



Spatial and vertical distribution of soil separates in *Entisols* of Uttar Pradesh

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ABSTRACT

Soil texture is an important physical property influencing water movement, nutrient retention, and overall soil productivity. This study evaluated the spatial and vertical distribution of soil particle-size fractions and classified soil texture using the USDA texture triangle. Soil samples were collected from five locations with three replications at three depth intervals (0–15, 15–30, and 30–45 cm). Results showed significant variation in sand, silt, and clay distribution among locations and within soil profiles, indicating spatial and vertical heterogeneity in soil texture. Sand remained the dominant fraction throughout the study area, ranging from 68.19–81.86%, while silt and clay ranged from 3.00–10.87% and 15.14–24.61%, respectively. Higher sand content was observed in L2 and L3, whereas L1 showed greater clay accumulation. Vertical variation within locations indicated moderate redistribution of soil particles and weak horizon differentiation. USDA texture classification revealed that soils were predominantly sandy loam, with limited occurrence of sandy clay loam and loamy sand. These findings suggest that soil texture in the study area is primarily influenced by spatial variability and may have important implications for water dynamics, nutrient availability, and site-specific soil management.

Keywords: Soil texture, Particle-size distribution, Soil depth, USDA texture triangle, Spatial variability

INTRODUCTION

Food security and agricultural productivity of any nation largely depend on the soil that sustains it. As populations rise, the challenge of ensuring a regular food supply has become one of the greatest concerns of modern agriculture. The continuous increase in global temperature, the impacts of climate change, recurring moisture deficits, and the depletion of soil resources are placing mounting pressure on agricultural land, threatening the sustainability of food production. In this setting, efficient soil resource

management is not optional but essential, because soil is the primary medium for plant growth, nutrient transformation, and water regulation. To secure sustainable food production, it becomes crucial to identify the soil properties that most strongly determine crop productivity.

Among the many soil properties, the physical ones play a dominant role and regulate water-holding capacity, infiltration, nutrient movement, aeration, seed germination, root development, and plant growth, making them fundamental indicators of soil

quality (Dewangan *et al.*, 2024). These physical traits directly influence the ability of plants to absorb water and nutrients, becoming key factors in crop response, fertilizer use efficiency, and productivity in both irrigated and rainfed systems (Singh *et al.*, 2021).

One of the most important physical indicators is particle size distribution, defined as the quantitative measurement of sand, silt, and clay fractions in a soil sample. This distribution controls soil behaviour in natural ecosystems, shaping water retention, permeability, aggregation, and nutrient dynamics (Bayat *et al.*, 2015). Clay-rich soils, with their fine pores and high cation exchange capacity, retain greater amounts of water and nutrients, reducing leaching but limiting aeration and drainage, on other hand sandy soils have larger pores that allow rapid drainage and aeration, though they hold less water and nutrients, silts, lying between sand and clay, exhibit intermediate characteristics, contributing to structural stability and moisture availability (Riza *et al.*, 2020). Together, these primary particles determine hydraulic functions such as field capacity, permanent wilting point, available water content, and nutrient storage and movement within the soil profile. In turn, these functions influence nutrient use efficiency, plant water availability, and ultimately agricultural productivity and food security.

Entisols, a soil order representing young soils at an early stage of formation, With limited horizon development and considerable variability caused by sedimentation and local environmental conditions and often show changes in particle-size distribution across soil depths (Baillie, 2001). These variations affect their physical functioning and agricultural suitability. Yet, despite the importance of soil texture in regulating soil processes, information on the depth-wise distribution of sand, silt, and clay fractions in *Entisols* across different locations remains limited.

To address this gap, the present study was conducted to evaluate the depth-wise distribution of sand, silt, and clay fractions in *Entisols* collected from multiple locations. The study further examined their implications for soil physical behaviour and sustainable soil management. The findings aim to improve understanding of soil variability and support strategies that enhance agricultural productivity and ensure food security.

MATERIALS AND METHODS

Study area description: The study was carried out in different districts of Uttar Pradesh, located in the Indo-Gangetic plains of India. Geographically, Uttar Pradesh extends from 23°52'N to 31°28'N latitudes and from 77°3'E to 84°39'E longitude and it covers an area of approximately 240,928 square kilometers, making it the fourth largest state in India. The state's altitude ranges from 80 to 250 meters above sea level, with the Gangetic Plain being the most significant agricultural region (Ministry of Tourism, Government of India, 2024).

Ghazipur, Mau and Prayagraj districts have been selected for this study depicted in Fig.1. Soils of the sampling site of these districts is *Typic Ustipsamments* having deep, well drained based on NBSS&LUP.

Sample collection, Processing, and Analysis: Soil samples were collected in November, 2024 from five location three replication and three depth (0-15, 15-30 and 30-45 cm) from Ghazipur, Mau and Prayagraj districts Uttar Pradesh. A total of 45 disturbed soil samples were collected and ground and sieves from less than 2 mm sieve in the laboratory for further physical analysis. The soil samples were processed and analysed for different particle size distribution with help of Bouyoucos hydrometer (Bouyoucos, 1936)

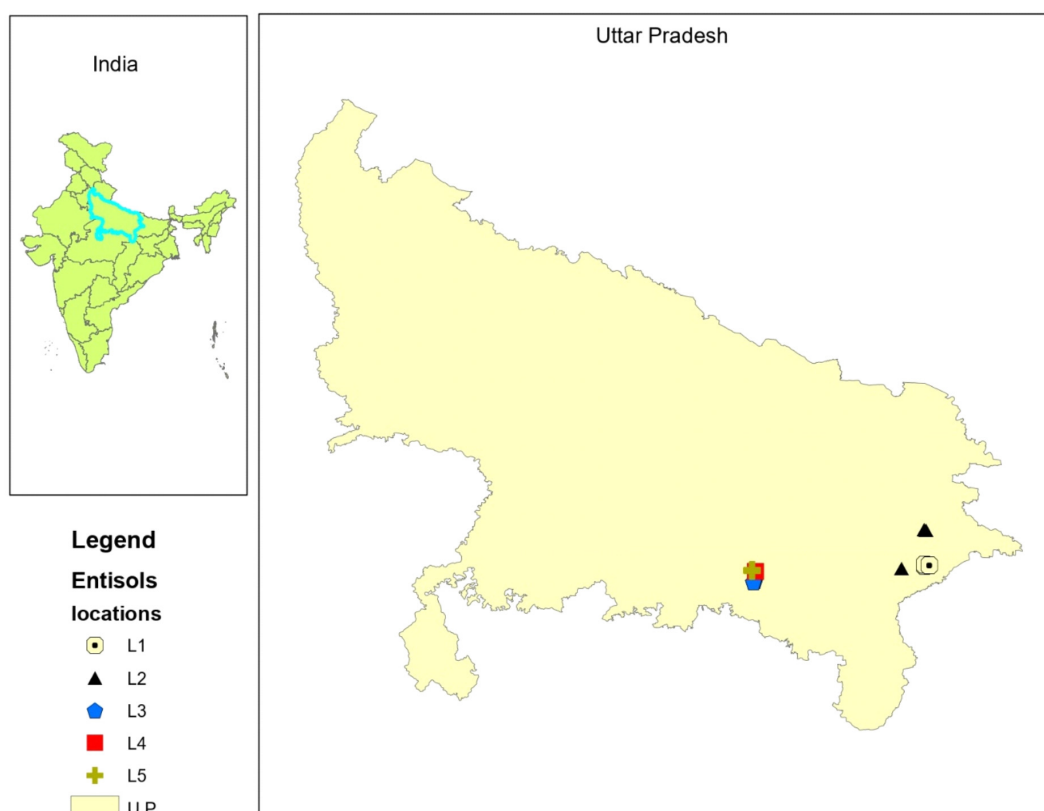
RESULTS AND DISCUSSION

Distribution of Soil Separates

The distribution of primary soil particles varied significantly among the five sampling locations of the study area as depicted in Table 1, indicating clear spatial heterogeneity in particle-size distribution across locations. Significant differences in the proportions of sand, silt, and clay indicate variability in the nature of sediment deposition, pedogenic processes, topographical conditions, and environmental factors governing soil development. Soil texture is generally considered a relatively stable physical property and plays an important role in controlling hydrological behaviour, nutrient dynamics, aeration status, aggregate formation, and overall soil productivity.

Distribution of Sand Fraction

The distribution of sand fraction exhibited significant variation among locations ($P < 0.05$) and

**Fig.1.** Study area map

Note: Mau (L₁), Ghazipur (L₂), Naini, Prayagraj (L₃), Fafamau, Prayagraj (L₄) and Suremanpurwa, Prayagraj (L₅)

Table 1. Average spatial distribution of sand, silt and clay content

Location	Sand (%)	Silt(%)	Clay (%)
L ₁	68.19 ± 4.88 ^c	7.2 ± 2.48 ^{abc}	24.61 ± 2.48 ^a
L ₂	78.59 ± 3.57 ^{ab}	5.71 ± 2.69 ^{bc}	15.7 ± 0.96 ^c
L ₃	81.86 ± 3.41 ^a	3 ± 2.03 ^c	15.14 ± 1.41 ^c
L ₄	70.59 ± 4.76 ^c	9.24 ± 6.44 ^{ab}	20.16 ± 3.12 ^b
L ₅	73.48 ± 3.98 ^{bc}	10.87 ± 3.26 ^a	15.65 ± 1.76 ^c

Note: Mau (L₁), Ghazipur (L₂), Naini, Prayagraj (L₃), Fafamau, Prayagraj (L₄) and Suremanpurwa, Prayagraj (L₅)

remained the dominant textural fraction throughout the study area, indicating substantial heterogeneity in the physical composition of Entisols. Mean sand content varied from 68.19 ± 4.88% to 81.86 ± 3.41%. The highest sand fraction was recorded in L₃, similar findings were also reported by Das *et al.* (2018), followed by L₂, whereas the lowest sand content was observed in L₁, followed by L₄. The comparatively lower sand content in L₁ may be associated with continuous puddling conditions under kharif rice cultivation, which promotes breakdown and accumulation of finer soil particles over time. In contrast, higher sand content in L₂ and L₃ suggests dominance of coarser sediments and relatively lower

intensity of weathering and translocation processes. The predominance of sand across most locations reflects the depositional nature and weak horizon development commonly associated with *Entisols*. Such soils generally possess larger pore spaces that favour rapid infiltration, improved drainage, and enhanced soil aeration (Thakur *et al.*, 2013). However, higher sand fractions are often accompanied by lower water-holding capacity and reduced nutrient retention, making soils more vulnerable to moisture stress and nutrient losses under agricultural conditions (Jarvis *et al.*, 2013). Therefore, spatial variation in sand distribution may have direct implications for irrigation scheduling and fertilizer management.

Distribution of Silt Fraction

Silt content demonstrated significant variation among all locations of the study area, which may be attributed to differences in sediment deposition and local environmental conditions. Mean silt content ranged from 3.00 ± 2.03% to 10.87 ± 3.26%. Among all locations, the highest silt content was recorded at L₅ (10.87 ± 3.26%), which was statistically at par

with L_4 ($9.24 \pm 6.44\%$), whereas the lowest silt content was observed at L_3 ($3.00 \pm 2.03\%$), which remained statistically comparable with L_2 ($5.71 \pm 2.69\%$). The observed variation in silt content may reflect differences in parent material composition, depositional environment, local erosion processes, topography, and land management practices. Although silt occurred in lower proportions compared with sand, its contribution to soil functioning remains important. Silt plays a major role in determining soil structure and available water capacity because it provides balanced physical characteristics between coarse and fine fractions. Higher silt content generally improves aggregation and moisture availability without substantially restricting permeability (Carrizo *et al.*, 2015). Therefore, locations with relatively elevated silt content may provide more favourable conditions for root growth and sustainable crop production.

Distribution of Clay Fraction

Clay content also varied significantly among locations and ranged from $15.14 \pm 1.41\%$ to $24.61 \pm 2.48\%$. The highest clay content was observed at L_1 ($24.61 \pm 2.48\%$), followed by L_4 ($20.16 \pm 3.12\%$), whereas lower values were recorded at L_2 , L_3 , and L_5 . The relatively higher clay content at L_1 may be linked to prolonged puddling and accumulation of finer particles, while lower clay content in L_2 and L_3 corresponds with the dominance of sandy materials. Clay particles possess greater surface area and adsorption capacity and therefore contribute substantially to nutrient retention and moisture

storage. Increased clay content generally improves cation exchange capacity and enhances soil buffering potential. However, excessive clay accumulation may reduce permeability and soil aeration. Overall, the spatial variation in clay distribution indicates differences in soil-forming processes and highlights its importance in determining soil physical quality and agricultural productivity across the study area.

Vertical Distribution of Soil Separates

The vertical distribution of primary soil particles across different locations and soil depths is presented in Table 2. The interaction between location and depth showed noticeable variation in particle-size distribution, indicating that vertical changes in soil texture differed among sampling locations. These variations suggest differences in sediment deposition, redistribution of soil particles, pedogenic development, and local land-use practices influencing soil profile characteristics. However, the magnitude of vertical variation was not uniform across all locations.

Distribution of Sand Fraction

Sand remained the dominant particle-size fraction throughout the soil profile and varied significantly among location–depth combinations ($P < 0.05$). Sand content ranged from $62.88 \pm 0.80\%$ to $86.08 \pm 0.20\%$. The highest sand content was recorded in L_3 at 30–45 cm depth ($86.08 \pm 0.20\%$), while the lowest value was observed in L_1 at 15–30 cm depth ($62.88 \pm 0.80\%$). Within L_1 , sand content decreased from surface to subsurface depth and

Table 2. Vertical distribution of soil separates across different locations in the study area

Location	Depth (cm)	Sand (%)	Silt(%)	Clay (%)
L_1	0-15	67.68 ± 0.4 ^{de}	7.13 ± 0.61 ^{abcd}	25.19 ± 0.46 ^{ab}
L_1	15-30	62.88 ± 0.8 ^e	10.07 ± 0.12 ^{abc}	27.05 ± 0.9 ^a
L_1	30-45	74.01 ± 0.9 ^{bcd}	4.4 ± 0.35 ^{cd}	21.59 ± 0.61 ^{bc}
L_2	0-15	80.35 ± 0.5 ^{ab}	4.13 ± 0.31 ^{cd}	15.52 ± 0.2 ^{ef}
L_2	15-30	73.95 ± 1.03 ^{bcd}	9.27 ± 0.42 ^{abc}	16.79 ± 0.61 ^{cdef}
L_2	30-45	81.48 ± 0.53 ^{ab}	3.73 ± 0.12 ^{cd}	14.79 ± 0.42 ^f
L_3	0-15	81.15 ± 0.31 ^{ab}	3.67 ± 0.12 ^{cd}	15.19 ± 0.23 ^{ef}
L_3	15-30	78.35 ± 0.5 ^b	4.93 ± 0.23 ^{cd}	16.72 ± 0.35 ^{cdef}
L_3	30-45	86.08 ± 0.2 ^a	0.4 ± 0 ^d	13.52 ± 0.2 ^f
L_4	0-15	70.15 ± 5.25 ^{cde}	8.53 ± 8.08 ^{abcd}	21.32 ± 3.67 ^{bcd}
L_4	15-30	74.01 ± 0.64 ^{bcd}	5.53 ± 3.82 ^{bcd}	20.45 ± 4.43 ^{bcde}
L_4	30-45	67.61 ± 5.62 ^{de}	13.67 ± 5.95 ^{ab}	18.72 ± 0.69 ^{cdef}
L_5	0-15	70.08 ± 0.2 ^{cde}	14.67 ± 0.12 ^a	15.25 ± 0.31 ^{ef}
L_5	15-30	74.15 ± 0.42 ^{bcd}	10.13 ± 0.12 ^{abc}	15.72 ± 0.53 ^{ef}
L_5	30-45	76.21 ± 5.84 ^{bc}	7.8 ± 2.43 ^{abcd}	15.99 ± 3.41 ^{def}

Note: Mau (L_1), Ghazipur (L_2), Naini, Prayagraj (L_3), Fafamau, Prayagraj (L_4) and Suremanpurwa, Prayagraj (L_5)

increased again at deeper layers, whereas L_2 and L_3 maintained relatively high sand content throughout the profile with a slight increase at 30–45 cm depth. In contrast, L_4 and L_5 showed comparatively moderate variation across depths. The dominance of sand in deeper layers at certain locations may indicate persistence of coarse parent material and limited downward movement of fine particles. Such distribution is commonly associated with Entisols due to weak horizon development and minimal pedogenic differentiation. Higher sand fractions generally favour rapid infiltration and drainage; however, they may reduce water-holding capacity and nutrient retention.

Distribution of Silt Fraction

Silt content exhibited considerable variation among location–depth combinations and ranged from $0.40 \pm 0.00\%$ to $14.67 \pm 0.12\%$. The highest silt content was recorded at L_5 (0–15 cm), whereas the lowest value occurred at L_3 (30–45 cm). At several locations, particularly L_1 , L_2 , and L_5 , silt content increased at intermediate depth (15–30 cm) before declining at deeper layers. However, this trend was not consistent across all locations. The accumulation of silt at subsurface depth may indicate localized redistribution of medium-sized particles through infiltration and sediment movement processes. Variation in silt distribution may also reflect differences in depositional environment, erosion intensity, topography, and land management practices (Hadda *et al.*, 2008). Since silt contributes to aggregate formation and available water capacity, these variations may influence soil physical quality and crop performance across locations.

Distribution of Clay Fraction

Clay content varied significantly among location–depth combinations and ranged from $13.52 \pm 0.20\%$ to $27.05 \pm 0.90\%$. The highest clay content was observed at L_1 (15–30 cm), whereas the lowest value was recorded at L_3 (30–45 cm). At location L_1 , clay content increased from surface to intermediate depth and then decreased at deeper layers, suggesting accumulation of finer particles below the surface horizon. Similar but less pronounced patterns were observed at selected locations, while L_2 , L_3 , and L_5 showed relatively stable clay distribution throughout the profile. The greater clay accumulation at intermediate depth may indicate limited downward translocation and deposition of fine particles. Higher

clay content generally enhances water retention, nutrient storage, and cation exchange capacity; however, excessive clay accumulation may reduce permeability and aeration. Overall, the results indicate that vertical changes in soil texture differed among locations, although sandy fractions remained dominant throughout the profile. These findings suggest that local pedogenic processes and depositional history influenced soil profile development and contributed to variability in soil physical functioning within the study area.

Soil Textural Classification (USDA Texture Triangle): The USDA texture triangle was used to classify soils of study area based on the relative proportions of sand, silt, and clay at different locations and sampling depths (Fig. 2). The distribution of soil samples on the texture triangle revealed that the study area was predominantly characterized by coarse-textured soils, with most samples falling within the sandy loam (SaLo) textural classes. A limited number of samples shifted toward the sandy clay loam (SaClLo) and loamy sand region due to increased clay proportions. The dominance of sandy loam texture corresponds with the high sand percentages observed across all locations (68.19–81.86%) and relatively low silt content (3.00–10.87%). These results indicate that coarse fractions dominantly constitute the major

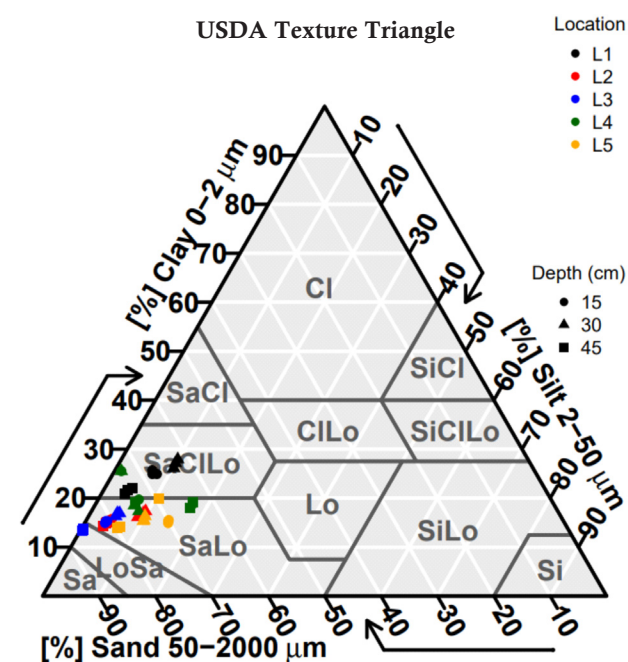


Fig. 2. Spatial and vertical soil texture classes of the study area
Note: Mau (L_1), Ghazipur (L_2), Naini, Prayagraj (L_3), Fafamau, Prayagraj (L_4) and Suremanpurwa, Prayagraj (L_5)

proportion of the soil matrix throughout the study area and preoperationally varied among all the the location and suggested that distribution pattern. Samples from L_2 and L_3 sampling sites clustered mainly within the loamy sand to sandy loam class, consistent with their significantly higher sand fraction and lower clay percentages. The predominance of these texture classes suggests soils with relatively high permeability, rapid infiltration and greater aeration. However, these soils are also expected to exhibit lower water-holding capacity and nutrient retention due to limited surface area for adsorption.

On otherhand, soils sample of the location L_1 and L_4 showing increasing clay percentage (20.16–24.61%) and sift toward to sandy clay loam texture class. The movement toward finer texture classes indicates greater accumulation of clay particles, which may enhance soil moisture storage and nutrient retention capacity higher cation exchange potential and improved aggregate formation. While soil sample of location L_5 occupied an intermediate position between loamy sand and sandy loam classes, which corresponds with its relatively increase silt content ($10.87 \pm 3.26\%$). This intermediate texture class may provide a balance between drainage and water retention capacity, potentially supporting more favorable physical conditions for root growth and nutrient availability.

Variation among sampling depths was relatively small in compared with differences among locations, indicating that spatial heterogeneity had a stronger impact on soil texture than vertical changes within the sampled profile in *Entisols*. This suggests that soil texture in the study area is largely controlled by local pedogenic factors and parent material deposition of the sediments rather than short-term surface processes.

Overall, the USDA texture classification confirms that the soils of the study area are predominantly sandy with moderate variation in finer fractions, such type of the textural characteristics have important implications for soil water dynamics, nutrient cycling, and land management practices, emphasizing the need for location-specific management strategies to optimize soil productivity.

CONCLUSION

The present study demonstrated considerable variation in soil particle-size distribution across

sampling locations and within soil profiles, indicating both spatial and vertical heterogeneity in soil texture. Results showed significant differences in sand, silt, and clay fractions among locations, reflecting the influence of sediment deposition, pedogenic processes, topography, and local environmental conditions. Sand remained the dominant soil fraction throughout the study area, with relatively higher proportions observed in L_2 and L_3 , whereas L_1 exhibited greater accumulation of clay. The location-wise vertical distribution of soil separates further revealed that changes in particle-size composition varied among depths and locations, suggesting localized redistribution of soil particles and weak horizon differentiation characteristic of *Entisols*. Although vertical changes were observed, spatial variation appeared more pronounced than depth-related variation. Based on the USDA texture triangle, the soils were predominantly classified as sandy loam, with limited occurrence of sandy clay loam and loamy sand, confirming the dominance of coarse-textured soils in the study area. These textural characteristics may influence water movement, nutrient retention, aeration, and soil productivity. Therefore, consideration of both spatial and vertical variability in soil texture is essential for developing site-specific soil management strategies and supporting sustainable land-use planning.

Conflict of Interest: The authors declare that they have no competing interests.

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