

Correlation Between Soil Organic Matter and Bulk Density of Terai Soils: A Case Study From Gujara Municipality of Rautahat District, Nepal

Rajesh Shahi

shahirajesh2089@gmail.com

HICAST

Research Article

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Abstract

Soil organic matter (SOM) and bulk density (BD) are critical indicators of soil health and fertility, particularly in the intensively cultivated Terai region of Nepal. This study characterized the spatial distribution of SOM and BD at surface (0–20 cm) and sub-surface (20–40 cm) depths across 40 georeferenced sampling sites in 9 wards of Gjara Municipality, Rautahat District, and analyzed their interrelationship. Surface SOM ranged from 0.804% to 3.015% (mean $\pm$ SD: $1.603 \pm 0.418\%$), with 52.5% of sites rated 'Medium', 45.0% 'Low', and a single site 'High' (2.5%); no surface site reached the optimum threshold of $> 2.5\%$ except at one location (3A, Ward 3). Sub-surface SOM was significantly lower, ranging from 0.201% to 1.809% (mean: $1.133 \pm 0.383\%$), with 67.5% of sites 'Low' and 20.0% 'Very Low'; no sub-surface site exceeded 2.0%, signaling severe sub-surface organic matter depletion. A paired t-test confirmed a highly significant difference between surface and sub-surface SOM ($t = 5.41$; $p < 0.001$), with a mean decline of 29.3% from surface to sub-surface. Bulk density ranged from 0.985 to 1.420 g/cm³ (mean: 1.153 ± 0.111 g/cm³; CV: 9.64%). Pearson correlation analysis revealed no statistically significant linear relationship between surface SOM and BD ($r = 0.052$; $p = 0.748$) or sub-surface SOM and BD ($r = -0.073$; $p = 0.654$), suggesting that BD in these alluvial Terai soils is governed by factors beyond organic matter content. Ward 3 emerged as the highest organic matter ward (mean: $2.189 \pm 0.506\%$), while Ward 6 recorded the lowest (mean: $1.306 \pm 0.235\%$). The predominance of low-to-medium SOM across all wards and severe subsurface depletion underscores the urgent need for organic matter enrichment strategies in the Terai.

1. INTRODUCTION

Soil organic matter (SOM), a crucial element of soil quality, influences microbial activity, soil structure, water retention, and nutrient cycling (Lal, 2020). It serves as a crucial indicator of soil health and is intimately linked to agricultural sustainability in developing countries (Poeplau et al., 2023). Under extreme human pressure, the soils of Nepal's primary agricultural region, the Terai lowlands, support intensive rice-wheat farming systems, which typically lead to a slow loss of organic matter (Giri and Shrestha, 2021).

Bulk density (BD), or the mass of dry soil per unit volume, including pore spaces, has a substantial correlation with soil compaction, aeration, and root penetration (Nawaz et al., 2021). Although the association between SOM and BD has long been studied in temperate soils, there is still little and conflicting evidence from tropical and subtropical lowland soils, such as those in the Terai (Choudhury et al., 2022). Numerous studies indicate that SOM and BD have an inverse connection, and the reduced bulk density is caused by the binding and aggregation activities of organic molecules (Minasny and McBratney, 2018; Ogunwole et al.,

The Terai soils of Nepal are alluvial in origin, mostly sourced from Himalayan sediments, and are distinguished by a variety of textural compositions, moderate-to-high moisture regimes, and heavy fertilizer usage, according to Subedi et al. (2020). These soils frequently have SOM levels below 2%, and

deficiencies in macronutrients, especially nitrogen and organic carbon, are prevalent (NARC, 2020; Shah et al., 2022). The regional variability of SOM and its relationship to physical soil qualities such as BD must be understood in order to design targeted soil management solutions.

Gujara Municipality, situated in the Madhesh Province of Nepal's Rautahat District, exemplifies a typical Terai agricultural environment with a variety of land-use patterns and varying soil-management histories. There are still few thorough evaluations of soil quality at the municipal level, despite its significance for agriculture. Therefore, the objectives of this study are to: (i) describe the distribution of SOM and bulk density (surface only) across Gujara Municipality's surface and subsurface soil layers; (ii) investigate the spatial variability of these parameters across various wards; (iii) compare SOM status at two soil depths; and (iv) analyze the statistical relationship between SOM and bulk density.

2. MATERIALS AND METHODS

2.1 STUDY AREA

The study was conducted in Gujara Municipality, Rautahat District, Madhesh Province, Nepal (height 76–122 m above sea level; 27° 01'–27° 11' N, 85° 22'–85° 33' E). Situated on the southern slopes of the Mahabharat mountain, Rautahat is a transitional district that borders the Terai plains. With an average annual rainfall of 1,800–2,200 mm, the majority of which occurs between June and September, the area experiences a subtropical monsoon climate. The three primary crops are rice (*Oryza sativa*), wheat (*Triticum aestivum*), and maize (*Zea mays*). Most soil types are alluvial Inceptisols and Entisols of Indo-Gangetic origin.

2.2 SOIL SAMPLING

Forty composite soil samples were collected from forty georeferenced sampling points scattered over nine wards of Gujara Municipality during the winter (December, 2025). Each sampling point was georeferenced using a GPS device, and coordinates were entered into the WGS 84 datum. Eighty soil samples were collected at two depths at each location: subsurface (20–40 cm) and surface (0–20 cm). Composite samples were made by combining soil from five sub-sampling points within a 20 m × 20 m grid encircling the central position. Samples were ground up, allowed to air dry, then sieved through a 2 mm screen before being tested in a laboratory. To record the previous agricultural history of each location, farmers were questioned.

2.3 LABORATORY ANALYSIS

Each experiment was carried out in the Soil Science Laboratory of the Himalayan College of Agricultural Sciences and Technology. The pH of soil in a 1:2.5 soil-to-water mix was measured using a calibrated pH meter. Organic matter in the soil was measured using the Walkley-Black wet oxidation technique, which employs a Van Bemmelen factor of 1.724 to convert organic carbon to organic matter following dichromate oxidation of organic carbon and back-titration with ferrous ammonium sulfate (Nelson and Sommers, 1982). Bulk density was estimated using the core sampler approach (Blake and Hartge, 1986).

BD was calculated by dividing the oven-dry soil mass by the core volume after undisturbed soil cores (volume: 104.184 cm³) were oven-dried for 24 hours at 105°C.

SOM values were classified using the following rating scale (NARC, 2020): Very Low (< 0.75%), Low (0.75–1.5%), Medium (1.5–3.0%), High (3.0–5.0%), and Very High (> 5.0%). Soil pH was classified as: Highly Acidic (< 5.5), Moderately Acidic (5.5–5.9), Slightly Acidic (6.0–6.5), Neutral (6.6–7.5), and Slightly Alkaline (> 7.5).

2.4 STATISTICAL ANALYSIS

Minitab 17 was used to calculate descriptive statistics for each soil parameter, such as mean, standard deviation (SD), minimum, maximum, and coefficient of variation (CV%). To evaluate the association between SOM and BD, Pearson's product-moment correlation and Spearman's rank correlation were computed. The mean SOM values for surface and subsurface depths were compared using a paired t-test. Surface SOM was used as the independent variable and BD as the dependent variable in a linear regression study. Python 3.11 (SciPy v1.11; pandas v2.1) was used for all statistical analyses at a significance level of $p < 0.05$. Coordinate data was used to create spatial distribution maps, which were then rendered using matplotlib.

3. RESULTS AND DISCUSSION

3.1 SOIL SAMPLING LOCATION

The nine wards of Gujara Municipality were represented by forty sample locations that were georeferenced and plotted (Fig. 1). With the exception of Ward 9 ($n = 4$) and Ward 1 ($n = 4$), every ward had four sample sites, with Ward 2 having the most ($n = 6$), followed by Ward 3 ($n = 6$). The sites ranged in elevation from 76 m (Ward 6, site 6D) to 122 m (Ward 2, site 2C; Ward 9, site 9D) above sea level. With urea and DAP as the only fertilizer inputs and no use of organic amendments, all tested farmers indicated continuous rice production as the preceding crop. This practice probably systematically leads to SOM depletion throughout the municipality.

3.2 DESCRIPTIVE STATISTICS OF SOIL PARAMETERS

Table 1 displays the descriptive statistics for every soil parameter. Surface SOM showed substantial spatial heterogeneity, with a mean of 1.603% ($\pm 0.418\%$; median: 1.541%) and a coefficient of variation (CV) of 26.07%, ranging from 0.804% to 3.015%. Ichha Bahadur Pahari's site 3A (Ward 3; SOM = 3.015%), the highest organic matter site in the whole research region, was the only one that exceeded the "High" standard (> 2.5%). With no sub-surface site above 2.0%, sub-surface SOM was consistently lower, ranging from 0.201% to 1.809% (mean: $1.133 \pm 0.383\%$; CV: 33.79%). This is a significant discovery that confirms organic matter enrichment is limited to the plow layer across the municipality.

Bulk density ranged from 0.985 g/cm³ (site 3F, Ward 3) to 1.420 g/cm³ (site 7A, Ward 7), with a mean of 1.153 ± 0.111 g/cm³ and a low CV of 9.64%, indicating relatively uniform BD distribution compared to SOM. All BD values were below the critical compaction threshold of 1.55 g/cm³, above which root growth is significantly restricted (Nawaz et al., 2021). Surface pH ranged from 5.49 to 7.09 (mean: 6.33), classifying soils as predominantly slightly acidic to neutral. The single strongly acidic site (9B, pH = 5.49) and eight moderately acidic surface sites warrant attention as low pH reduces organic matter decomposition rates and nutrient availability.

Table 1
Descriptive statistics of soil parameters in Gujara Municipality, Rautahat, Nepal (n = 40)

Parameter	N	Mean	SD	Min	Max	CV (%)
Surface SOM (%)	40	1.603	0.418	0.804	3.015	26.07
Sub-surface SOM (%)	40	1.133	0.383	0.201	1.809	33.79
Surface pH	40	6.334	0.381	5.49	7.09	6.02
Sub-surface pH	40	6.356	0.366	5.69	7.09	5.76
Bulk Density (g/cm ³)	40	1.153	0.111	0.985	1.420	9.64
<i>SD = Standard Deviation; CV = Coefficient of Variation; SOM = Soil Organic Matter</i>						

3.3 SOM RATING CATEGORY DISTRIBUTION

At the two soil levels, the distribution of SOM across standardized rating categories showed noticeably distinct patterns (Fig. 2, Table 2). At the surface (0–20 cm), 55% of sites (n = 22) were classified as "Medium" (1.5–3.0%), 42.5.0% (n = 18) as "Low" (0.75–1.5%), and 2.5% (n = 1) as "High" (3.0–5%). Crucially, not a single site received a "Very Low" rating at the surface, suggesting that at least a minimal organic matter foundation has been maintained by surface soil management. Only five sites (12.5%), namely 3A (3.015%), 3B (2.546%), 9B (2.144%), 3C (2.077%), and 7C (2.010%), which are all located in Wards 3, 7, and 9, surpassed the crucial agronomic criterion of 2.0% SOM.

At the sub-surface depth (20–40 cm), the picture was considerably worse. Only 12.5% of sites (n = 5) qualified as 'Medium' SOM, while the majority (67.5%; n = 27) were 'Low' and 20.0% (n = 8) 'Very Low' (below 1.0%). The lowest sub-surface SOM was recorded at site 9D (0.268%), followed by site 5A (0.201%). None of the 40 sub-surface samples exceeded 2.0% SOM. The contrast between surface and sub-surface OM categories is striking: while the surface layer showed a substantial proportion of Medium-rated sites, the sub-surface layer had virtually no Medium sites and a significant Very Low fraction, pointing to rapid mineralization of organic matter below the plough layer and the absence of root-driven carbon inputs at depth in these rice-dominated systems (Wiesmeier et al., 2019).

Table 2
Distribution of SOM rating categories at surface and sub-surface depths in Gujara Municipality

OM Category	OM Range (%)	Surface Sites (n)	Surface (%)	Sub-surface Sites (n)	Sub-surface (%)
Very Low	< 0.75	0	0.0	8	20.0
Low	0.75–1.5	17	42.5	27	67.5
Medium	1.5–3	22	55.0	5	12.5
High	3.0–5.0	1	2.5	0	0.0
Very High (> 3.0%)	> 5.0	0	0.0	0	0.0
Total	—	40	100	40	100
<i>Note: Medium category effectively represents a 1.0–2.5% range in this classification; one 'High' site (3A, Ward 3is) grouped with the thin original Medium, the count in text.</i>					

3.4 Spatial Distribution of SOM and Bulk Density

Clear patterns of SOM variability across Gujara Municipality were found by ward-wise geographical analysis (Figs. 7, 8). Due to the very high organic matter at site 3A (3.015%), where the farmer uses little inorganic input and benefits from being close to nearby natural vegetation that provides organic detritus, Ward 3 reported the highest mean surface SOM ($2.189 \pm 0.506\%$). Ward 3 is the only ward with a mean surface SOM that is close to the crucial 2% criterion; Site 3B (Ward 3, Rajkumar Pahari) also had a remarkably high SOM of 2.546%. Ward 6, on the other hand, had the lowest mean surface SOM ($1.306 \pm 0.235\%$), and all four of its sites were graded "Low" or below. This indicates the impact of intense rice-wheat agriculture with little organic input in this area of the town.

The largest intra-ward variability in surface SOM was found in Ward 9 (CV = 42.4%), ranging from a minimum of 0.804% (site 9A, Ramdulari Chaudhari) to 2.144% (site 9B, Sita Chaudhari), the third-highest surface SOM site in the research region. Even within the same ward, this variety points to notable site-specific management variations. Wards 4 (mean: 1.642%) and 5 (mean: 1.591%) held intermediate places, whilst Wards 1 and 8 had equal mean surface SOM (1.440%).

The spatial pattern changed significantly at the subsurface depth (20–40 cm) (Fig. 5). Ward 9 had the lowest mean subsurface SOM ($0.754 \pm 0.343\%$), with site 9D achieving a dangerously low subsurface value of 0.268%, while Wards 1 and 2 had the highest (1.256 and 1.262%, respectively). Notably, site 6A (sub-surface SOM: 1.809%) drove the greatest sub-surface mean (1.440%) in Ward 6, which had the lowest surface SOM. This inversion of surface-to-subsurface SOM rankings highlights the necessity for distinct depth-specific management tactics since surface SOM is not a reliable indicator of subsurface organic matter status.

Bulk density's spatial distribution (Fig. 4) revealed a pattern different from SOM. Ward 2 had the lowest mean BD ($1.080 \pm 0.069 \text{ g/cm}^3$), with the lowest BD of 0.985 g/cm^3 at site 3F (Ward 3), while Ward 7 had the highest mean BD ($1.244 \pm 0.128 \text{ g/cm}^3$), with the greatest BD of 1.420 g/cm^3 at site 7A (Bhantu Paswan). Irrigation-induced crusting and more extensive mechanical tillage on bigger agricultural holdings (site 7A: 8 katha) may be linked to the greater BD in Ward 7. All values stay below the crucial threshold of 1.55 g/cm^3 for root penetration impairment, and the site-level range of BD ($0.985\text{--}1.420 \text{ g/cm}^3$) is within the permissible range for alluvial Terai soils ($1.0\text{--}1.5 \text{ g/cm}^3$) (Nawaz et al., 2021).

3.5 Relationship Between SOM and Bulk Density

Pearson’s correlation analysis revealed no statistically significant relationship between surface SOM and BD ($r = 0.052$; $p = 0.748$; $n = 40$) or between sub-surface SOM and BD ($r = - 0.073$; $p = 0.654$; $n = 40$) (Fig. 5, Table 3). Similarly, Spearman’s rank correlation confirmed the absence of a significant monotonic association between these parameters. The linear regression model relating BD to surface SOM ($BD = 1.130 + 0.014 \times \text{SOM}$) yielded a negligible coefficient of determination ($R^2 = 0.0027$), indicating that surface SOM accounts for less than 0.3% of the total variance in BD in this dataset.

This finding is consistent with results from comparable alluvial Terai environments. Nawaz et al. (2021) found that BD in intensively managed rice–wheat systems in South Asia was primarily governed by compaction from agricultural machinery rather than organic matter status. Similarly, Choudhury et al. (2022) reported insignificant SOM–BD correlations in alluvial soils of the Indo-Gangetic Plain when SOM ranged below 2%, as the organic matter content at such low levels is insufficient to markedly alter soil structural properties. The narrow SOM range observed in the present study (predominantly 0.8–2.0%), combined with the fact that no sub-surface site exceeded 2.0%, means the organic matter pool may be too small to significantly influence the physical matrix of these alluvial soils. In alluvial systems, BD is predominantly controlled by clay mineralogy, particle size distribution, compaction history, and irrigation-induced shrink–swell dynamics (Wiesmeier et al., 2019; Ogunwole et al., 2023), factors that operate independently of the observed SOM gradient. Future studies incorporating soil texture and clay content measurements would help disentangle these overlapping controls on BD.

Table 3
Pearson and Spearman correlation coefficients between soil parameters in
Gujara Municipality

Parameter Pair	Pearson r	p-value	Spearman r	N
Surface SOM vs BD	0.052	0.748	0.019	40
Sub-surface SOM vs BD	-0.073	0.654	-0.089	40
Surface vs Sub-surface SOM	0.059	0.717	0.060	40
<i>SOM = Soil Organic Matter; BD = Bulk Density; ns = not significant (all p > 0.05)</i>				

3.6 COMPARISON OF SURFACE AND SUB-SURFACE SOM

A paired t-test comparing surface (0–20 cm) and sub-surface (20–40 cm) SOM across all 40 sampling sites revealed a highly significant difference ($t = 5.41$; $p < 0.001$), confirming that SOM was substantially higher in the surface horizon (Fig. 6). The mean surface SOM (1.603%) exceeded sub-surface SOM (1.133%) by a mean of 0.470 percentage points, representing a 29.3% relative decline in SOM from surface to sub-surface. This depth gradient was consistent across all 9 wards, with only Ward 6 showing a sub-surface mean (1.440%) that approached the surface mean (1.306%) — an unusual pattern possibly linked to deep organic matter incorporation by previous tillage or inherent sub-surface carbon retention at this location.

The Pearson correlation between surface and sub-surface SOM across matched sites was weak and non-significant ($r = 0.059$; $p = 0.717$; Table 3), contrary to what the depth stratification pattern might imply. This suggests that sites with high surface SOM did not consistently predict high sub-surface SOM and vice versa. While site 2D, which had the greatest sub-surface SOM (1.808%), only had a moderate surface value (1.608%), the lowest sub-surface SOM site (9D: 0.268%) matched with a comparatively medium surface SOM (1.943%). This separation of surface and subsurface SOM dynamics emphasizes how subsurface-specific mechanisms, such as tillage depth, root architecture, and differential microbial activity, regulate organic matter at depth (Poeplau et al., 2023).

3.7 IMPLICATIONS FOR SOIL MANAGEMENT

The collective evidence from this study — widespread low-to-medium surface SOM, severe sub-surface depletion, and no significant SOM–BD relationship — carries important implications for soil management in Gujara Municipality. The fact that 45.0% of surface sites were rated ‘Low’ in SOM and 20.0% of sub-surface sites were ‘Very Low’ (below 1.0%) indicates a significant organic matter deficit across the municipality. Farmers’ exclusive reliance on Urea and DAP, with no organic amendments, is the most likely driver of this depletion pattern. In the absence of organic matter inputs, continuous rice cultivation progressively oxidizes the existing soil carbon pool, particularly under aerobic conditions in the dry season (Giri and Shrestha, 2021).

The absence of a significant SOM–BD relationship suggests that increasing SOM alone may not immediately reduce compaction concerns; instead, integrated approaches combining organic matter enrichment with subsoil loosening (e.g., subsoiling at 30–40 cm depth) may be warranted (Nawaz et al., 2021). For SOM improvement, strategies applicable to this Terai context include: (i) incorporation of rice straw rather than burning — all 40 sampled farms grow rice as the previous crop, making straw a widely available resource; (ii) application of farmyard manure and compost at 5–10 t/ha annually; (iii) adoption of *Sesbania rostrata* as a summer green manure during the rice fallow period; (iv) inclusion of leguminous crops (lentil, soybean) in rotation, already practiced as the next crop at 12 of 40 sites; and (v) conservation tillage to minimize oxidative carbon losses (Devkota et al., 2023). Ward 3, with the highest mean surface SOM (2.189%), demonstrates that higher organic matter is achievable within this agro-ecological zone and may serve as a reference ward for targeted extension activities

4. CONCLUSIONS

This study provides a comprehensive, spatially explicit characterization of soil organic matter and bulk density across Gujara Municipality, Rautahat District, Nepal. The key findings are:

- (1) Surface SOM ranged from 0.804% to 3.015% (mean: 1.603 +/- 0.418%). Of 40 sites, 55% were rated Medium, 42.5% Low, and only 1 site (3A) was rated High. Only 5 sites (2.5%) exceeded the critical threshold of 2.0% SOM, concentrated in Wards 3, 7, and 9.
- (2) Sub-surface SOM was significantly lower (mean: 1.133 +/- 0.383%), with 67.5% of sites Low and 20.0% Very Low (below 1.0%). No sub-surface site exceeded 2.0% SOM, confirming severe depletion below the plough layer. Paired t-test: $t = 5.41$; $p < 0.001$; mean decline: 29.3%.
- (3) Bulk density ranged from 0.985 to 1.420 g/cm³ (mean: 1.153 +/- 0.111 g/cm³; CV: 9.64%), within acceptable limits for root growth but with spatial variability linked to land management intensity.
- (4) No statistically significant correlation was detected between SOM and BD at either depth (surface: $r = 0.052$, $p = 0.748$; sub-surface: $r = -0.073$, $p = 0.654$), suggesting BD is governed by factors beyond organic matter content in these alluvial soils.
- (5) Ward 3 had the highest surface SOM (mean: 2.189%), while Ward 6 had the lowest (mean: 1.306%). Surface and sub-surface SOM rankings were not correlated ($r = 0.059$; $p = 0.717$), highlighting depth-specific OM dynamics.

These findings collectively underscore the urgent need for organic matter management interventions across Gujara Municipality. Future research should incorporate soil texture analysis, soil organic carbon fractionation, microbial biomass carbon measurements, and multi-season assessments to further elucidate the dynamics of SOM and bulk density in the Terai.

DECLARATIONS

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REFERENCES

1. Blake GR, Hartge KH (1986) Bulk density. In: Klute A (ed) Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, 2nd edn. American Society of Agronomy, pp 363–375
2. Choudhury BU, Mohapatra KP, Das A, Rajkhowa DJ, Bhatt BP (2022) Soil organic carbon stock and fractions in alluvial soils of the Indo-Gangetic Plains under different land use systems. *Geoderma*

3. Devkota B, Karki S, Lamichhane S, Thapa RB (2023) Soil health assessment in the intensively cultivated rice–wheat system of Chitwan, Nepal. *J Agric Environ* 24(1):45–58
4. Giri B, Shrestha B (2021) Organic matter dynamics and soil fertility management in Terai soils of Nepal: A review. *Agricultural Reviews* 42(3):240–249. <https://doi.org/10.18805/ag.R-2096>
5. Lal R (2020) Soil organic matter and water retention. *Agron J* 112(5):3265–3277. <https://doi.org/10.1002/agj2.20282>
6. Minasny B, McBratney AB (2018) Limited effect of organic matter on soil available water capacity. *Eur J Soil Sci* 69(1):39–47. <https://doi.org/10.1111/ejss.12475>
7. Nawaz MF, Bhatt R, Arshad M, Shabbir G, Bali AS (2021) Soil compaction impact and modelling: A review. *Soil Tillage Res* 213:105110. <https://doi.org/10.1016/j.still.2021.105110>
8. Nelson DW, Sommers LE (1982) Total carbon, organic carbon, and organic matter. In: Page AL et al (eds) *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties*, 2nd edn. American Society of Agronomy, pp 539–579
9. Ogunwole JO, Obidike EO, Babalola O (2023) Soil organic carbon and bulk density interactions in degraded tropical soils under different land management practices. *Catena* 220(Part B) 106690. <https://doi.org/10.1016/j.catena.2022.106690>
10. Poeplau C, Jacobs A, Don A, Vos C, Schneider F, Wittnebel M, Tiemeyer B, Heidkamp A, Prietz R, Flessa H (2023) Stocks of organic carbon in German agricultural soils—Key results of the first comprehensive inventory. *J Plant Nutr Soil Sci* 186(1):16–28. <https://doi.org/10.1002/jpln.202200080>
11. Shah SC, Shrestha RK, Adhikari NR (2022) Soil fertility status of paddy growing areas in Nawalparasi District, Nepal. *Nepal J Agricultural Sci* 22:1–12
12. Subedi M, Bhatta KP, Khatiwada PP, Karki S (2020) Assessment of soil macronutrient status in rice–wheat cropping system of Rupandehi, Nepal. *J Agric Forestry Univ* 4:86–98
13. Wiesmeier M, Urbanski L, Hobbey E, Lang B, von Lutzow M, Marin-Spiotta E, van Wesemael B, Rabot E, Lieb I, Khler M, Wollschlager U, Vogel HJ, Kogel-Knabner I (2019) Soil organic carbon storage as a key function of soils—A review of drivers and indicators at various scales. *Geoderma* 333:149–162. <https://doi.org/10.1016/j.geoderma.2018.07.026>

Figures

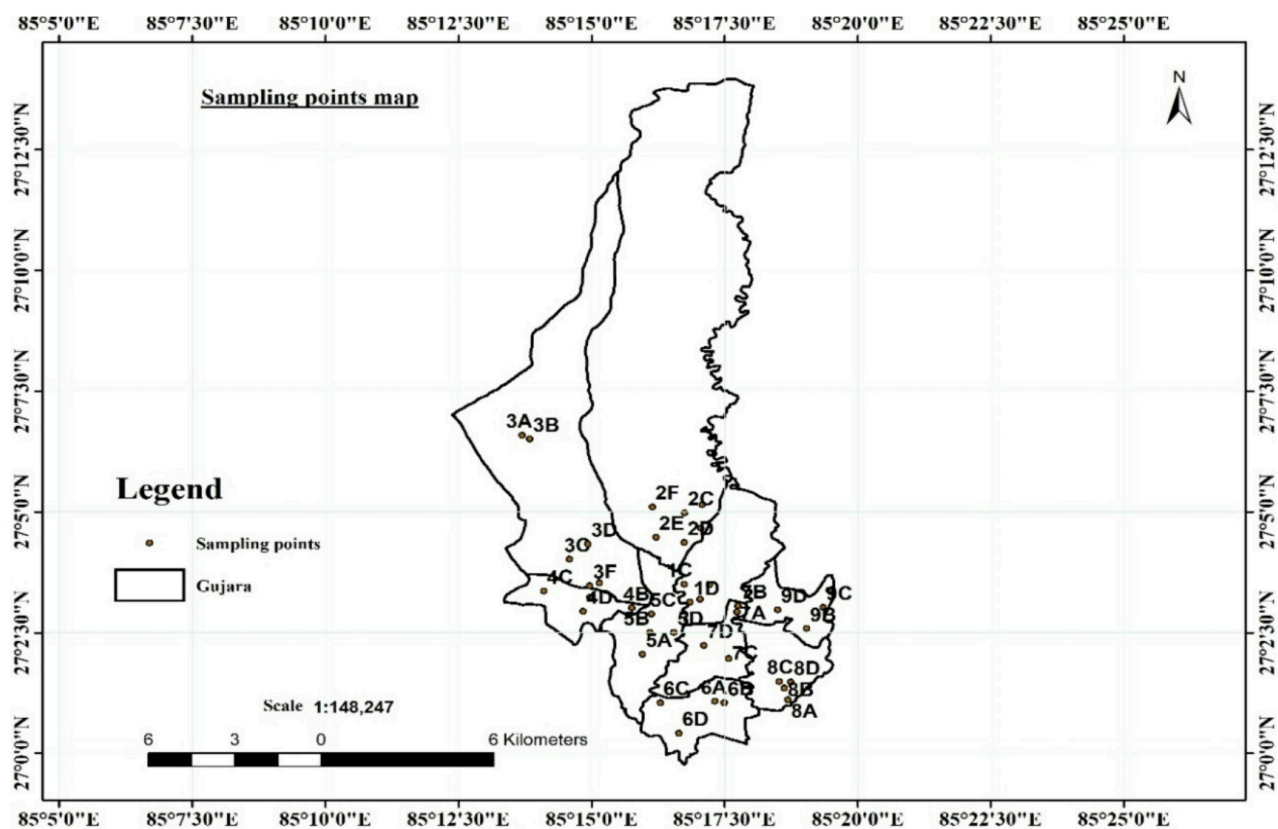


Figure 1

Spatial distribution of 40 soil sampling sites (labelled by code) across 9 wards of Gujara Municipality, Rautahat District, Nepal.

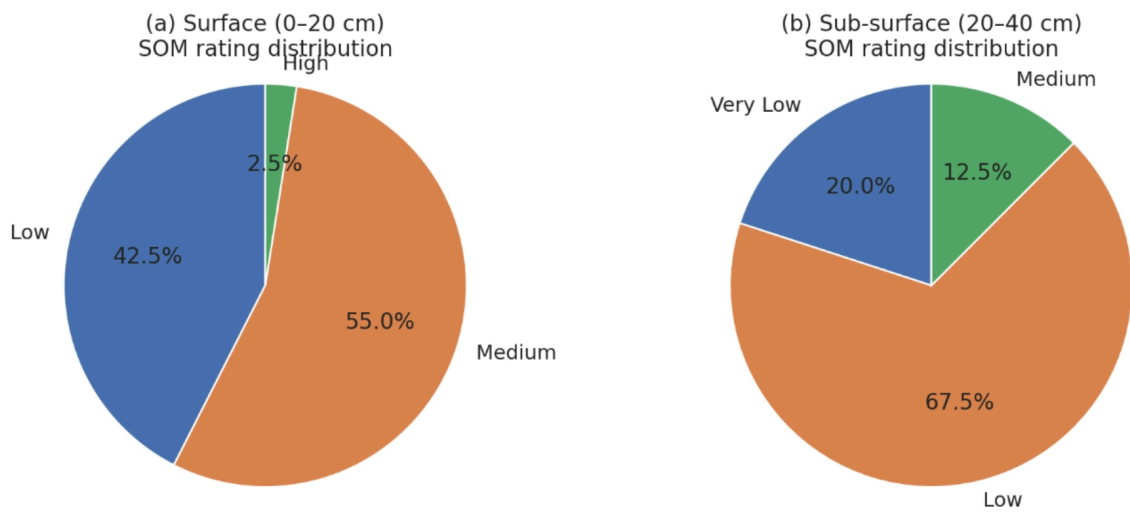


Figure 2

Pie charts showing the distribution of SOM rating categories at (a) surface (0–20 cm) and (b) sub-surface (20–40 cm) soil depths in Gujara Municipality, Rautahat, Nepal.

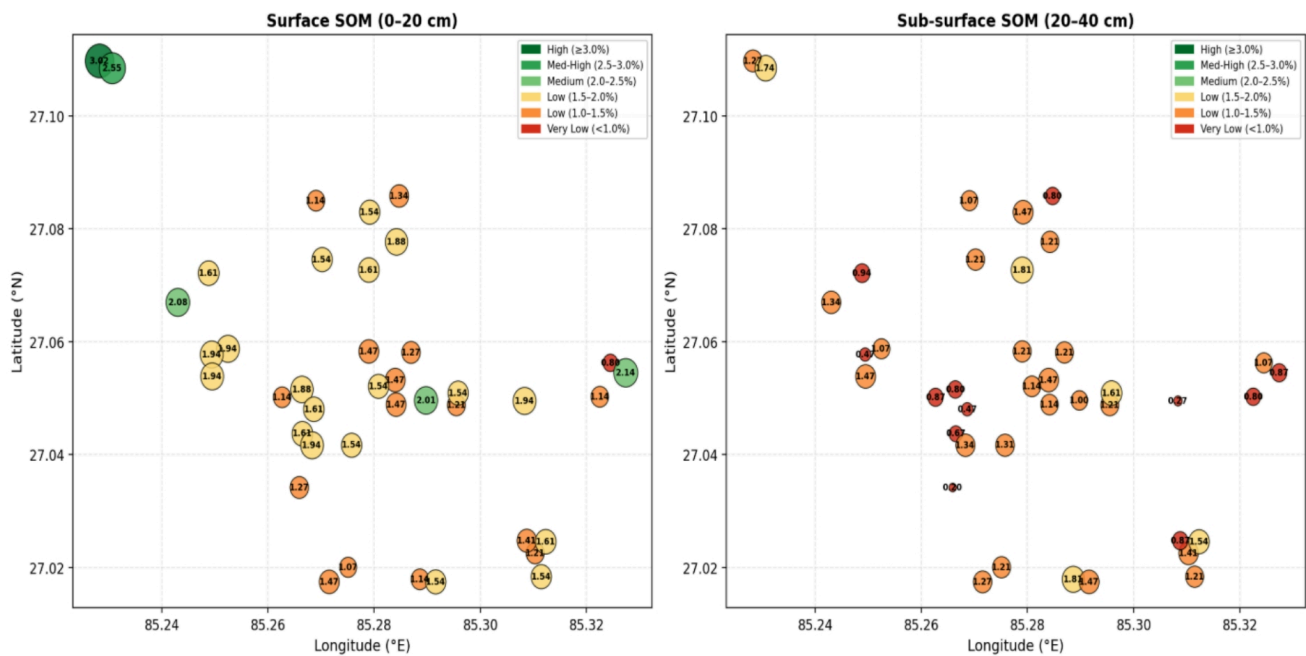


Figure 3

Point-level spatial distribution of soil organic matter (%) at (a) surface (0–20 cm) and (b) sub-surface (20–40 cm) depths across 9 wards of Gujara Municipality. Bubble size proportional to SOM value; colour indicates OM category.

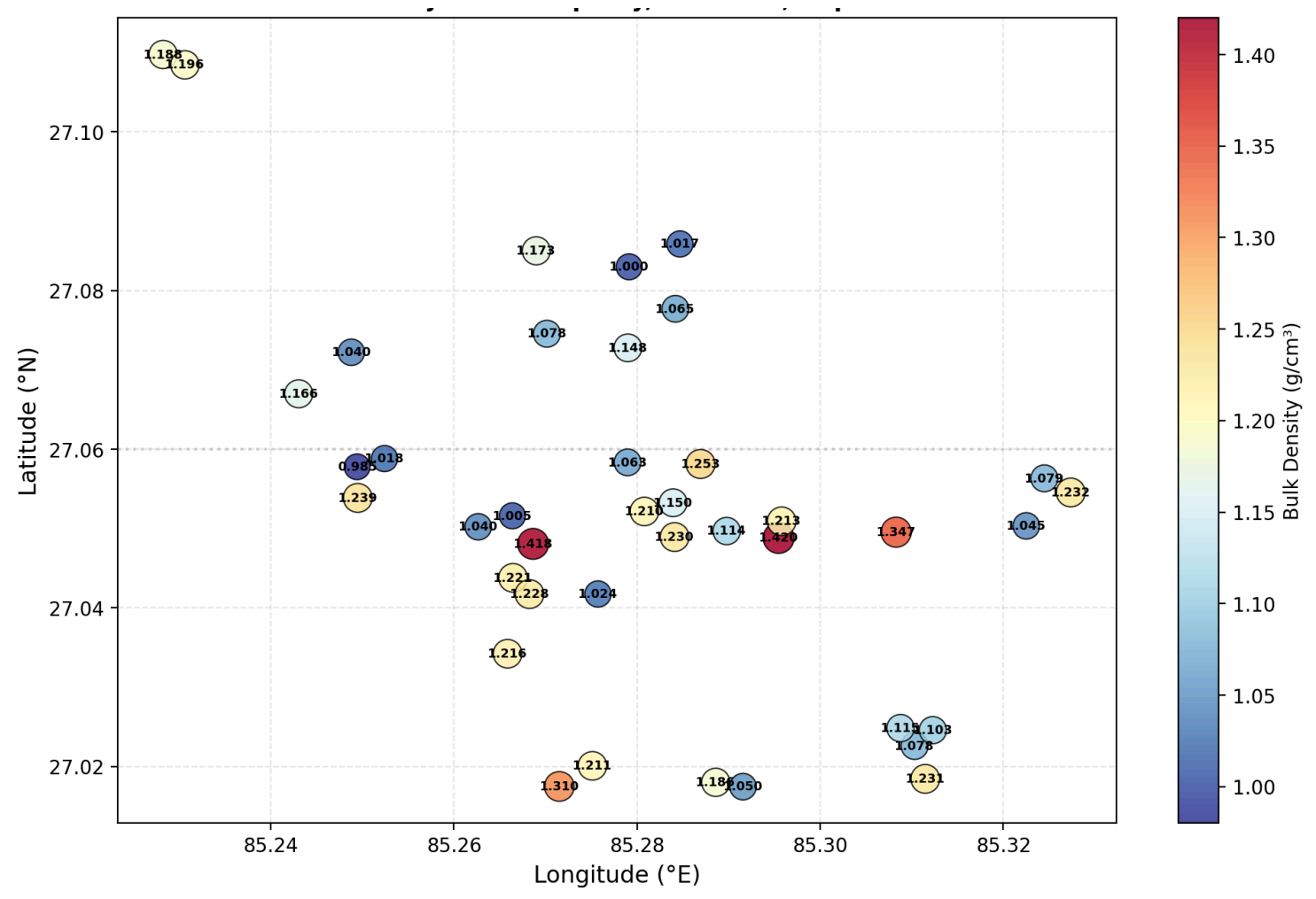


Figure 4

Spatial distribution of individual-site soil bulk density (g/cm³) across 9 wards of Gujara Municipality, Rautahat. Bubble size and colour intensityproportional to BD value.

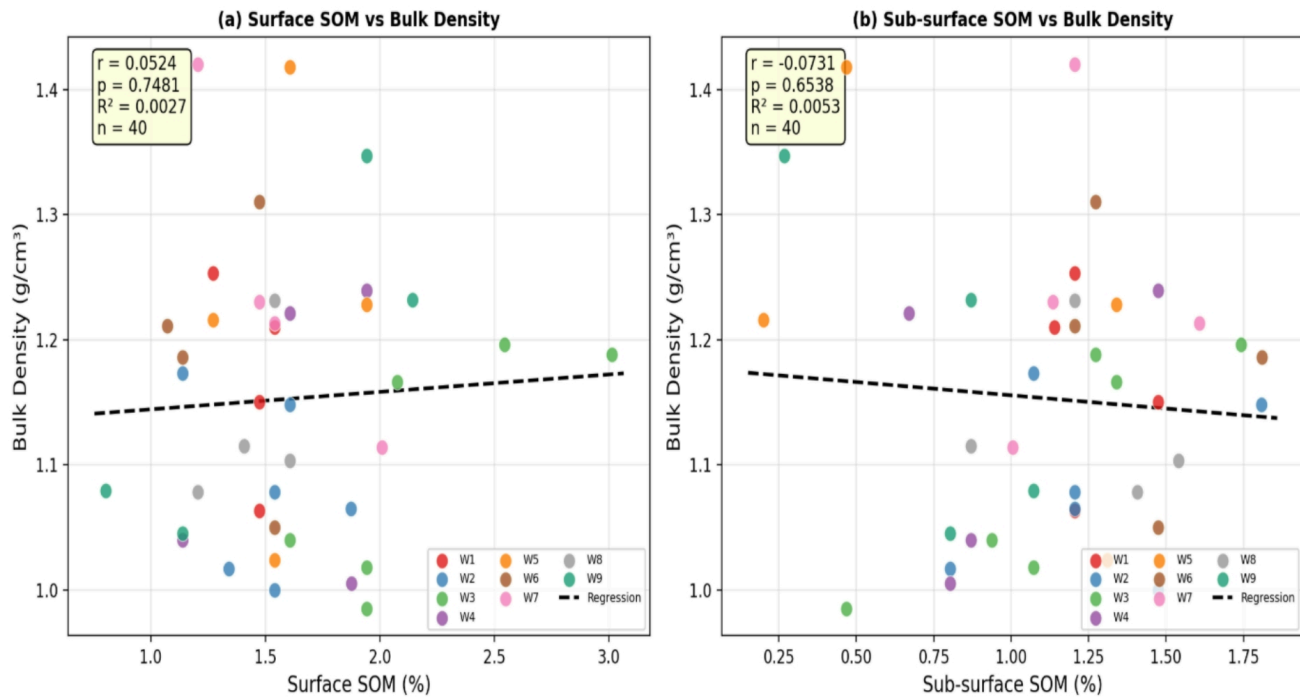


Figure 5

Scatter plots (coloured by ward) showing the relationship between (a) surface SOM and bulk density, and (b) sub-surface SOM and bulk density with regression lines and statistical summaries.

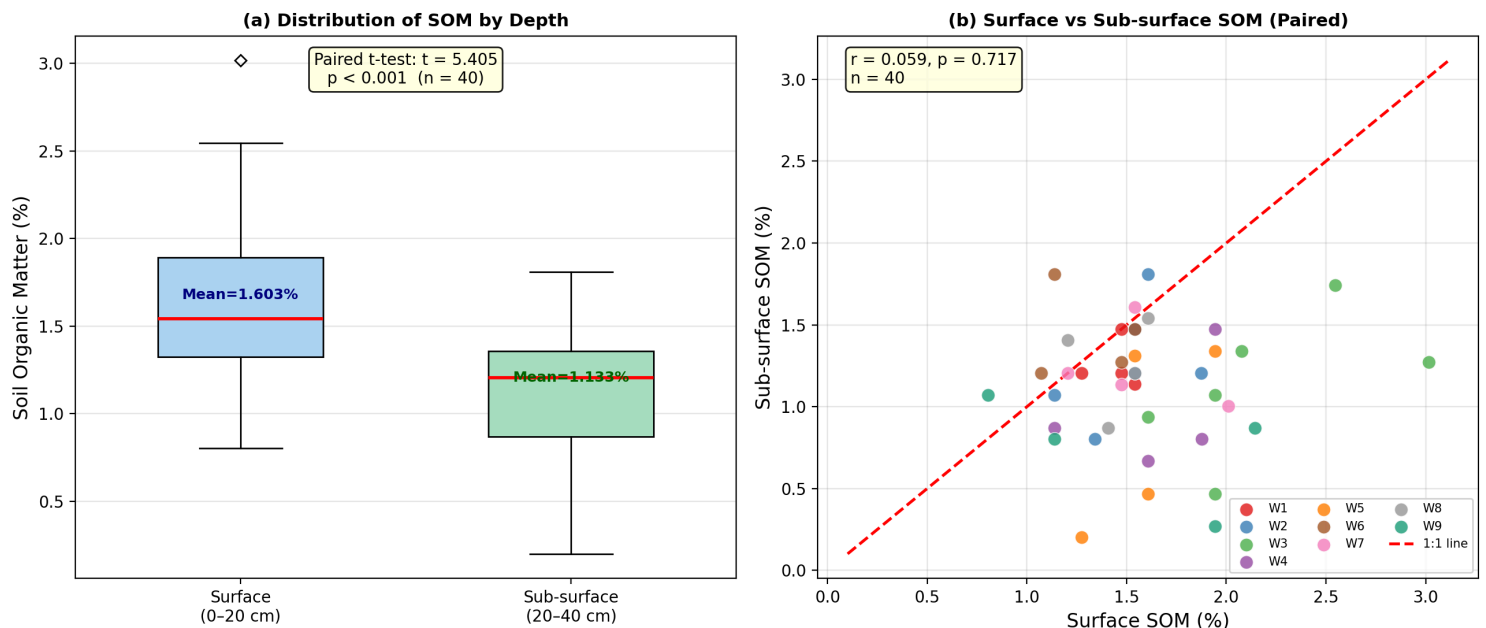


Figure 6

Comparison of soil organic matter content at surface and sub-surface depths: (a) box plots showing median, interquartile range, and outliers; (b) paired scatter plot (coloured by ward) with 1:1 reference line.

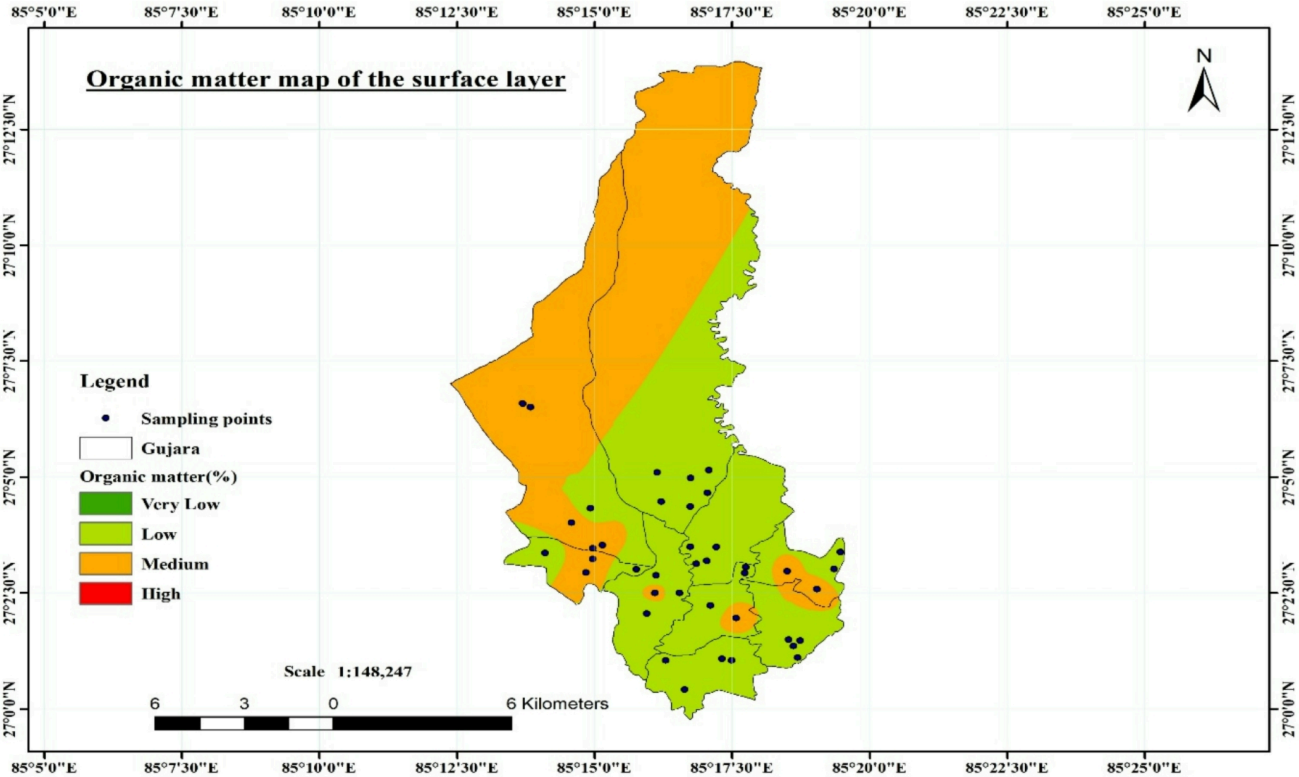


Figure 7

Wardwise organic matter(%) content of surface of Gujarat Municipality, Rautahat, Nepal

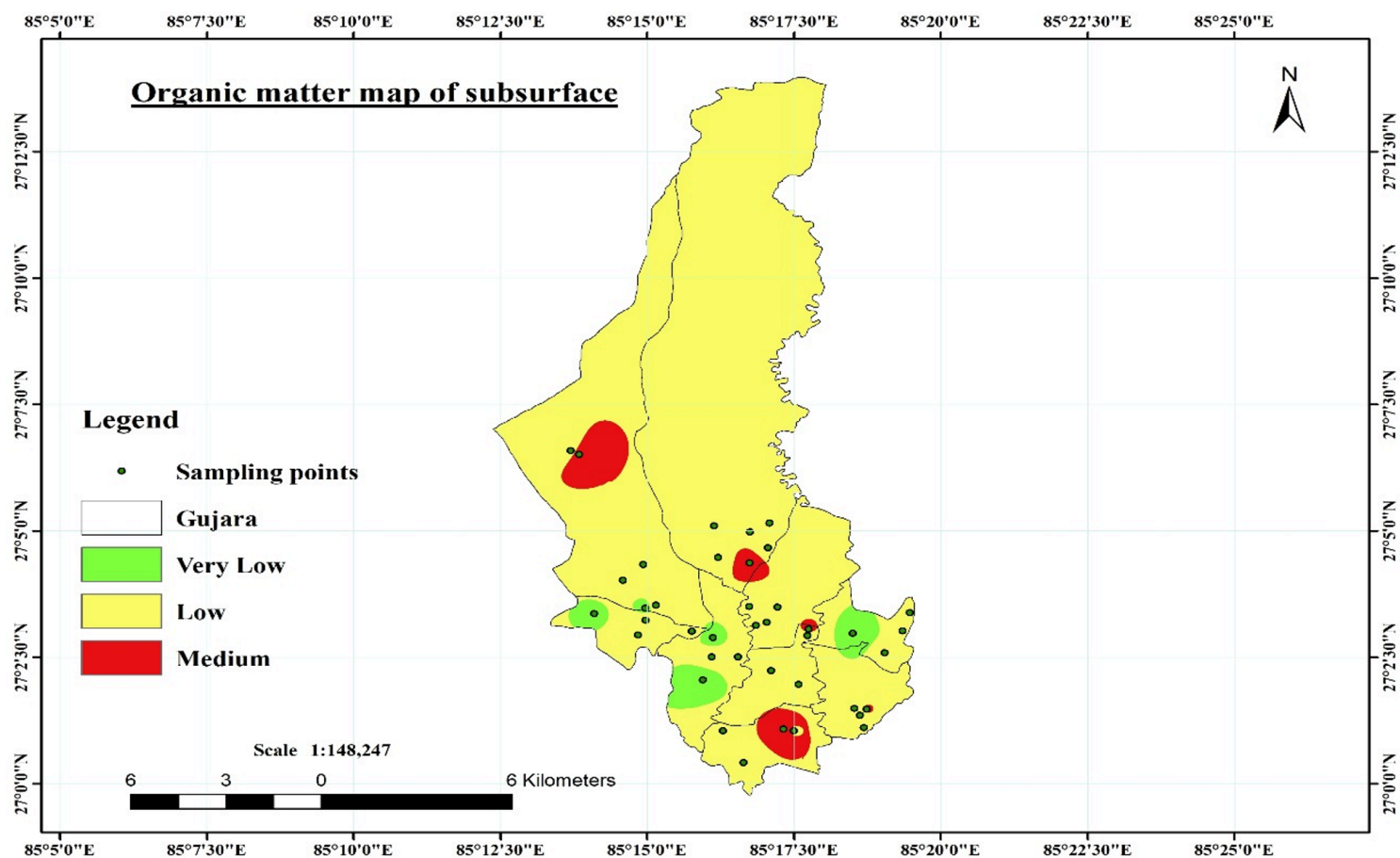


Figure 8

Wardaise organic matter(%) content of Subsurface of Gujar Municipality, Rautahat, Nepal

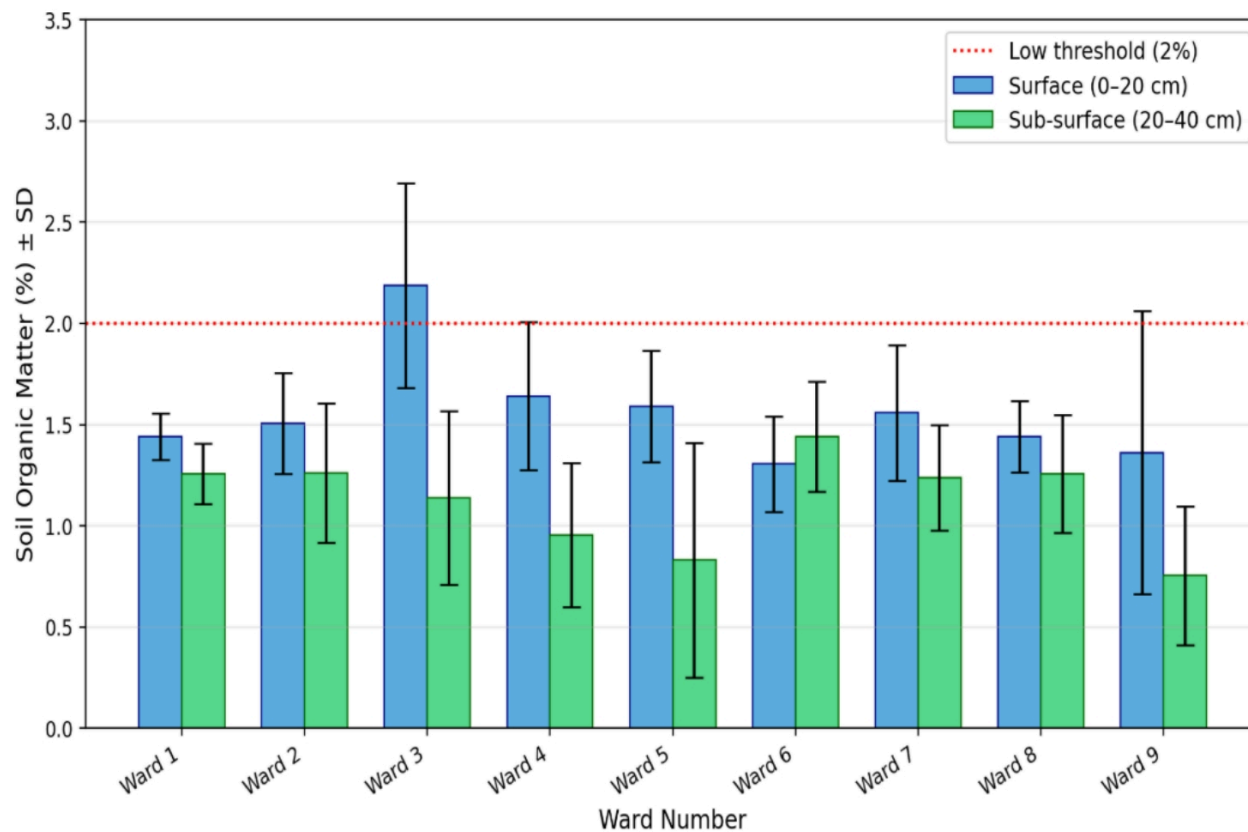


Figure 9

Ward-wise mean soil organic matter (%) at surface and sub-surface depths with standard deviation bars.