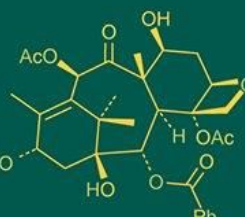


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Status of chemical properties of soil in semi-arid region of Bundelkhand, Uttar Pradesh

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Abstract

The present investigation was conducted during 2021-2022 with the objective of developing an oil resource inventory for the Bundelkhand region. This study, titled “status of chemical properties of soil in semi-arid region of Bundelkhand, Uttar Pradesh,” aimed to assess the organic carbon status and related soil parameters within the study area. Soil samples were randomly collected from Badokhar Khurd in the Banda district of Bundelkhand, Uttar Pradesh, and analyzed using standard protocols to determine the levels of organic carbon (OC) and available nutrients, including nitrogen (N), phosphorus (P), and potassium (K). The results showed that organic carbon levels ranged from 0.16% to 0.92%, available nitrogen from 121.21 to 380.47 kg ha⁻¹, available phosphorus from 6.50 to 22.34 kg ha⁻¹, and available potassium from 120.62 to 415.65 kg ha⁻¹. These findings highlight the variability in soil fertility across different land-use systems in the semi-arid Bundelkhand region and provide a foundation for sustainable soil and land management practices.

Keywords: Organic carbon, nitrogen, phosphorus, potassium

Introduction

It is now more crucial than ever for stakeholders, including landholders, cultivators, builders, and the general public, to actively engage in the protection and conservation of soil resources. This collective effort is vital to safeguard soil quality and enhance productivity sustainably. Stakeholder activities often impact soil quality more significantly than natural processes themselves (Biradar *et al.*, 2020) [1]. Soil, a non-renewable natural resource, serves as a reservoir of essential nutrients and a habitat for microorganisms capable of sustaining life indefinitely. The properties of soil are influenced by several factors, including climate, biotic organisms, parent material, time, geographical location, and agricultural practices. Understanding the characteristics, distribution, and location of soils is fundamental to effective developmental planning within specific regions. Since the advent of agriculture, there has been an inherent curiosity about soil potential and land productivity (Carter *et al.*, 2004) [5]. Organic matter, which consists of decomposed plant and animal residues, plays a critical role in maintaining soil fertility. It enhances the soil's buffering capacity, thereby improving crop viability (Fageria, 2012) [6]. However, socioeconomic factors, such as urbanization and deforestation at village, block, district, and regional levels, significantly alter land use patterns. These disruptions often lead to long-term impacts on soil quality and landscape stability (Wu, 2015) [21]. Evaluating soil parameters requires careful consideration of continuous spatial and temporal variability. Traditional soil analysis methods, while detailed, are labor-intensive and time-consuming, making it difficult to extrapolate comprehensive information for large areas based solely on point measurements. To address this limitation, geostatistical modeling has emerged as a powerful tool. It enables the creation of spatial maps that depict soil fertility variations over extensive regions. Among these geostatistical techniques, kriging is widely recognized as an essential spatial interpolation method. It provides accurate and reliable predictions for land resource inventories, allowing researchers and planners to develop strategies for sustainable soil and land management. By integrating advanced geospatial approaches, the understanding of soil variability can be significantly enhanced, contributing to better resource utilization and environmental conservation.

Materials and Methods

Banda was carried out in the years 2021-22. "A total of 100 samples were collected from Badokhar Khurd cultivable area using random sampling. Standard analytical procedures were used for determining nutrient status of collected soil samples. The following subheadings show the details of the experiment, materials used, and procedures used for the current studies. The "Badokhar Khurd" is located in Banda district, The elevation varies from mean sea level and 430 meters above it. Bundelkhand's Banda district is made up of uneven uplands interspersed with swampy lowlands. Based on soils, geography, climate, and natural vegetation, Banda is separated into four sub-regions. This area has rough topography due to erosion induced by river tributaries and rivers themselves. The district has a slope that runs from north-west to east, which cause variation in soil quality and topography from west to east. Banda district soils are generally classified as red or black soils. The Bundelkhand soils locally known as Rakar, Kabar, Parua, and Mar belongs to Alfisols, Vertisols, Inceptisols and Vertisols soil order, respectively). Poor organic carbons, available Nitrogen & Phosphorus, slightly acidic to neutral soil pH are the main characteristics of the soil of the Bundelkhand districts. Medium to high fertility level of available micronutrients is found in the Banda. Mar is most valuable soils in the district, where most crops can be cultivated effectively even in rainy conditions. When compared to other existing soils, the Mar soil has a comparatively high organic matter and clay concentration. It may be prone to water stagnation due to its high clay content.

Methodology

During the summer of 2021, a total of 100 geolocated surface soil samples (0-10 cm depth) were systematically collected from Badokhar Khurd, a semi-arid region in Bundelkhand, Uttar Pradesh. The location was selected due to its diverse land-use systems and the challenges posed by soil degradation in the area. The primary objective of this sampling was to assess soil fertility and analyze key parameters to better understand the soil's capacity for sustainable agricultural practices. The soil samples were carefully collected using standard geostatistical sampling methods to ensure the spatial representation of the study area. Following collection, the samples were air-dried under shade to prevent alteration of the soil's physical and chemical properties due to direct sunlight or excessive heat. Once dried, the soil samples were gently ground using non-metallic tools to maintain their natural characteristics and then passed through a 2 mm sieve to remove debris, stones, and coarse materials. The prepared soil samples were subsequently analyzed using standard laboratory protocols as recommended by Jackson (1973) [8] and Black (1965) [2]. These methods included determining soil organic carbon using the Walkley-Black method, which is widely acknowledged for its precision in assessing organic matter content (Walkley & Black, 1934) [20]. Additionally, key macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) were measured using techniques outlined by Subbiah and Asija (1956) [17] and Olsen *et al.* (1954) [11]. Geolocated sampling and rigorous processing ensured reliable and reproducible results. These findings contribute to the growing body of research focusing on soil health in semi-arid regions, including studies by Lal (2004) [10], who

emphasized the role of soil organic carbon in enhancing agricultural productivity, and Hillel (2007) [7], who highlighted the importance of sustainable soil management practices in arid and semi-arid zones.

Results and Discussion

The soil samples along with their random sampling were collected from Badokhar Khurd. The soil samples were Analyzed by adopting standard protocols. The data pertaining to different parameters have categorized as per standard rating. The data regarding to organic carbon (OC) and available N, P and K are given below.

Properties/nutrients	Min	Max	Mean	SD	CV
OC	0.16	0.92	0.49	0.21	45.34
N	119.21	387	210.56	52.51	21.17
P	6.5	22.92	17.45	6.21	43.66

With the help of standard protocol sell the soil samples were analyzed. All the parameters' data have been categorized according to standard rating. The data regarding to organic carbon (OC) and available N, P are given below.

Organic carbon (OC)

The organic carbon content of soil samples collected from the Badokhar Khurd area ranged from 0.16% to 0.92%, with a mean value of 0.45%. This indicates a generally low level of organic carbon, with a standard deviation of 0.21 and a coefficient of variation (CV) of 45.34%. Among the analyzed samples, 70.67% were categorized as low ($\leq 0.5\%$) in organic carbon content, 27.33% fell into the medium category (0.51%-0.75%), and only 2% were classified as high ($> 0.75\%$). The predominance of low organic carbon content (70.67%) aligns with the findings of Puran Dharan Naidu M.V.S. (2020), who characterized, classified, and studied the fertility of soils in the Puttur Mandal, a semi-arid region. Similarly, Rajendiran *et al.* (2020) [14] evaluated block-level soil organic carbon in the Jhabua District of Madhya Pradesh, India, and reported that most samples fell into the low category, attributing this to higher oxidation rates driven by elevated temperatures. These conditions are consistent with the semi-arid climate of the Bundelkhand region, where intense heat accelerates the decomposition of organic matter, thereby reducing organic carbon levels in the soil. Other studies further corroborate these findings. Lal (2004) [10] emphasized that semi-arid regions are particularly prone to organic carbon depletion due to factors such as limited vegetation cover, high temperatures, and frequent soil disturbances. Likewise, Hillel (2007) [7] pointed out that sustainable soil management practices are critical in such regions to mitigate organic matter loss. Fageria (2012) [6] also highlighted the importance of maintaining organic matter for enhancing soil fertility and buffering capacity, which is crucial for crop viability in challenging environments. The findings from the Badokhar Khurd area underscore the urgent need for targeted soil management strategies to improve organic carbon levels. Practices such as organic amendments, conservation tillage, and crop residue incorporation can help mitigate carbon loss and enhance soil productivity in similar semi-arid regions. This study adds to the growing body of evidence advocating for sustainable approaches to soil conservation in resource-constrained environments.

Available nitrogen (N)

The available nitrogen content in the soils of the Jari Village study area ranged from 116 to 380 kg ha⁻¹, with a mean value of 220 kg ha⁻¹. This indicates a generally low availability of nitrogen in the region's soils. The calculated standard deviation was 58.55, while the coefficient of variation (CV) stood at 25.17%, reflecting moderate variability within the sampled soils. A total of 75% of the soil samples were categorized as low in available nitrogen, while only 25% fell into the medium fertility category. The low nitrogen content observed in the study area can be attributed to the limited presence of soil organic carbon, which serves as a primary reservoir for nitrogen in soils. The semi-arid climatic conditions of the Bundelkhand region, characterized by high temperatures and low humidity, further exacerbate nitrogen depletion. These conditions accelerate the oxidation of organic matter, reducing its buildup and potentially increasing nitrate (NO₃⁻) loss through leaching. Similar findings were reported by Leela Wathi *et al.* (2009) [23], who highlighted the impact of semi-arid conditions on organic matter decomposition and nitrate leaching. As established in previous studies, most soil nitrogen is derived from organic sources, underscoring the link between low organic carbon levels and nitrogen deficiency. Rajendiran *et al.* (2020) [14] also reported similar trends in the Jhabua District of Madhya Pradesh, where the majority of soil samples exhibited low nitrogen content due to rapid organic matter decomposition under semi-arid conditions. Furthermore, Lal (2004) [10] emphasized that nitrogen deficiency in semi-arid soils often results from poor organic matter management and frequent soil disturbances. Fageria (2012) [6] advocated for the use of organic amendments and legume-based cropping systems to enhance nitrogen availability. These findings highlight the need for sustainable soil management practices tailored to the unique challenges of semi-arid regions like Bundelkhand.

Available phosphorous (P)

The available phosphorus status of soils in the Badokhar Khurd area ranged from 6.50 to 22.34 kg ha⁻¹, with a mean value of 17.35 kg ha⁻¹. These results indicate low to medium levels of soil-available phosphorus in the region. The standard deviation was calculated at 5.56, while the coefficient of variation (CV) was 43.62%, reflecting considerable variability in phosphorus content across the study area. The distribution of available phosphorus showed that 4% of the soil samples were in the high range, 77% fell within the medium range, and 19% were categorized as low. This spatial distribution highlights that the majority of soils in the study area possess suboptimal levels of phosphorus, which may limit crop productivity. The observed low to medium phosphorus levels can be attributed to several factors, including phosphorus fixation by clay minerals and significant removal through crop uptake, as reported by Supriya *et al.* (2019) [18]. Phosphorus fixation is a common issue in soils with high clay content, where phosphorus becomes bound to mineral particles, rendering it unavailable to plants. Similar findings were reported by Olsen *et al.* (1978) [12], who described the challenges of phosphorus availability in agricultural soils. Additionally, continuous cropping and inadequate replenishment of soil nutrients contribute to phosphorus depletion, as noted by Fageria (2012) [6]. The semi-arid conditions of Bundelkhand further exacerbate phosphorus limitations. High temperatures and

low organic matter content reduce the availability of phosphorus by limiting microbial activity, which is essential for organic phosphorus mineralization (Lal, 2004) [10]. Singh *et al.* (2018) [16] emphasized that soil management practices, such as the application of organic amendments and phosphate-solubilizing microorganisms, can significantly improve phosphorus availability in similar environments.

Spatial Variability of Soil Nutrients Based on GIS-Based Thematic Maps

The spatial distribution of soil nutrients in the study area was analyzed using GIS-based interpolated maps, providing a clear depiction of the variability across different categories of soil fertility. These maps offer valuable insights into nutrient management and soil health.

Soil Organic Carbon (OC)

The interpolated map for soil organic carbon (OC) revealed a significant portion of the area, approximately 1720.33 hectares, classified under the low category. This constituted 84.73% of the total village area, highlighting a widespread deficiency in organic carbon. The medium category accounted for 308.67 hectares (15.20%), while the high category covered a mere 2.72 hectares (0.33%). These figures emphasize the urgent need for practices to increase organic matter content, such as incorporating crop residues, using organic amendments, and adopting conservation agriculture practices.

Available Nitrogen (N)

The spatial variability map for available nitrogen showed that the majority of the study area, 92.62% (1880.60 hectares), fell into the low category, leaving only 7.44% (151.13 hectares) in the medium range. The complete absence of a high nitrogen category underlines the pressing need for nitrogen supplementation through sustainable practices like green manuring, legume-based cropping systems, and precise nitrogen fertilization.

Available Phosphorus (P)

The map for available phosphorus presented a different pattern. A staggering 97.54% of the area (1980.35 hectares) was found in the medium category, which is relatively better compared to other nutrients. However, 48.46 hectares (2.36%) were categorized as low, and only a negligible portion, 2.91 hectares (0.14%), fell into the high category. The medium phosphorus levels indicate the need for site-specific phosphorus management, considering the phosphorus fixation tendencies of the soil and its depletion due to crop removal.

Available Potassium (K)

The distribution map for available potassium showed that 91.80% (1864.54 hectares) of the area fell into the medium category. The low category accounted for 8.23% (167.19 hectares), and a tiny fraction, 0.07% (1.47 hectares), was in the high category. This suggests moderate potassium availability but highlights pockets of deficiency that require targeted interventions like potash application or the use of organic potassium sources.

Grouping of Soil Nutrients and Nutrient Index

The study grouped soil nutrients based on the Percent Sample Deficient (PSD) approach, categorizing the samples into low, medium, and high fertility levels. This grouping

provided an initial understanding of the nutrient deficiencies prevalent in the Badokhar Khurd area. However, the point data-based analysis lacked the spatial precision needed to fully capture the heterogeneity of soil fertility across the village.

The adoption of kriging-based maps significantly enhanced the accuracy and detail of spatial variability assessments. These interpolated maps allowed for a more nuanced understanding of soil nutrient distribution, highlighting areas that require specific interventions.

Factors Influencing Spatial Variability

The observed spatial variability in soil properties can be attributed to a range of factors, including:

- **Pedogenic Characteristics:** Soil formation processes and inherent properties such as texture and mineralogy (Jenny, 2012; Quine and Zhang, 2002) ^[9, 13].
- **Biotic and Abiotic Interactions:** The dynamic interplay between soil organisms, vegetation, and environmental factors.
- **Land Use and Management:** Farming practices, fertilizer application, and other land management strategies significantly influence soil nutrient status (Brejda *et al.*, 2000; Vieira and Paz-Gonzalez, 2003) ^[4, 19].

Sharma *et al.* (2013) ^[15] and Bogunovic *et al.* (2017) ^[3] highlighted that variations in soil nutrient levels are often linked to differences in land management practices at both macro and micro scales. The thematic maps generated through GIS provide a valuable tool for identifying such variations and developing site-specific nutrient management plans.

Implications for Soil Fertility Management

The spatial distribution maps reveal considerable variability in soil chemical properties across the village. These maps serve as a foundation for precision agriculture practices, enabling farmers to tailor nutrient applications based on specific soil conditions. By addressing the variability in soil fertility, the use of GIS-based maps can enhance nutrient use efficiency, reduce input costs, and improve agricultural sustainability.

Conclusion

The study highlights significant spatial variability in soil nutrients (organic carbon, nitrogen, phosphorus, and potassium) in Badokhar Khurd, emphasizing the predominance of low organic carbon and nitrogen levels. Phosphorus and potassium showed medium levels but with localized deficiencies. GIS-based interpolated maps provided precise insights into nutrient distribution, revealing the need for site-specific nutrient management. Factors influencing this variability include pedogenic processes, biotic-abiotic interactions, and land management practices. Addressing these challenges through sustainable practices like organic amendments, conservation agriculture, and precision fertilization can enhance soil health and productivity. These findings underscore the importance of integrating GIS-based tools for informed agricultural planning in semi-arid regions.

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