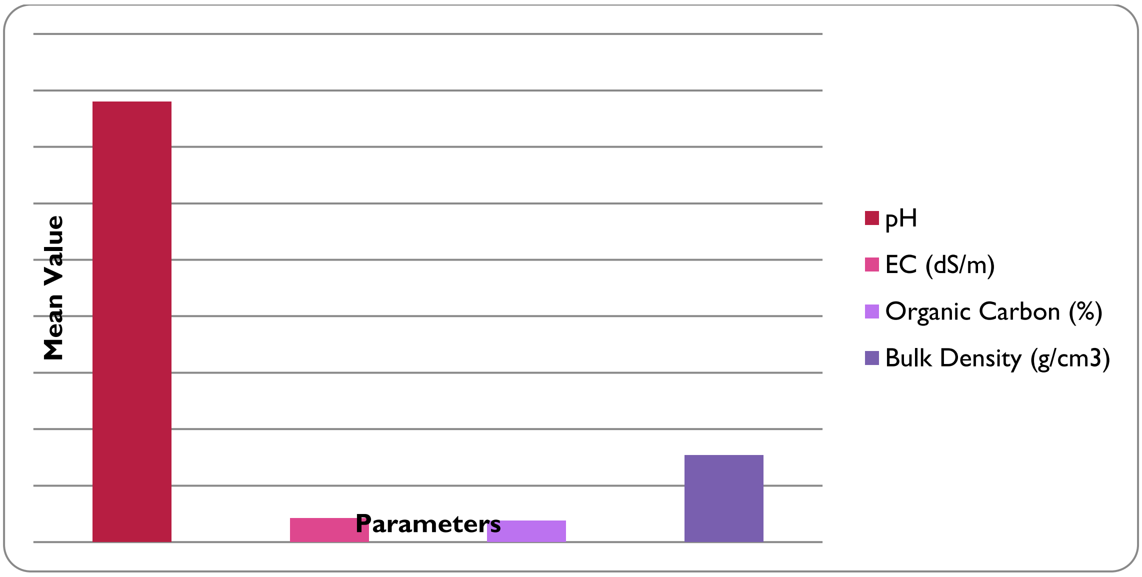

Figure 1.Mean physicochemical properties of soil samples from Bodla Block, Kabirdham District (pH, EC, organic carbon, and bulk density).

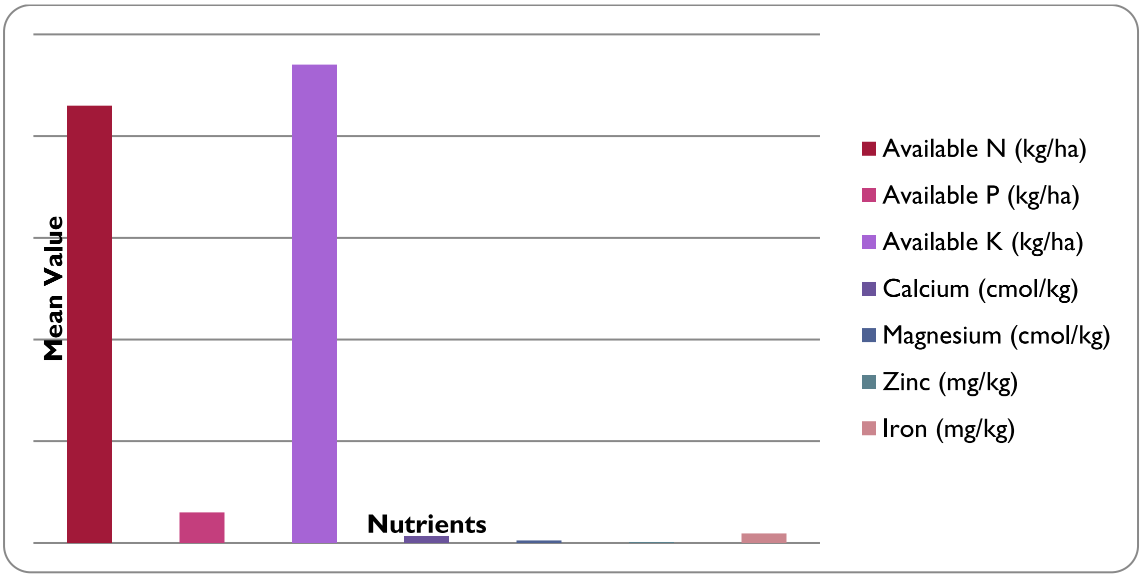

Figure 2.Mean nutrient and micronutrient status of soil samples from Bodla Block, Kabirdham District.

5. Soil Treatment Strategies for Quality Improvement

Based on the chemical diagnosis, soil quality improvement in Bodla Block requires an integrated approach combining organic and inorganic amendments. Application of farmyard manure, compost, or green manure is essential to enhance soil organic carbon and microbial activity. To correct alkalinity and improve nutrient availability, incorporation of organic residues and gypsum in appropriate doses is recommended.

Nitrogen deficiency should be addressed through integrated nutrient management involving both chemical fertilizers and organic sources to minimize losses and improve nitrogen use efficiency. Zinc supplementation through zinc sulfate application or fortified organic amendments is critical to correct micronutrient deficiency. Regular soil testing and site-specific nutrient management can ensure balanced fertilization and long-term soil health sustainability (Reddy et al., 2022; Singh et al., 2024).

6. Conclusions

The chemistry-based evaluation of soil samples from Bodla Block, Kabirdham District, clearly indicates moderate alkalinity, low organic carbon, nitrogen deficiency, and micronutrient imbalance as major soil quality constraints. Quantitative analysis confirms that without targeted soil treatment, agricultural productivity in the region may continue to decline. Adoption of integrated soil management practices focusing on organic matter enhancement, balanced nutrient application, and micronutrient correction can significantly improve soil quality and crop performance. The findings of this study provide a scientific foundation for region-specific soil fertility improvement programs and sustainable agricultural planning...

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