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Research Article

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Posted Date: September 15th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11022260/v1>

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Additional Declarations: The authors declare no competing interests.

Spatial Assessment and Mapping of Soil Fertility Status in Chaurjahari Municipality, Rukum West, Nepal

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Article type: Research

Abstract

The mid-hill landscapes of Nepal have spatially varied soil fertility, and site-specific nutrient management requires locally resolved data, which are still hard to come by for the recently established municipalities in Karnali Province. Using georeferenced data from 52 surface soil samples (0–20 cm) collected from farmers' fields across nine wards and GIS-based sample-point classification and geostatistical (ordinary kriging) analysis, this study evaluated and mapped soil fertility (pH, organic matter [OM], total nitrogen [TN], available phosphorus [P2O5], and available potassium [K2O]) throughout Chaurjahari Municipality, Rukum West, Nepal. With 55.8% of samples neutral, 23.1% alkaline, and 21.2% acidic, the average soil pH was 6.99 ± 0.63 (range 5.6–8.0). Available P2O5 (mean 60.6 ± 17.0 kg ha⁻¹) was predominantly medium to high (98.1% combined: 40.4% medium, 57.7% high, and a single very-high sample, 1.9%), whereas OM (mean $1.73 \pm 1.00\%$) and TN (mean $0.086 \pm 0.051\%$) were mostly low or very low (73.1% and 59.6% combined, respectively). Available K2O was the most variable parameter (CV = 78.1%), with 44.2% of samples rated very low. The near-perfect correlation between OM and TN ($r = 1.00$) indicates that TN in this dataset was derived from OM via a fixed conversion factor rather than measured independently, a point that must be confirmed with the source laboratory. Semivariogram analysis showed only weak-to-moderate spatial dependence for all five parameters (nugget:sill ratio 34–70% for pH, OM, TN and K2O; effectively pure nugget for P2O5), so sample-point classification maps, rather than smoothed continuous surfaces, are presented as the primary spatial product, with cross-validated ordinary-kriging surfaces reported as supplementary, exploratory evidence of broad spatial trend. K2O depletion was concentrated in the northern uplands and higher OM/TN in the southern wards, identifying OM and K2O as the most fertility-limiting parameters. These findings highlight the value of low-cost, georeferenced soil testing for agricultural planning in Nepal's mountain municipalities and provide a transparent, reproducible foundation for ward-level, site-specific nutrient management.

Keywords: *soil fertility; spatial variability; geostatistics; ordinary kriging; GIS mapping; soil nutrients*

1. Introduction

Soil fertility, defined as the capacity of soil to supply essential nutrients in adequate amounts and proportions for plant growth, underpins the productivity and sustainability of agricultural systems worldwide [1]. In mountainous countries such as Nepal, where agriculture remains the primary livelihood for the majority of the rural population, maintaining and improving soil fertility is central to food security and rural income [2]. Nepal's hill and mountain soils are, however, widely reported to be constrained by low organic matter, deficient nitrogen and potassium, and variable soil reaction, driven by steep topography, intensive cultivation on marginal terraces, limited use of balanced fertilizers, and continuous nutrient mining without adequate replenishment [2,3].

Soil properties are rarely uniform across a landscape; they vary spatially in response to parent material, topography, climate, land use, and management history, a phenomenon widely recognized in soil science as spatial variability [4]. Ignoring this variability and applying blanket fertilizer recommendations at the district or national scale can result in over-fertilization in some areas and under-fertilization in others, with attendant economic losses and environmental risk [4,5]. Geographic Information Systems (GIS), combined with georeferenced soil sampling and geostatistical analysis, offer a practical means of capturing and quantifying this variability, enabling the production of thematic soil fertility maps that can guide site-specific nutrient management, targeted extension advice, and rational fertilizer subsidy allocation [5,6]. Realizing this potential, however, depends on applying and reporting the spatial interpolation procedure itself — typically kriging or a related geostatistical estimator — with enough methodological detail (semivariogram model, parameters, and cross-validation) that the resulting maps can be assessed and reproduced [5,17].

Among the soil properties commonly used to assess fertility status, soil reaction (pH), organic matter (OM), total nitrogen (TN), available phosphorus (P_2O_5) and available potassium (K_2O) are considered the core indicators in routine soil testing programs, because they directly influence nutrient availability, microbial activity, and crop response to fertilization [3,7]. Soil pH governs the availability of most plant nutrients and the activity of soil microorganisms; organic matter is central to nutrient cycling, water-holding capacity and soil structure; nitrogen, phosphorus and potassium are the primary macronutrients limiting crop yield in most cropping systems [3].

A growing body of work by Nepal's Soil Science Division (Khumaltar) and affiliated researchers has produced GIS-based soil fertility assessments for individual farms, research stations and municipalities across the country, from the Terai lowlands to the mid-hills and high mountains, including comparable mid-hill and Karnali Province settings such as Jumla, Gulmi, Ilam, Kalikot and Dailekh [6,8–13]. These studies consistently report low to medium organic matter and nitrogen status, moderate-to-high

phosphorus availability arising from long-term phosphatic fertilizer use, and considerable spatial and altitudinal variability in potassium status [8,9,11,12]. Comparable studies specific to Rukum West District and its constituent municipalities, however, remain scarce in the accessible literature, representing a clear knowledge gap for evidence-based soil and nutrient management planning in this relatively newly formed and data-scarce part of Karnali Province.

Chaurjahari Municipality lies in Rukum West (Western Rukum) District of Karnali Province on the bank of the Sani Bheri River [14,15]. As with much of the mid-western hill region, its terraced and hill-slope farmlands support subsistence-oriented cereal and vegetable cultivation under considerable topographic and altitudinal variation. Systematic, spatially explicit information on the fertility status of these soils is presently limited, constraining the ability of local agricultural offices and farmers to target soil amendments and fertilizer use efficiently.

This study therefore aims to assess and map the spatial distribution of soil fertility status — specifically soil pH, organic matter, total nitrogen, available phosphorus and available potassium — across Chaurjahari Municipality, Rukum West, Nepal, using georeferenced field/laboratory data from named farmers' fields, GIS-based sample-point classification, and a fully documented geostatistical (ordinary kriging) analysis. The specific objectives of the study are: (i) to determine the descriptive statistics, variability and fertility classification of soil pH, OM, TN, available P₂O₅ and available K₂O across the sampled area; (ii) to map the spatial distribution of each parameter and to formally quantify its spatial structure through semivariogram analysis and cross-validated kriging, identifying areas of relatively low, medium and high fertility; and (iii) to draw practical, evidence-based implications for site-specific soil fertility management in Chaurjahari Municipality.

2. Materials and Methods

2.1 Study Area

Chaurjahari Municipality is located in Rukum West (Western Rukum) District, Karnali Province, Nepal, centered approximately at 28.65°N, 82.20°E, on the bank of the Sani Bheri (Bheri) River [14,15]. Rukum West District as a whole is characterized by rugged mid-hill topography, with elevations that range from the Bheri River valley floor upward into steep forested and cultivated hillslopes; the district shares its borders with Jajarkot to the north/east, Salyan to the south and Dolpa to the north [16].

Within the sampled portion of Chaurjahari Municipality, the soil dataset used in this study spans an elevation range of 224–1099 m above sea level (a.s.l.) (mean 861 ± 148 m; Table 1), indicating

substantial altitudinal variation within municipal boundaries that is likely to influence temperature, rainfall distribution, and consequently soil-forming processes and land use.

2.2 Soil Sampling and Sample Collection

A total of 52 surface soil samples (0–20 cm depth) were collected from individually identified farmers' fields distributed across nine wards of Chaurjahari Municipality, Rukum West, Nepal. A random sampling approach was used to select representative farmer fields and sampling locations, while maintaining a minimum distance between adjacent sampling points to ensure adequate spatial coverage and reduce the likelihood of collecting closely clustered samples.

The sampling locations were identified and recorded using a Global Positioning System (GPS) device, with latitude and longitude recorded in decimal degrees under the World Geodetic System 1984 (WGS 84) datum. Within each selected field, soil was collected following a zigzag sampling pattern to capture within-field variability and obtain a representative composite sample. Sampling points were selected from different parts of the field rather than from a single location, while avoiding field boundaries, bunds, manure piles, irrigation channels, and other locally disturbed areas.

At each selected location, the soil sample was collected using standard soil-sampling procedures and assigned a unique identification code (CH.M.1–CH.M.52). The geographic coordinates, participating farmer's name, and corresponding sample identification were recorded immediately in the field with the farmer's permission (Supplementary Table S1). The collected samples were properly labelled, transported to the laboratory, and processed for the determination of soil fertility parameters. This combination of random field selection, systematic spatial separation, zigzag within-field sampling, and GPS-based georeferencing was adopted to obtain representative soil samples and capture the spatial variability of soil fertility across the study area.

2.3 Laboratory Analysis

Soil samples were analyzed for pH, organic matter (%), total nitrogen (%), available phosphorus (P_2O_5 , $kg\ ha^{-1}$) and available potassium (K_2O , $kg\ ha^{-1}$). Nepal's Soil Science Division (NSSRC), Khumaltar, and its affiliated regional laboratories, whose classification scheme this dataset's rating categories most closely resemble, conventionally determine soil pH potentiometrically in a 1:2 soil–water suspension, organic matter by the Walkley–Black wet-oxidation method, total nitrogen by the Kjeldahl method, available phosphorus by the Olsen (or Modified Olsen) method for near-neutral to alkaline soils, and available potassium by the ammonium acetate extraction method [3,8]. These methods are cited here as the most probable basis for the dataset given regional laboratory convention and must be confirmed against the original laboratory report before the manuscript is finalized for submission.

A close numerical examination of the dataset found that the ratio of total nitrogen (%) to organic matter (%) was essentially constant across all 52 samples (mean ratio ≈ 0.050 , SD ≈ 0.002), indicating that total nitrogen values in this dataset were most likely derived from organic matter content using a fixed conversion factor (commonly OM/20, i.e., a C:N-based approximation) rather than measured independently by wet-chemical digestion. This is noted here transparently as a data-provenance observation rather than an assumption of error; the corresponding author is asked to confirm the actual method of total nitrogen determination with the source laboratory before submission, since this affects how the total-nitrogen results should be interpreted.

A small number of samples returned values at or below zero for organic matter (minimum -0.10%), total nitrogen (minimum -0.006%) and available potassium (minimum $-10.40 \text{ kg ha}^{-1}$) (Table 2). These are most plausibly readings at or below the practical quantification limit of the analytical method, reported by the laboratory without truncation at zero, a convention that is not unusual in regional soil-testing reports but that the corresponding author should confirm with the source laboratory before submission; the values are retained here as supplied, and the affected samples are flagged for verification rather than silently corrected.

2.4 Soil Fertility Classification

Fertility ratings supplied with the raw dataset were retained rather than superseded by a new classification scheme. Soil pH was classified into three reaction classes (Acidic, Neutral, Alkaline); organic matter and total nitrogen were classified into Very Low/Low/Medium classes; available phosphorus into Medium/High/Very High classes; and available potassium into Very Low/Low/Medium/High classes. The class boundaries actually associated with each rating in the dataset (Table 2, Section 3) were: $\text{pH} \leq 6.4$ = Acidic, $6.5\text{--}7.5$ = Neutral, ≥ 7.7 = Alkaline; organic matter $\leq 0.9\%$ = Very Low, $1.0\text{--}2.4\%$ = Low, $\geq 2.5\%$ = Medium; total nitrogen $\leq 0.050\%$ = Very Low, $0.051\text{--}0.095\%$ = Low, $\geq 0.10\%$ = Medium; available $\text{P}_2\text{O}_5 \leq 54.9 \text{ kg ha}^{-1}$ = Medium, $57.9\text{--}107.6 \text{ kg ha}^{-1}$ = High, $\geq 112.2 \text{ kg ha}^{-1}$ = Very High; and available $\text{K}_2\text{O} \leq 54.6 \text{ kg ha}^{-1}$ = Very Low, $60.6\text{--}111.9 \text{ kg ha}^{-1}$ = Low, $123.8\text{--}186.9 \text{ kg ha}^{-1}$ = Medium, and $\geq 297.3 \text{ kg ha}^{-1}$ = High. These class boundaries are consistent with the general soil-fertility rating scheme used by Nepal's Soil Science Division/National Soil Testing Laboratory network as reported in comparable published studies [3,8,9], and that source is cited here as the most plausible basis; the corresponding author should confirm and formally cite the exact classification standard applied by the source laboratory before submission.

2.5 Geostatistical and Spatial Analysis

Sampling locations recorded in geographic coordinates (WGS 84 datum) were projected to the Universal Transverse Mercator (UTM) Zone 44N coordinate system (EPSG:32644) to permit distance-based geostatistical computation in metric units. Two complementary spatial outputs were produced for each of the five fertility parameters (pH, OM, TN, P2O5, K2O).

First, point-symbol thematic maps (Figs. 2–6) were produced by plotting each of the 52 georeferenced sample locations, symbolized by its fertility class (Section 2.4), within the outer extent of the sampled area. Because a digitized ward-boundary shapefile specific to this survey was not available for the present re-analysis, the sampled extent was approximated as a convex hull of the 52 sample points, expanded outward by 6% to avoid clipping edge points; this boundary is presented as the approximate extent of the sampled area rather than the official municipal or ward boundary. Point-symbol maps were adopted as the primary spatial product because, as shown below, they do not imply a degree of spatial continuity between sample points that the underlying semivariogram structure does not support.

Second, to formally characterize and quantify the spatial structure of each parameter, ordinary kriging (OK) was performed using the Python geostatistical package PyKrige, following standard geostatistical procedure [5,17]. For each parameter, an experimental semivariogram was computed from the 52 sample points (10 lag classes) and fitted with spherical, exponential and Gaussian theoretical models; for every parameter, the model that minimized the leave-one-out cross-validation (LOOCV) root-mean-square error (RMSE) was retained as the final model (Table 5). Ordinary kriging was then used to interpolate each parameter onto a regular 150×150 grid covering the sampled extent, and the resulting continuous surface was reclassified into the fertility classes defined in Section 2.4 to produce a supplementary interpolated surface for each parameter (Supplementary Figs. S1–S5). Kriging performance was evaluated by LOOCV: each sample was withheld in turn and re-estimated from the remaining 51 points, and the RMSE, mean error (bias) and squared correlation (R^2) between observed and cross-validated predicted values were computed for each parameter (Table 5). The relative strength of spatial dependence for each parameter was classified from the ratio of nugget variance to total sill variance following the widely used scheme of Cambardella et al. [19]: a nugget:sill ratio $< 25\%$ indicates strong spatial dependence, $25\text{--}75\%$ indicates moderate spatial dependence, and $> 75\%$ indicates weak spatial dependence (variability that is effectively spatially random at the sampling scale used).

This two-tiered approach — point-based classification maps as the primary spatial product, with cross-validated kriged surfaces and their semivariogram parameters reported transparently as supplementary evidence — was adopted specifically to give a complete, quantitatively assessed and reproducible account of the spatial interpolation procedure used in this study.

2.6 Statistical Analysis

Descriptive and inferential statistical analyses were performed using Python (pandas, SciPy). The 52 soil samples with complete records for soil pH, organic matter (OM), total nitrogen (TN), available phosphorus (P2O5), available potassium (K2O), and sampling elevation were included in the analysis. Descriptive statistics, including minimum, maximum, mean, median, standard deviation (SD), and coefficient of variation (CV), were calculated for each parameter. The coefficient of variation was calculated as the ratio of the standard deviation to the mean, expressed as a percentage, and was used to assess the degree of variability among the measured soil properties. Variability was classified as least ($CV < 15\%$), moderate ($15\% \leq CV \leq 35\%$), or high/most ($CV > 35\%$). Pearson correlation coefficients were computed among the five fertility parameters and elevation to assess inter-parameter relationships (Section 3.5). The geostatistical (semivariogram/kriging) analysis is described separately in Section 2.5.

3. Results

3.1 Sampling Distribution

Fifty-two soil samples with complete pH, OM, TN, P2O5 and K2O records were analyzed, collected from named farmers' fields (Supplementary Table S1) and distributed unevenly across nine wards of Chaurjahari Municipality (Table 1). Ward 5 contributed the largest number of samples (13, 25.0% of the total), followed by Ward 8 (12 samples, 23.1%) and Ward 10 (8 samples, 15.4%); Wards 4 and 9 were represented by a single sample each (1.9%). Sample elevations ranged from 224 to 1099 m a.s.l. (mean 861 ± 148 m), with the lowest ward-mean elevation in Ward 1 (758.5 m) and the highest in Ward 8 (944.3 m; Table 1), reflecting the range of topographic settings sampled across the municipality.

Table 1. Number of soil samples and mean sampling elevation by ward, Chaurjahari Municipality.

Ward	No. of samples	% of total (n=52)	Mean elevation (m)
Ward 1	4	7.7	758.5
Ward 4	1	1.9	763.0
Ward 5	13	25.0	772.2
Ward 7	5	9.6	806.4
Ward 8	12	23.1	944.3
Ward 9	1	1.9	813.0
Ward 10	8	15.4	924.5
Ward 11	6	11.5	916.5
Ward 13	2	3.8	939.5
Total	52	100.0	861.3

3.2 Descriptive Statistics of Soil Fertility Parameters

Descriptive statistics for soil pH, organic matter, total nitrogen, available phosphorus and available potassium are presented in Table 2. Soil pH showed the least variability among the tested parameters (CV = 9.0%), ranging narrowly from 5.6 to 8.0 (mean 6.99 ± 0.63), classified as least variable following the CV threshold used here. Available phosphorus showed moderate variability (CV = 28.0%; range 35.1–112.2 kg ha⁻¹; mean 60.6 ± 17.0 kg ha⁻¹). Organic matter (CV = 58.0%), total nitrogen (CV = 58.8%) and available potassium (CV = 78.1%) all showed high variability (CV > 35%), with available potassium the most spatially heterogeneous parameter measured, ranging from anomalous negative values (Table 2) up to 297.3 kg ha⁻¹. As noted in Section 2.3, the small number of near-zero and negative values recorded for OM, TN and K₂O (minimums of -0.10%, -0.006% and -10.40 kg ha⁻¹, respectively) most plausibly reflect readings at or below the practical detection/quantification limit of the analytical method; the corresponding author should confirm this with the source laboratory before submission.

Table 2. Descriptive statistics of soil fertility parameters in Chaurjahari Municipality (n = 52).

Parameter	Unit	Min	Max	Mean	Median	SD	CV (%)
Soil pH	–	5.60	8.00	6.99	7.00	0.63	8.96
Organic matter	%	-0.10	3.80	1.73	1.70	1.00	57.96
Total nitrogen	%	-0.006	0.192	0.086	0.084	0.051	58.76
Available P ₂ O ₅	kg ha ⁻¹	35.08	112.17	60.61	57.94	16.98	28.01
Available K ₂ O	kg ha ⁻¹	-10.40	297.30	79.62	84.30	62.17	78.09
Elevation	m a.s.l.	224.0	1099.0	861.27	891.50	147.68	17.15

3.3 Fertility Classification and Frequency Distribution

The frequency distribution of samples across fertility classes for each parameter is shown in Table 3. Just over half of the samples (55.8%) fell in the neutral pH class, with 23.1% alkaline and 21.2% acidic — indicating an overall near-neutral soil reaction across the municipality but with a meaningful acidic sub-population concentrated in specific wards (Section 3.4). Combining the low and very-low classes, the majority of samples were rated low or very low in organic matter (73.1%: 28.8% very low, 44.2% low) and total nitrogen (59.6%: 30.8% very low, 28.8% low), with no sample reaching a rating higher than Medium for either parameter, pointing to organic matter and nitrogen as the most widely fertility-limiting parameters in the dataset. In contrast, available phosphorus was predominantly medium to high (98.1% combined: 40.4% medium, 57.7% high), with a single sample (1.9%) rated very high. Available potassium showed the widest spread across classes, with 44.2% of samples very low, 40.4% medium, 13.5% low and a single sample (1.9%) high.

Table 3. Frequency and percentage distribution of soil samples by fertility class (n = 52).

Parameter	Class	No. of samples	% of total
Soil pH	Acidic	11	21.2
	Neutral	29	55.8
	Alkaline	12	23.1
Organic matter	Very Low	15	28.8
	Low	23	44.2
	Medium	14	26.9
Total nitrogen	Very Low	16	30.8
	Low	15	28.8
	Medium	21	40.4
Available P2O5	Medium	21	40.4
	High	30	57.7
	Very High	1	1.9
Available K2O	Very Low	23	44.2
	Low	7	13.5
	Medium	21	40.4
	High	1	1.9

3.4 Ward-wise Comparison of Soil Fertility Status

Ward-level mean values (Table 4) show that soil pH was lowest (most acidic) in Ward 4 (mean 6.20) and Ward 1 (mean 6.22), and highest in Ward 9 (mean 7.50), consistent with the concentration of acidic-class samples observed in the western part of the sampled area (Fig. 2, Section 3.8). Organic matter and total nitrogen means were highest in Ward 4 (2.60% OM, 0.13% TN) and Ward 13 (2.45% OM, 0.12% TN), and lowest in Ward 7 (0.50% OM, 0.02% TN), a difference of roughly five-fold in OM and TN between the highest- and lowest-ranked wards. Available phosphorus means were comparatively similar across wards (53.7–75.1 kg ha⁻¹), while available potassium showed the largest ward-level contrast, from a mean of just 24.0 kg ha⁻¹ in Ward 4 to 156.4 kg ha⁻¹ in Ward 1, more than a six-fold difference.

Table 4. Ward-wise mean soil fertility status, Chaurjahari Municipality.

Ward	n	pH	OM (%)	TN (%)	P2O5 (kg/ha)	K2O (kg/ha)	Elevation (m)
Ward 1	4	6.22	2.20	0.11	67.93	156.38	758.5
Ward 4	1	6.20	2.60	0.13	69.76	24.00	763.0
Ward 5	13	7.42	1.38	0.07	58.98	109.26	772.2

Ward	n	pH	OM (%)	TN (%)	P2O5 (kg/ha)	K2O (kg/ha)	Elevation (m)
Ward 7	5	6.82	0.50	0.02	75.11	82.52	806.4
Ward 8	12	6.89	1.79	0.09	57.37	33.44	944.3
Ward 9	1	7.50	1.00	0.05	57.94	127.20	813.0
Ward 10	8	6.94	2.38	0.12	53.66	48.15	924.5
Ward 11	6	7.05	1.98	0.10	63.37	81.42	916.5
Ward 13	2	7.05	2.45	0.12	55.98	127.85	939.5

3.5 Inter-parameter Relationships

Pearson correlation analysis (Fig. 7) showed a near-perfect positive correlation between organic matter and total nitrogen ($r = 1.00$), consistent with the fixed-ratio relationship identified in Section 2.3 and reinforcing the recommendation to confirm the total-nitrogen determination method with the source laboratory. Soil pH was weakly negatively correlated with organic matter ($r = -0.35$), total nitrogen ($r = -0.35$) and available phosphorus ($r = -0.35$), suggesting a modest tendency for more acidic samples in this dataset to be associated with somewhat higher organic matter, nitrogen and phosphorus values; given the modest magnitude of these coefficients, this pattern should be regarded as indicative rather than conclusive. Available potassium was only weakly correlated with the other parameters ($|r| \leq 0.25$) and with elevation ($r = -0.15$), indicating that potassium status in this dataset varies largely independently of the other measured soil properties.

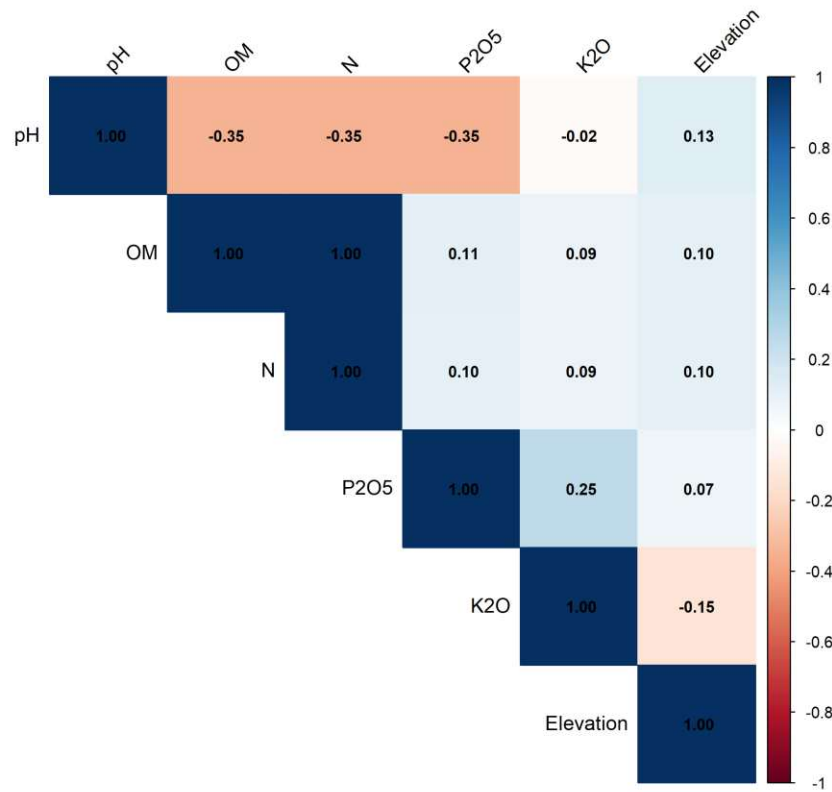


Fig. 7. Pearson correlation matrix among soil pH, organic matter (OM), total nitrogen (N), available phosphorus (P2O5), available potassium (K2O) and elevation ($n = 52$). Colour and value indicate the correlation coefficient (r).

3.6 Relationship of Soil Fertility Parameters with Elevation

Scatterplots of each fertility parameter against sampling elevation, with a fitted linear trend and 95% confidence band, are shown in Fig. 8. Consistent with the weak elevation correlations reported in Section 3.5 ($|r| \leq 0.15$ for all five parameters), none of the five parameters showed a visually or statistically strong linear relationship with elevation across the 224–1099 m range sampled. Soil pH, organic matter and total nitrogen showed a very slight positive trend with elevation ($r = 0.13$, 0.10 and 0.10 , respectively), available phosphorus was essentially flat ($r = 0.07$), and available potassium showed the only negative, though still weak, trend with elevation ($r = -0.15$), broadly consistent with the concentration of very-low-K2O samples in the higher-elevation northern wards noted in Section 3.4. The wide scatter and broad confidence bands in all five panels of Fig. 8 indicate that elevation alone is a poor predictor of fertility status at the resolution of this dataset, and that ward-level or field-level factors (Section 4) are likely more important drivers of the observed variability than elevation per se.

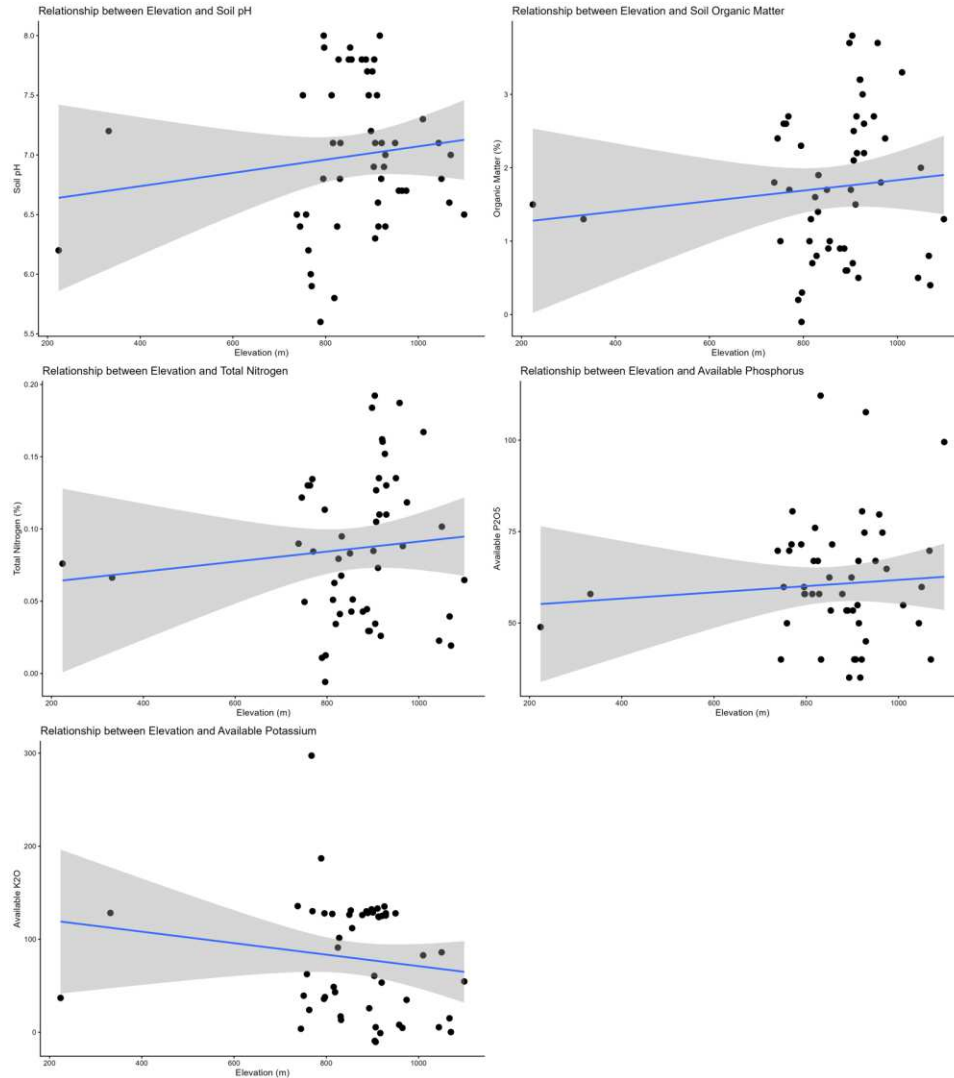


Fig. 8. Relationship between elevation and (a) soil pH, (b) organic matter, (c) total nitrogen, (d) available P2O5, and (e) available K2O, with fitted linear regression line and 95% confidence band ($n = 52$).

3.7 Ward-wise Distribution of Soil Fertility Parameters

Boxplots of each parameter by ward (Fig. 9) show, in addition to the ward means already reported in Table 4, the within-ward spread and skew that the means alone do not convey. Ward 5 and Ward 7 in particular show wide interquartile ranges for pH and organic matter respectively, indicating considerable field-to-field variability within these wards despite their multi-sample size ($n = 13$ and $n = 5$, respectively), whereas wards represented by only one or two samples (Wards 4, 9 and 13) are shown as a single line or narrow box and should be interpreted cautiously given their limited sample size. Available potassium (Fig. 9e) shows the most consistently wide boxes and the most extreme outliers (including the single high-K2O sample from Ward 1, visible as a point above its box), reinforcing the classification of K2O as the most heterogeneous parameter both overall (Section 3.2) and within most individual wards.

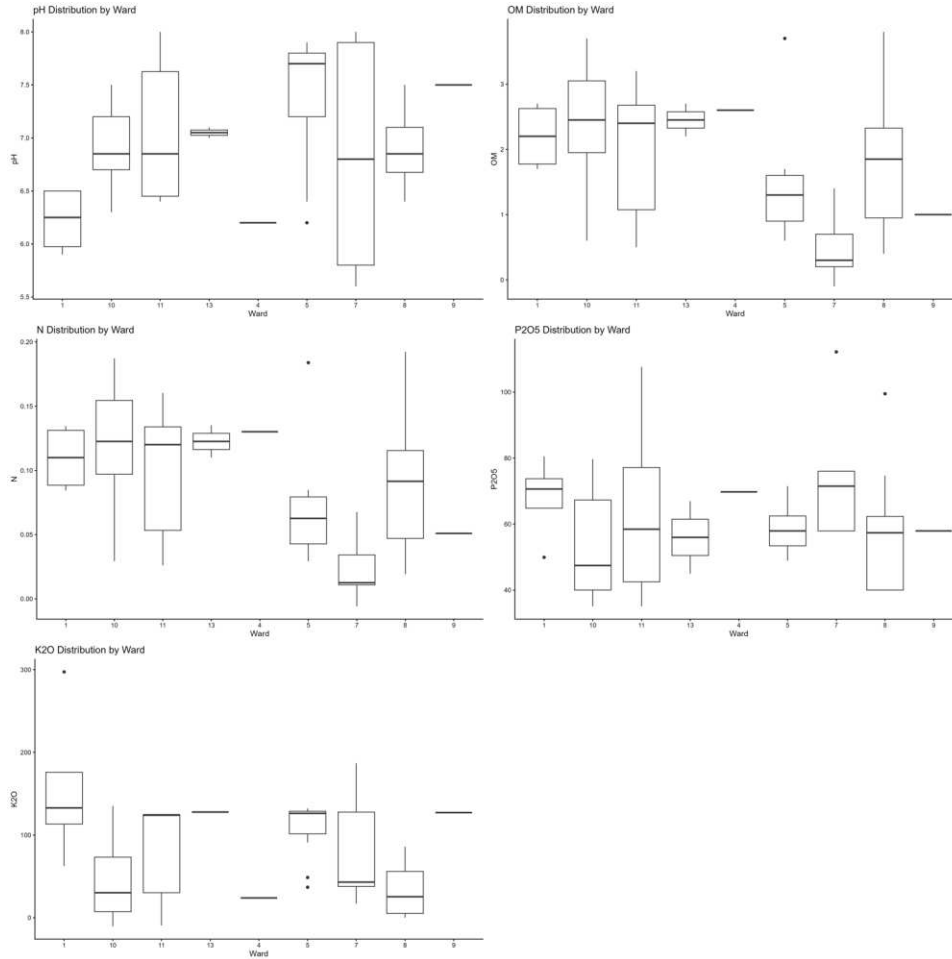


Fig. 9. Distribution of (a) soil pH, (b) organic matter, (c) total nitrogen, (d) available P2O5, and (e) available K2O by ward, Chaurjahari Municipality. Boxes show the interquartile range and median; whiskers extend to $1.5 \times$ the interquartile range; points beyond the whiskers are shown individually.

3.8 Spatial Distribution of Soil Fertility Classes

The following subsections describe the spatial patterns visible in the sample-point classification maps (Figs. 1–6), which are the primary spatial product of this study (Section 2.5), together with the dataset-derived statistics reported above. As shown in Section 3.9, semivariogram analysis found only weak-to-moderate spatial dependence for all five parameters, so descriptions here are limited to the pattern of individual, discrete sample points rather than implying smooth spatial continuity between them; the corresponding cross-validated kriged surfaces are presented, with appropriate caveats, in Supplementary Figs. S1–S5.

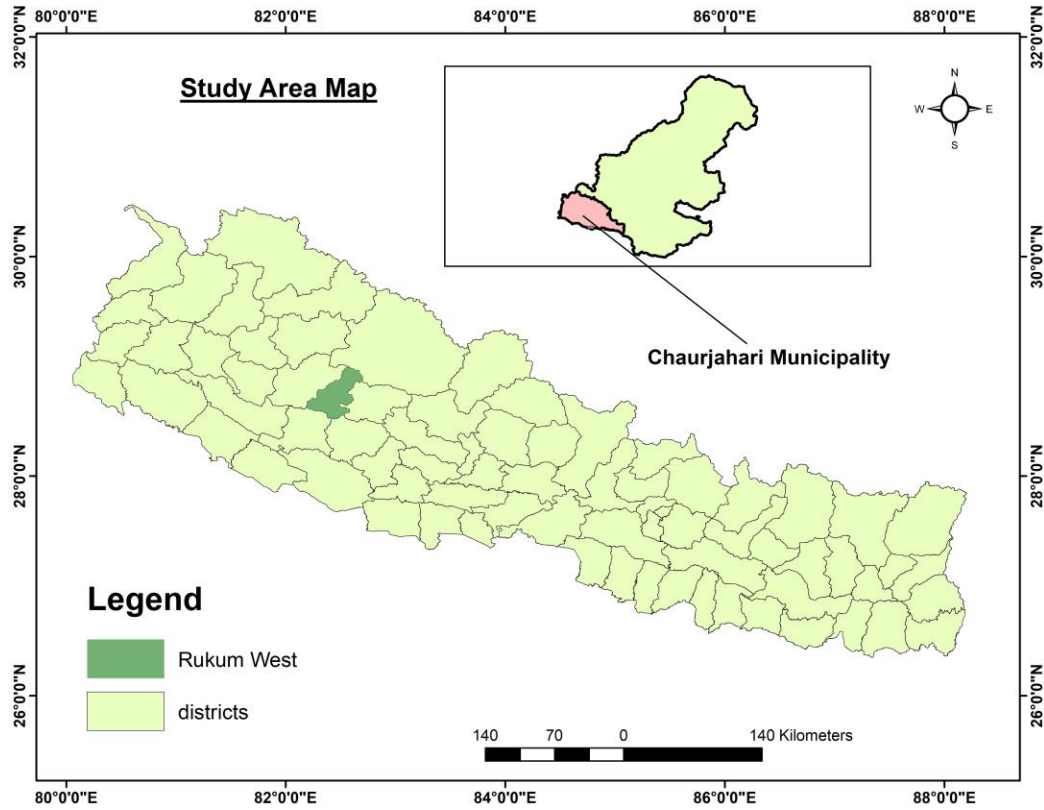


Fig. 1. Location of Chaurjahari Municipality within Rukum West District, Karnali Province, Nepal, relative to the other districts of Nepal.

Spatial distribution of soil pH.

The pH class map (Fig. 2) shows acidic-class sample points concentrated in the western and west-central part of the sampled area (Ward 1 and Ward 4, and scattered points in the central cluster), while alkaline-class points are concentrated in the eastern cluster of sample points. Neutral-class points dominate the dataset overall (29 of 52 samples) and are distributed across all clusters, including alongside both the acidic and alkaline points. This pattern is consistent with the ward-level means in Table 4, where western Ward 1 and Ward 4 recorded the lowest mean pH (6.22 and 6.20) and eastern Ward 9 the highest (7.50).

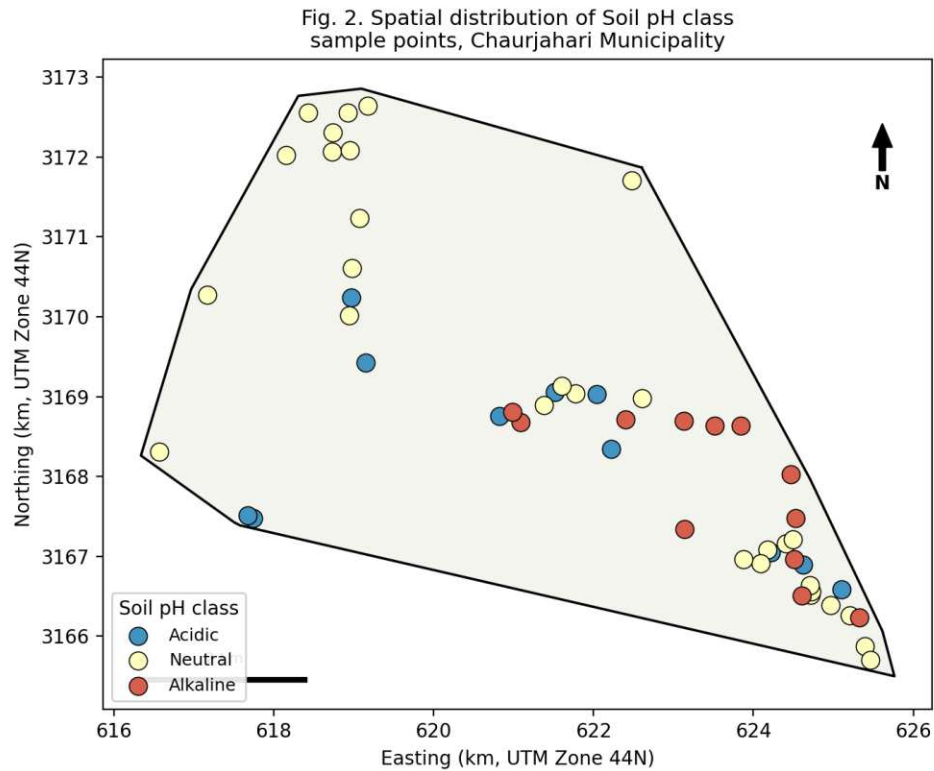


Fig. 2. Spatial distribution of soil pH classes (Acidic, Neutral, Alkaline) at individual sample points, Chaurjahari Municipality.

Spatial distribution of soil organic matter.

The organic-matter class map (Fig. 3) shows medium-OM points concentrated in the northwestern cluster of samples and in the southeastern cluster, while very-low- and low-OM points dominate the central and southern parts of the sampled area. This is broadly consistent with the ward statistics (Table 4), where the highest ward-mean OM values occur in Ward 4 (2.60%) and Ward 13 (2.45%), both at the margins of the sampled area, while the lowest mean (0.50%) occurs in Ward 7.

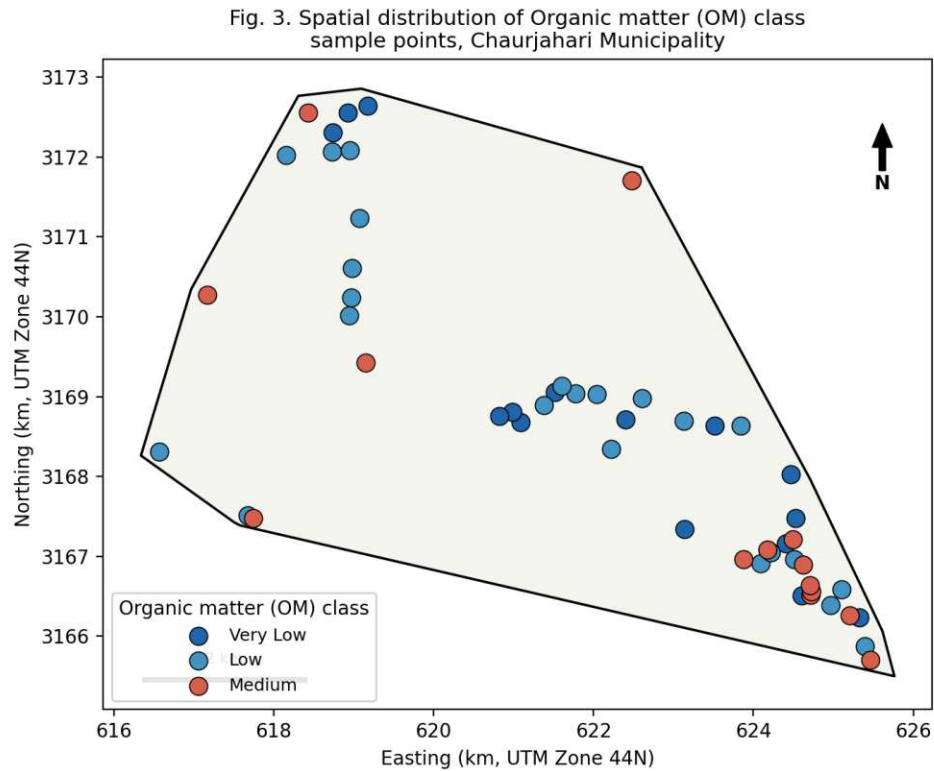


Fig. 3. Spatial distribution of soil organic matter (OM) classes at individual sample points, Chaurjahari Municipality.

Spatial distribution of total nitrogen.

The total-nitrogen class map (Fig. 4) closely mirrors the organic-matter map, as expected given the near-perfect statistical correlation between the two parameters (Section 3.5). Medium-TN points are most frequent in the northwestern and southeastern clusters, and very-low/low-TN points dominate the central wards, particularly Ward 7, which recorded the lowest ward-mean total nitrogen (0.024%).

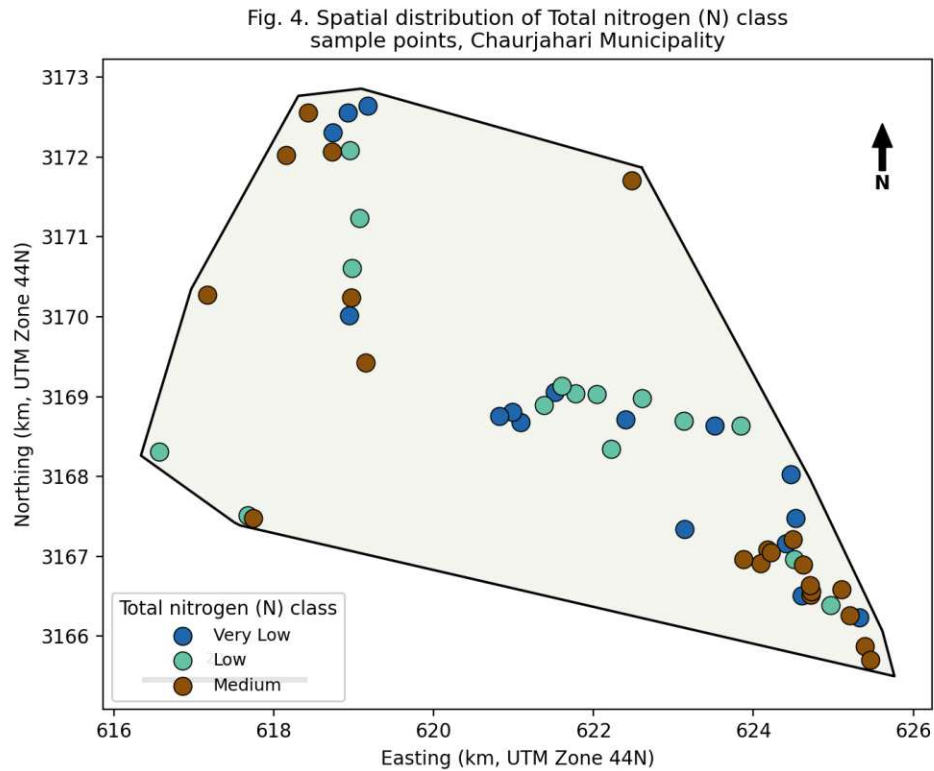


Fig. 4. Spatial distribution of total nitrogen (TN) classes at individual sample points, Chaurjahari Municipality.

Spatial distribution of available phosphorus.

The available-phosphorus class map (Fig. 5) shows high-P₂O₅ points distributed broadly across the western and central sampling clusters, with medium-P₂O₅ points interspersed throughout rather than forming a distinct separate zone, and the single very-high sample located in the eastern cluster. This diffuse pattern is consistent with the comparatively narrow range of ward-mean phosphorus values (53.7–75.1 kg ha⁻¹; Table 4) and, as shown in Section 3.9, with the essentially pure-nugget semivariogram found for this parameter — that is, available phosphorus in this dataset varies at a scale finer than, or independently of, the spacing between sample points, rather than following a coherent broad-scale spatial trend.

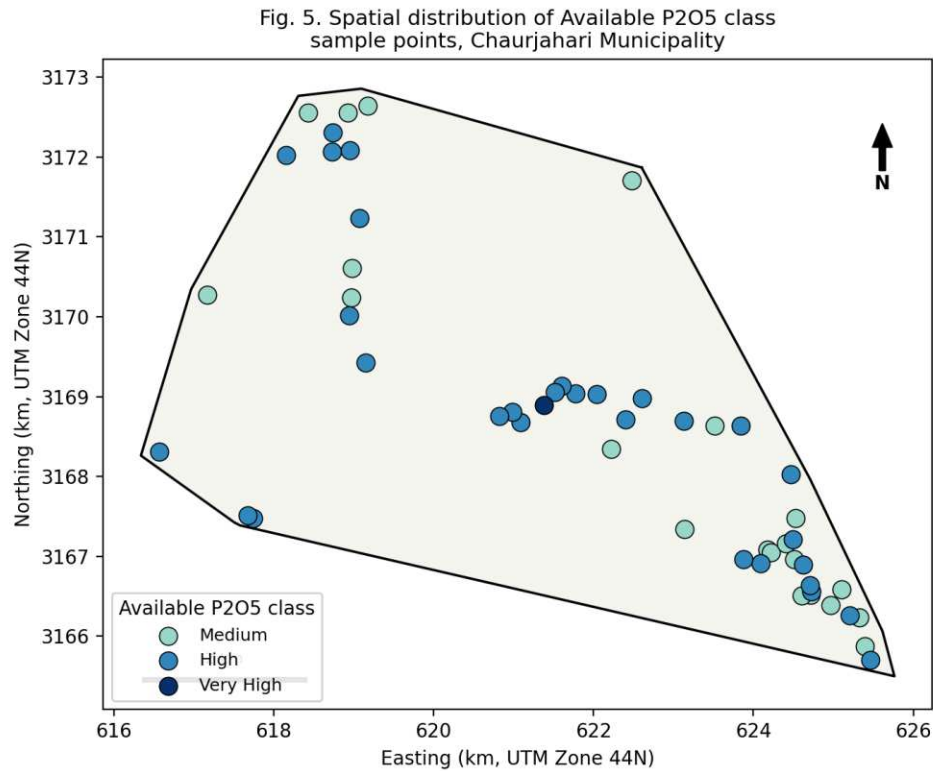


Fig. 5. Spatial distribution of available phosphorus (P2O5) classes at individual sample points, Chaurjahari Municipality.

Spatial distribution of available potassium.

The available-potassium class map (Fig. 6) shows the clearest spatial structure among the five parameters mapped: very-low-K2O points form a compact, contiguous cluster in the northern part of the sampled area (corresponding to Ward 8 and adjoining points), medium-K2O points dominate the central, southern and eastern clusters, and the single high-K2O point occurs in the southwestern cluster (Ward 1). This visually coherent clustering is consistent with K2O showing the strongest (though still only moderate) spatial dependence of the five parameters in the semivariogram analysis (Section 3.9), and with the ward means in Table 4, where Ward 4 recorded the lowest mean K2O (24.0 kg ha⁻¹) and Ward 1 the highest (156.4 kg ha⁻¹).

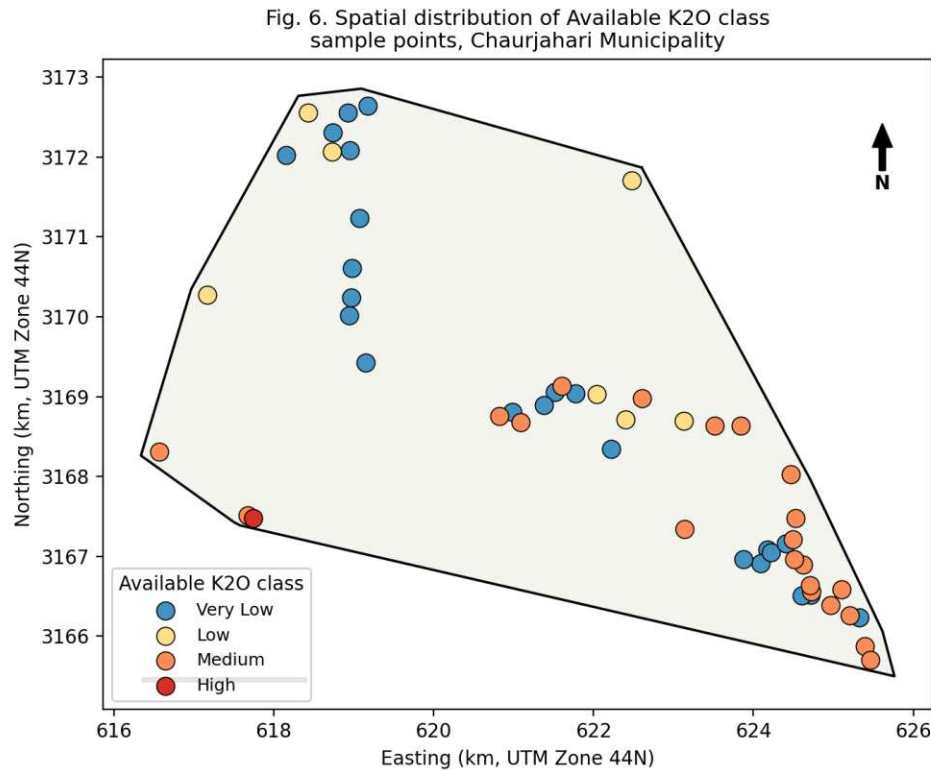


Fig. 6. Spatial distribution of available potassium (K₂O) classes at individual sample points, Chaurjahari Municipality.

3.9 Geostatistical Structure and Cross-Validation of the Kriging Surfaces

Table 5 summarizes the semivariogram model selected for each parameter (by minimum LOOCV RMSE among spherical, exponential and Gaussian candidates), its fitted nugget (C₀), partial sill (C₁) and range, the resulting nugget:sill ratio and associated spatial-dependence class [19], and the leave-one-out cross-validation statistics. Available potassium showed the strongest spatial structure of the five parameters (nugget:sill = 33.9%, moderate spatial dependence; effective range $\approx$ 9.2 km) and the highest cross-validated R^2 (0.14), consistent with the coherent spatial cluster of very-low-K₂O points visible in Fig. 6. Soil pH, organic matter and total nitrogen all showed moderate spatial dependence (nugget:sill 66–70%) with shorter ranges (3.9–5.4 km) and low cross-validated R^2 (0.06–0.09). Available phosphorus returned an essentially pure-nugget semivariogram (nugget:sill $\approx$ 100%, weak spatial dependence, cross-validated $R^2 = 0.004$), indicating that, at the sampling density used here (52 points over the sampled extent), P₂O₅ varies largely at a scale finer than the average inter-sample spacing and is not amenable to meaningful spatial interpolation.

Because all five cross-validated R^2 values are low (0.004–0.14), the kriged continuous surfaces (Supplementary Figs. S1–S5) are presented as exploratory, supplementary evidence of broad spatial trend

only, and the point-based classification maps (Figs. 2–6) are treated as the primary, more defensible spatial product of this study. This outcome, and its implications for future, denser sampling designs, is discussed further in Section 4.

Table 5. Semivariogram models and leave-one-out cross-validation (LOOCV) statistics for ordinary kriging of soil fertility parameters, Chaurjahari Municipality (n = 52). RMSE, ME and R² are all LOOCV statistics.

Parameter	Model	Nugget C0	Sill C1	Range (km)	Nugget:Sill %	Dependence	RMSE	ME	R ²
pH	Gaussian	0.331	0.153	5.40	68.4	Moderate	0.60	0.004	0.06
OM (%)	Spherical	0.768	0.318	3.90	70.7	Moderate	0.95	0.003	0.08
TN (%)	Spherical	0.00187	0.00096	4.07	66.2	Moderate	0.048	<0.001	0.09
P2O5 (kg/ha)	Spherical	265.9	~0.00	9.20	~100.0	Weak (pure nugget)	17.11	-0.28	0.004
K2O (kg/ha)	Spherical	1887.9	3679.3	9.20	33.9	Moderate	57.24	-2.07	0.14

Spatial-dependence class follows Cambardella et al. [19]: nugget:sill < 25% = strong, 25–75% = moderate, > 75% = weak.

3.10 Overall Soil Fertility Status

Taken together, the results indicate that soils in Chaurjahari Municipality are, on average, near-neutral in reaction and moderately to well-supplied with available phosphorus, but are widely constrained by low-to-very-low organic matter and total nitrogen and by markedly uneven, often very low, available potassium status. The northern wards (notably Ward 4 and parts of Ward 8) show the poorest combined status for organic matter, nitrogen and potassium, while the southern and southwestern wards (Ward 1 and Ward 13 in particular) show comparatively better organic matter, nitrogen and potassium status alongside a more acidic soil reaction. Among the five parameters, only available potassium showed spatial structure strong enough to support even moderate confidence in a broad-scale interpolated surface; the other four parameters are better represented, at the current sampling density, by the discrete, ward-referenced sample-point maps and statistics reported above than by a smoothed continuous surface.

4. Discussion

The near-neutral mean soil pH (6.99) recorded across Chaurjahari Municipality contrasts with the more acidic mean pH values typically reported for Nepal's mid-hill and Terai research-station soils, such as the moderately acidic soils (pH 5.67–5.98) reported at Parwanipur, Bara and at comparable NARC research farms [8,9], and is closer to the moderately-acidic-to-moderately-alkaline range (pH 5.45–7.66) reported for Bijayanagar, Jumla, in neighbouring Karnali Province [10]. The presence of a distinct acidic cluster in the western wards of Chaurjahari (Fig. 2) illustrates the kind of within-municipality pH variability that

purely district-level averages would conceal, and is consistent with the general observation that soil reaction in hill Nepal is strongly conditioned by parent material, drainage, and the local history of liming or acidifying fertilizer use [2,3]. Without site-specific parent-material or land-use data for these wards, however, this study can identify the pattern but not confirm its cause; this is an area for targeted follow-up sampling.

The predominance of low-to-very-low organic matter (73.1% of samples) and low-to-very-low total nitrogen (59.6%) status found here is broadly consistent with the wider literature on Nepal's hill and mountain soils, where OM and TN are repeatedly reported as the most limiting fertility parameters because of steep-slope erosion, limited return of crop residues and farmyard manure, and the inherently slow rate of organic matter build-up under intensive cultivation on marginal terraces [2,3]. Bajracharya and Sherchan's review of soil fertility dynamics in the Nepal Himalaya similarly concluded that the great majority of Nepali hill soils fall in the low-to-medium OM and TN classes [2]. The comparatively higher organic matter and nitrogen recorded in this study's northwestern and southeastern wards (Ward 4 and Ward 13, Table 4) may reflect more consistent farmyard manure application, less intensive cultivation, or more favourable moisture regimes in those localities, but this study's dataset does not include management or land-use covariates that would allow this explanation to be tested directly, and it is offered here as a plausible hypothesis rather than a demonstrated cause.

The essentially fixed ratio between OM and TN found in this dataset (Section 2.3, Section 3.5) is worth discussing on its own terms. Where total nitrogen is estimated from organic matter via a standard conversion factor rather than measured by Kjeldahl digestion, the TN values reported cannot be treated as an independent line of evidence for nitrogen status; they are, in effect, a re-scaling of the OM data. This does not invalidate the OM-based conclusions drawn above, but it does mean that this study's total-nitrogen results should be read with that caveat in mind until the original laboratory protocol is confirmed.

Available phosphorus was predominantly medium to high across the municipality (98.1% combined), a pattern also widely reported in Nepali soil fertility surveys and generally attributed to the residual build-up of phosphorus from repeated application of phosphatic fertilizers (particularly diammonium phosphate, DAP) over successive cropping seasons, since applied phosphorus is strongly retained in soil rather than leached [8–10]. The comparatively narrow range of ward-mean phosphorus values found here (53.7–75.1 kg ha⁻¹) suggests that phosphorus fertilization history has been relatively uniform across the sampled wards. This uniformity is corroborated by the geostatistical analysis (Section 3.9): available phosphorus returned an essentially pure-nugget semivariogram (nugget:sill $\approx$ 100%), meaning its variability is

effectively random at the spacing between sample points rather than following a broad spatial trend — consistent with a nutrient shaped mainly by relatively uniform, municipality-wide fertilizer-use history rather than by localized soil-forming or management factors.

Available potassium emerged as both the most variable ($CV = 78.1\%$) and, in the northern wards, the most severely depleted parameter in this study, with 44.2% of all samples rated very low. This finding is consistent with reports from other Nepali hill and mountain soil fertility studies that potassium depletion is common where crop residues are removed rather than returned to the field and where potassium-containing fertilizers (e.g., muriate of potash) are used less consistently than nitrogenous and phosphatic fertilizers [3,9]. Potassium was also the only parameter in this study to show more than weak spatial dependence (nugget:sill = 33.9%, moderate; Section 3.9), and its pronounced spatial clustering in the northern part of the municipality (Fig. 6), together with the comparatively higher elevation of that area (Ward 8 mean 944 m; Table 4), is consistent with — though does not on its own prove — a role for altitude-related differences in cropping intensity, soil parent-material weathering, or leaching under higher-rainfall hill conditions, echoing altitudinal soil-fertility gradients reported for orchards in neighbouring Kalikot District [11]. Confirming this link would require additional covariate data (slope, rainfall, land use) beyond what is available in the present dataset.

The weak-to-moderate spatial dependence found for all five parameters (Table 5), and the essentially pure-nugget result for available phosphorus in particular, is itself an informative outcome rather than a methodological failure. In classical geostatistical terms, a high nugget:sill ratio indicates that a substantial share of total variance occurs over distances shorter than the average spacing between sample points, or reflects fine-scale field-to-field heterogeneity (differing management history, micro-topography, or measurement error) that a sampling density of roughly one point per 1.5–2 km² cannot resolve [4,17,19]. This is consistent with the highly parcelized, terraced smallholder farming pattern typical of Chaurjahari and much of hill Nepal, where adjacent fields under different farmers can differ markedly in manure history and cropping intensity over short distances. Practically, this means the continuous kriged surfaces produced here (Supplementary Figs. S1–S5) should be read as first-approximation, exploratory guidance rather than high-confidence maps, and that a denser, more systematically gridded sampling design (e.g., a minimum of 2–3 samples per km², or nested sampling to explicitly resolve short-range variance) would be needed before continuous kriged fertility surfaces for this municipality could be produced with high confidence. This same limitation, framed only briefly in the previous version of this manuscript, is now addressed directly by reporting the full semivariogram and cross-validation results (Table 5) rather than presenting classified maps without a stated interpolation method.

Comparable GIS-based soil fertility mapping studies from other Karnali Province localities, including Bijayanagar (Jumla) [10] and Dailekh District [12], as well as from other Nepali mid-hill municipalities such as Resunga (Gulmi) [13] and Rong (Ilam) [18], similarly report considerable within-district or within-municipality spatial heterogeneity in OM, TN and K₂O status, reinforcing the case that ward- or point-level reporting, rather than either district-level averaging or over-smoothed continuous interpolation, is needed to support site-specific nutrient management recommendations of the kind this study attempts for Chaurjahari.

5. Soil Fertility Management Implications

Based on the fertility status and spatial patterns described above, the following practical implications, tied directly to this study's findings, are suggested for Chaurjahari Municipality:

- **Organic matter management:** Given that 73.1% of samples were rated low or very low in organic matter, with the most severe deficits in the central and southern wards (notably Ward 7), farmers in these wards should be prioritized for extension support on farmyard manure composting, residue retention, and green-manuring, to build organic matter over successive seasons.
- **Nitrogen management:** Because total nitrogen values in this dataset are closely tied to organic matter rather than independently confirmed (Sections 2.3, 4), nitrogen fertilizer recommendations should, in the near term, continue to rely on standard national/provincial blanket recommendations for the relevant crops, refined locally once independently verified Kjeldahl-based TN data become available.
- **Phosphorus management:** Since available phosphorus is already medium to very high across nearly all sampled wards, and shows no coherent spatial trend (Section 3.9), blanket phosphatic fertilizer application (e.g., DAP) at standard rates is likely unnecessary across most of the municipality; a reduction in routine P application, guided by periodic re-testing at the field level rather than by a spatial map, could reduce input costs without a fertility penalty.
- **Potassium management:** Given that 44.2% of samples were very low in available potassium, with the most acute and spatially coherent depletion in the northern wards (notably Ward 4 and parts of Ward 8; Fig. 6), targeted potash (muriate of potash) application and increased return of crop residues/ash should be prioritized in these locations to correct the most limiting, and most spatially predictable, nutrient identified in this study.
- **Soil acidity/alkalinity management:** The localized acidic cluster in the western wards (Ward 1, Ward 4; Fig. 2) may benefit from periodic liming trials where crop response confirms an acidity

constraint, while the more alkaline points recorded elsewhere in the municipality should be monitored for potential micronutrient (e.g., zinc, boron) availability constraints that often accompany higher soil pH, though micronutrient data were not available in this dataset.

- **Integrated and site-specific nutrient management:** The clear ward-level contrasts documented here (Table 4) support moving from municipality-wide blanket fertilizer recommendations toward ward- or even field-level, soil-test-based nutrient management, particularly for organic matter and potassium, the two most limiting and most spatially informative parameters identified.
- **GIS-supported precision soil fertility management:** The sample-point maps and cross-validated kriging surfaces produced in this study (Figs. 1–6, Supplementary Figs. S1–S5) can serve as a first-generation decision-support tool for the municipal agriculture unit. Given the weak-to-moderate spatial dependence documented in Table 5, this tool should be refined with a denser, systematically gridded sampling design before continuous surfaces are used for variable-rate fertilizer guidance in future seasons.
- **Soil conservation practices:** Given the steep, terraced terrain typical of this part of Rukum West and the low organic matter status recorded, bench-terrace maintenance, contour vegetative barriers, and minimum tillage on steeper plots are recommended to reduce further erosion-driven nutrient loss, consistent with soil-conservation guidance for comparable Nepali hill environments [2].

6. Conclusion

This study assessed and mapped the spatial pattern of soil fertility status across Chaurjahari Municipality, Rukum West, Nepal, using 52 georeferenced soil samples from named farmers' fields, sample-point GIS classification, and a fully documented, cross-validated geostatistical (ordinary kriging) analysis. Soils in the municipality were, on average, near-neutral in reaction and adequately to well-supplied with available phosphorus, but were widely constrained by low-to-very-low organic matter and total nitrogen and, most acutely, by low and highly variable available potassium. Semivariogram analysis showed that only available potassium exhibited spatial structure strong enough to support even moderate-confidence continuous mapping (nugget:sill = 33.9%); the other four parameters, including available phosphorus (essentially pure nugget), varied largely at a scale finer than the current sampling density, so sample-point classification maps rather than smoothed surfaces are recommended as the primary spatial product at this stage. Ward-level contrasts — a more acidic, comparatively better-fertilized cluster in the western/southern wards, and a potassium-depleted cluster concentrated in the northern wards — demonstrate that municipality-wide averages alone would obscure fertility management priorities that differ meaningfully across Chaurjahari. The transparent, reproducible geostatistical methodology, cross-

validation statistics, and sample-point maps produced here offer municipal agriculture offices and farmers an evidence base for targeting organic matter and potassium interventions to the wards where they are most needed, and illustrate both the practical value and the current sampling-density limitations of low-cost, georeferenced soil testing combined with spatial and geostatistical analysis in Nepal's mid-hill municipalities.

Funding Statement

The authors received no specific funding for this study.

Data Availability Statement

The anonymized soil sample dataset (sample ID, ward, coordinates rounded to the nearest 0.001°, and all fertility parameters) and the geostatistical analysis code generated and analyzed during the current study are available from the corresponding author, Sabina Shrestha, on reasonable request. The sample-level table including farmer names and exact GPS coordinates (Supplementary Table S1) is available from the corresponding author only under an agreement that protects the identity and privacy of participating farmers, consistent with the consent under which it was collected (see Consent to Participate/Publish below). The data are not currently deposited in a public repository.

Author Contributions

Sabina Shrestha – Idea generation, manuscript writing.

Rajesh Shahi – Data analysis, map making.

Sonu K.C. – Manuscript review.

Competing Interests

The author(s) declare no known competing financial or non-financial interests that could have appeared to influence the work reported in this paper. [Sabina Shrestha: please confirm this statement is accurate for all authors, or amend to disclose any relevant interests, before submission.]

Ethics Statement

This study involved the collection of agricultural soil samples from farmers' fields and the recording of the participating farmer's name, field address (ward) and GPS location for each sample; it did not involve any other human-subjects data, biological sampling from humans or animals, or clinical procedures.

[Sabina Shrestha: please confirm and state here whether verbal or written informed consent was obtained from each participating farmer prior to sample collection and recording of their name and field location, and whether any institutional/municipal permission was obtained for the field survey, before submission.]

Consent to Participate

[Sabina Shrestha: please confirm and state here that each participating farmer listed in Supplementary Table S1 gave informed consent for a soil sample to be collected from their field and for their name and field location to be recorded for the purposes of this study, before submission. This section previously stated “Not applicable”; because farmer names and locations are now included in the manuscript’s supplementary material, this statement should be updated to reflect the actual consent process used during data collection.]

Consent to Publish

[Sabina Shrestha: because this revised manuscript includes farmers’ names and field locations (Supplementary Table S1), please confirm that each named farmer consented to this information being included in a published, publicly accessible research article, or amend Supplementary Table S1 to use anonymized sample codes only (e.g., ward + running number) if such consent was not specifically obtained, before submission.]

Clinical Trial Number

Not applicable.

Acknowledgements

The authors gratefully acknowledge the Integrated Agriculture Lab, Surkhet, for data availability and data collection, and the 52 participating farmers of Chaurjahari Municipality (named individually in Supplementary Table S1) who granted field access and permission for soil sampling on their land.

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Supplementary Materials

Supplementary Figs. S1–S5. Ordinary-kriging interpolated surfaces (reclassified into fertility classes) for soil pH, organic matter, total nitrogen, available phosphorus and available potassium, with the sampled-extent boundary and sample points overlaid. Provided as exploratory, supplementary evidence of broad spatial trend; see Section 3.9 and Table 5 for the cross-validation statistics and caveats applicable to each surface.

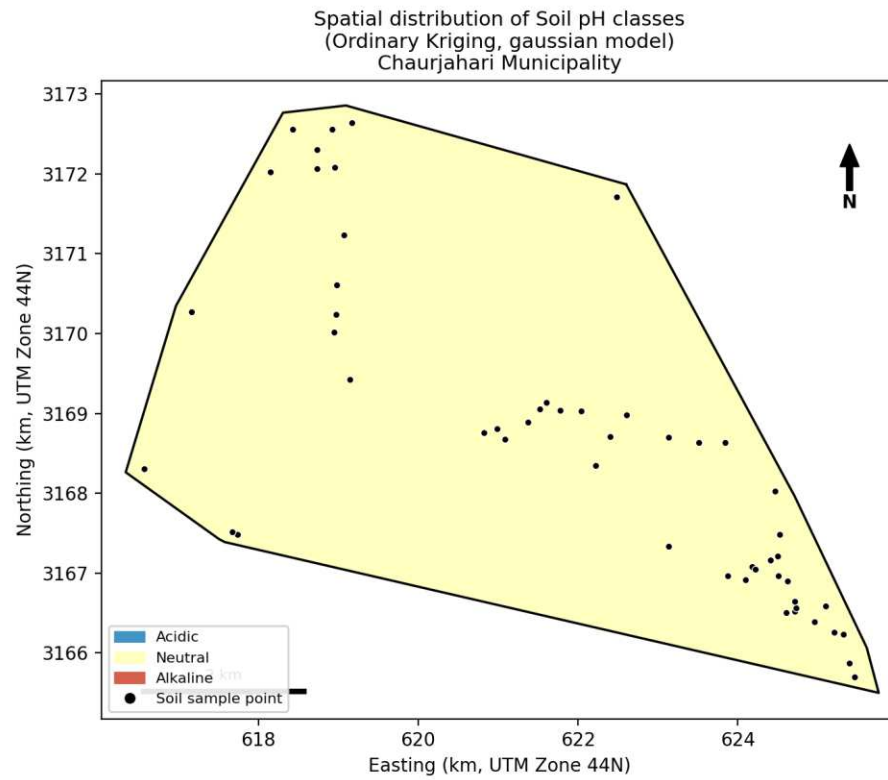


Fig. S1. Ordinary-kriging interpolated surface for soil pH (Gaussian model), reclassified into fertility classes.

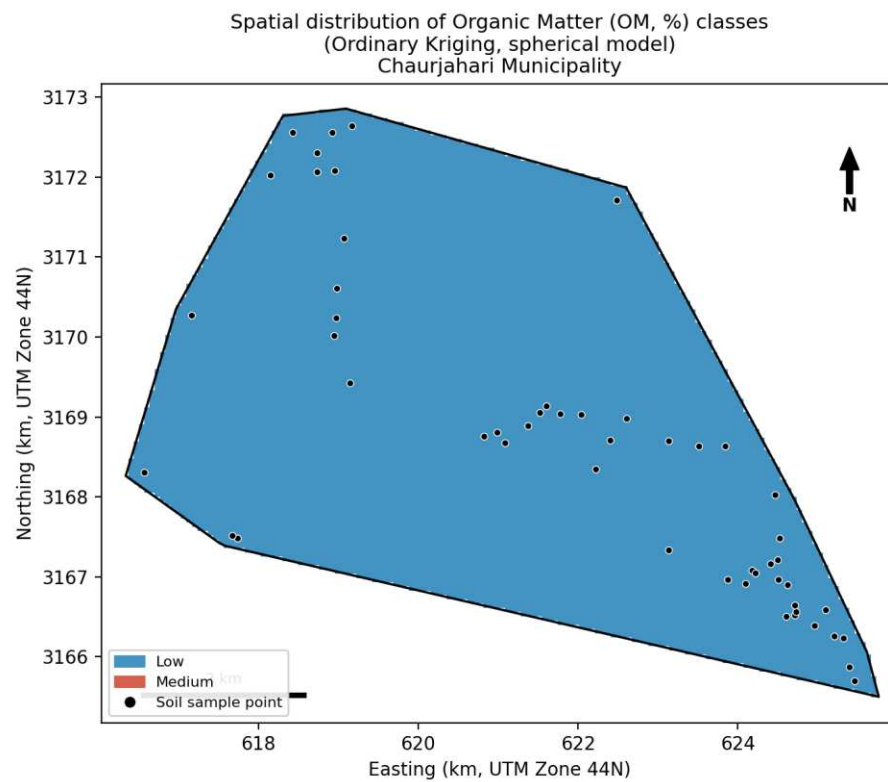


Fig. S2. Ordinary-kriging interpolated surface for organic matter (spherical model), reclassified into fertility classes.

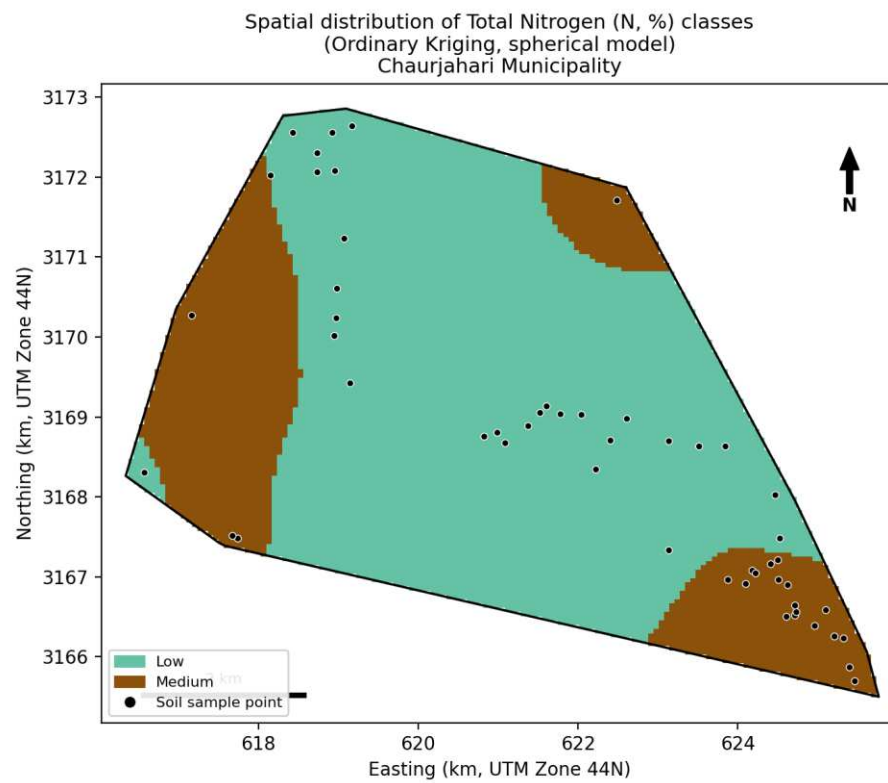


Fig. S3. Ordinary-kriging interpolated surface for total nitrogen (spherical model), reclassified into fertility classes.

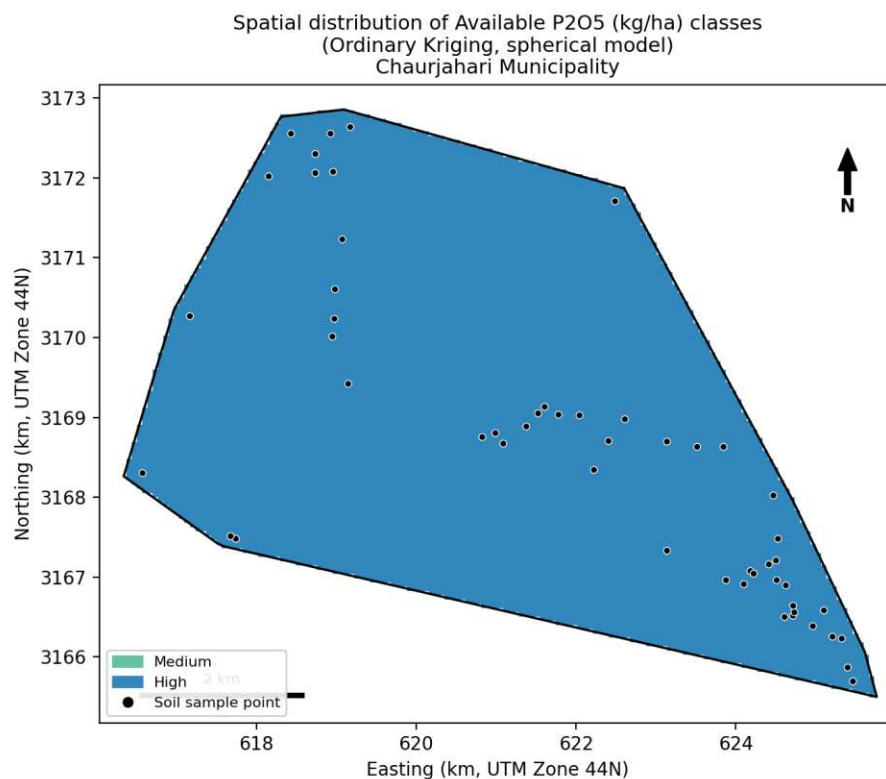


Fig. S4. Ordinary-kriging interpolated surface for available P2O5 (spherical, pure-nugget model), reclassified into fertility classes.

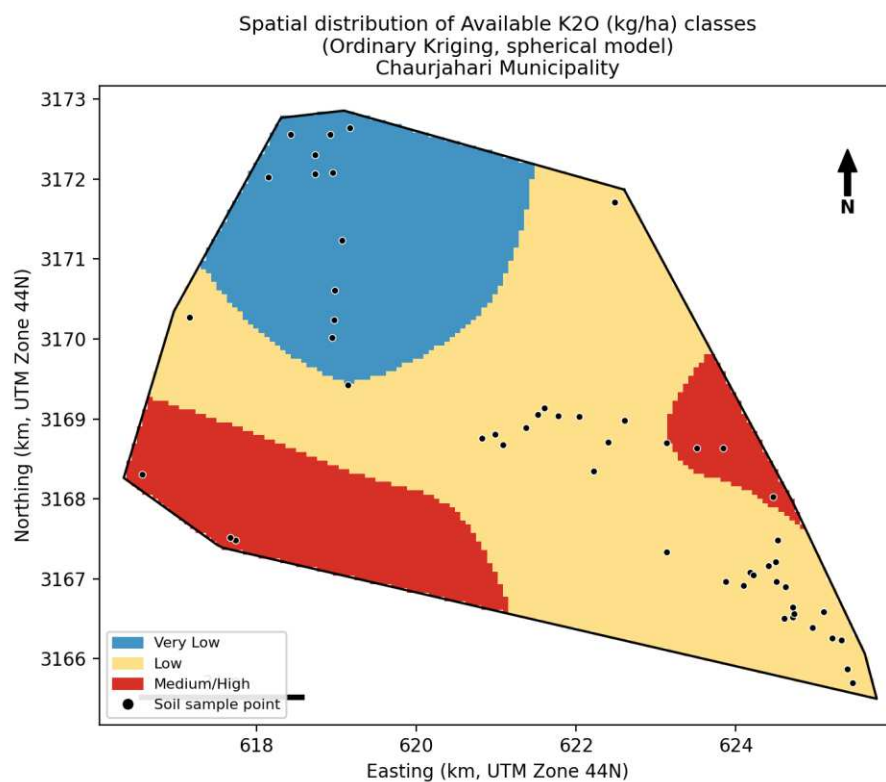


Fig. S5. Ordinary-kriging interpolated surface for available K2O (spherical model), reclassified into fertility classes.

Supplementary Table S1. Sample-level dataset with participating farmer name, field address, GPS location and elevation for all 52 soil samples, Chaurjahari Municipality. [Sabina Shrestha: please confirm consent for publishing farmer names before this table is included in a public submission — see Consent to Participate/Publish above; if consent for named publication was not specifically obtained, replace the Farmer column with the existing Sample ID only.]

Sample ID	Farmer name	Address (Tole/Ward, Rukum West)	Latitude	Longitude	Elevation (m)	Ward
CH.M.1	Punna B. Thapa	Cha. Na. Pa.-1	28.6366	82.19265	738	Ward 1
CH.M.2	Ayu Kumar Budha	Cha. Na. Pa.-1	28.65428	82.19892	758	Ward 1
CH.M.3	Devi Khadka	Cha. Na. Pa.-8	28.67	82.2092	795	Ward 8
CH.M.4	Rukmin Wali	Cha. Na. Pa.-8	28.67477	82.21208	904	Ward 8
CH.M.5	Putala Malla	Cha. Na. Pa.-8	28.67472	82.21717	1044	Ward 8
CH.M.6	Gorkha Gharti	Cha. Na. Pa.-8	28.67547	82.2197	1070	Ward 8
CH.M.7	Dhiraj Malla	Cha. Na. Pa.-8	28.67247	82.21522	1067	Ward 8
CH.M.8	Bimala Khadka	Cha. Na. Pa.-8	28.6703	82.21515	1050	Ward 8
CH.M.9	Roshan Jiyam	Cha. Na. Pa.-8	28.67047	82.21743	1099	Ward 8
CH.M.10	Rashiram B.K.	Cha. Na. Pa.-8	28.66675	82.25345	1010	Ward 8
CH.M.11	Binita Keshi	Cha. Na. Pa.-8	28.66278	82.21852	965	Ward 8
CH.M.12	Kalpana Regmi	Cha. Na. Pa.-8	28.65715	82.21755	832	Ward 8
CH.M.13	Hare Kami	Cha. Na. Pa.-8	28.6518	82.21712	751	Ward 8
CH.M.14	Tej B. Budha	Cha. Na. Pa.-8	28.65383	82.21742	745	Ward 8
CH.M.15	Sita Pun	Cha. Na. Pa.-4	28.64643	82.21912	763	Ward 4
CH.M.16	Bal B. Rana	Cha. Na. Pa.-10	28.62485	82.27032	920	Ward 10

Sample ID	Farmer name	Address (Tole/Ward, Rukum West)	Latitude	Longitude	Elevation (m)	Ward
CH.M.17	Gita Pun	Cha. Na. Pa.-10	28.62335	82.26942	974	Ward 10
CH.M.18	Janak Kumar Pun	Cha. Na. Pa.-10	28.6238	82.26717	958	Ward 10
CH.M.19	Mukesh Pun Magar	Cha. Na. Pa.-10	28.62452	82.27073	907	Ward 10
CH.M.20	Padme Rana	Cha. Na. Pa.-10	28.62557	82.27265	893	Ward 10
CH.M.21	Bishram Pun	Cha. Na. Pa.-10	28.6197	82.27573	907	Ward 10
CH.M.22	Parmali Rana	Cha. Na. Pa.-11	28.61962	82.2746	905	Ward 11
CH.M.23	Galbir Khatri	Cha. Na. Pa.-11	28.61707	82.28192	917	Ward 11
CH.M.24	Gagan Pun	Cha. Na. Pa.-10	28.6185	82.27827	911	Ward 10
CH.M.25	Nirmala Biyam	Cha. Na. Pa.-10	28.6173	82.28073	926	Ward 10
CH.M.26	Himalaya Ma. Vi.	Cha. Na. Pa.-11	28.62028	82.2797	914	Ward 11
CH.M.27	Khadka Prasad Wali	Cha. Na. Pa.-13	28.6138	82.28262	929	Ward 13
CH.M.28	Lal B. Wali	Cha. Na. Pa.-13	28.61225	82.2833	950	Ward 13
CH.M.29	Ratna K. Keshi	Cha. Na. Pa.-11	28.62008	82.27588	913	Ward 11
CH.M.30	Devi K. Khatri	Cha. Na. Pa.-11	28.62082	82.2757	921	Ward 11
CH.M.31	Lakshuman Keshi	Cha. Na. Pa.-11	28.62313	82.27487	929	Ward 11
CH.M.32	Yagya B. Wali	Cha. Na. Pa.-5	28.62375	82.27367	901	Ward 5
CH.M.33	Udayaram Wali	Cha. Na. Pa.-5	28.62602	82.27358	898	Ward 5
CH.M.34	Manjit Keshi	Cha. Na. Pa.-5	28.6284	82.27393	890	Ward 5
CH.M.35	Parvati Keshi	Cha. Na. Pa.-5	28.63332	82.2734	878	Ward 5
CH.M.36	Nim B. Keshi	Cha. Na. Pa.-5	28.63888	82.267	850	Ward 5
CH.M.37	Devika Gautam	Cha. Na. Pa.-5	28.63895	82.26368	853	Ward 5
CH.M.38	Damodar Dhakal	Cha. Na. Pa.-5	28.63952	82.25978	856	Ward 5

Sample ID	Farmer name	Address (Tole/Ward, Rukum West)	Latitude	Longitude	Elevation (m)	Ward
CH.M.39	Krishna Kumari Awasthi	Cha. Na. Pa.-5	28.64215	82.25445	332	Ward 5
CH.M.40	Manjit Rawat	Cha. Na. Pa.-5	28.62725	82.2597	887	Ward 5
CH.M.41	Dinesh Sharma	Cha. Na. Pa.-5	28.63972	82.25233	828	Ward 5
CH.M.42	Dukai Jaisi	Cha. Na. Pa.-5	28.63645	82.25047	224	Ward 5
CH.M.43	Gopal Wali	Cha. Na. Pa.-5	28.64262	82.24865	825	Ward 5
CH.M.44	Dalli B. Thapa	Cha. Na. Pa.-5	28.64275	82.24593	816	Ward 5
CH.M.45	Radha Nepali	Cha. Na. Pa.-9	28.64363	82.24417	813	Ward 9
CH.M.46	Putali Badhi	Cha. Na. Pa.-7	28.6429	82.24332	819	Ward 7
CH.M.47	Bhadra B. Bhandari	Cha. Na. Pa.-7	28.64143	82.24185	831	Ward 7
CH.M.48	Tek B. Khatri	Cha. Na. Pa.-7	28.63952	82.23885	796	Ward 7
CH.M.49	Sher B. Khatri	Cha. Na. Pa.-7	28.64073	82.23787	797	Ward 7
CH.M.50	Savitra Keshi	Cha. Na. Pa.-7	28.6403	82.23618	789	Ward 7
CH.M.51	Rishi Lamichhane	Cha. Na. Pa.-1	28.62905	82.20453	768	Ward 1
CH.M.52	Girij Lamichhane	Cha. Na. Pa.-1	28.62937	82.20385	770	Ward 1