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Research paper

Effect of Land Management on Soil Characteristics in Mid-Hill Regions of Bagmati Province, Nepal

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Abstract

The land management has a considerable impact on soil characteristics and quality that directly affects the production functions of an agricultural ecosystem, and the sustainability of the system. The comprehensive analysis of soil characteristics in relation to the land use patterns is very limited in Nepal. Therefore, the present work evaluated soil quality of agricultural and barren lands in the mid-hills of Nepal using Soil Quality Index (SQI). For this purpose, 32 composite soil samples were collected, and pH, electrical conductivity (EC), organic matter (OM), total Kjeldahl nitrogen (TKN), available phosphorus (AP), exchangeable potassium (K), and soil texture were measured using standard analytical procedures. The results revealed higher EC (380.93 ± 650.04 µS cm^{-1}), TKN (0.16 ± 0.12%), AP (554.30 ± 409.36 kg ha^{-1}), and K (361.41 ± 430.53 kg ha^{-1}) in the agricultural land. Although the agricultural land has slightly higher SQI, the higher EC and other nutrients may lead to the soil salinization and disruption of soil functions as compared to the barren land. Thus, sustainable agronomic approaches considering nutrients enrichment along with conservation of natural characteristics are crucial for soil stability in the mid-hill agroecosystem of Nepal.

Keywords: *Agricultural Land; Barren Land; Mid-Hill; Physicochemical Characteristics; Soil Quality Index.*

1. Introduction

Land management has a significant effect on soil quality, which in turn affects plant productivity, ecosystem health, and environmental quality [1 - 3]. In Nepal, mid-hill regions are characterized by high heterogeneity in soil conditions based on the different types of cultivation, fertility, and land abandonment [4], [5]. Agricultural lands are commonly treated with inorganic fertilizers and organic manure, which alter the chemical, physical, and biological characteristics [6]. On the other hand, unproductive or unused soil is often characterized by a lack of nutrients, soil erosion, and loss of organic soil [7], [8]. Thus, assessment of soil quality in various land applications is a key to sustainable land management [9]. Conventional approaches are based on measurements of individual parameters, including soil organic carbon, total Kjeldahl nitrogen, available phosphorus, pH, bulk density, cation exchange capacity, and aggregate stability [10], [11]. However, a composite measure like Soil Quality Index brings an integrated, and understandable measurement [11].

Agroecosystem resilience depends on the soil quality, which has an impact on the productivity of the agroecosystem, carbon sequestration, and environmental sustainability [12], [13]. In Nepal, agriculture is the main source of livelihood, where food security faces threats due to decreased soil fertility caused by soil erosion, intensive cultivation, and poor nutrient replacement [14], [15]. The mid-hill regions of Nepal are undergoing rapid land use transition, and agricultural growth and farmland abandonment are changing the characteristics of soil [16 - 18].

Soil health is the general term used to define the capacity of the soil to function as the vital system for the living organism [19]. There are a number of indices to measure soil health. Most common indices are Soil Quality Index (SQI) that combines physical, chemical, and biological indicators [20], [21], the Carbon Management Index (CMI) which measures the dynamics of organic carbon [22], [23], and the Nutrient Balance Index (NBI) that quantifies the ratios of macronutrients [24]. These indices have been used all over the world but are not sufficiently used in Nepal where site-specific challenges of soil degradation still exist [10], [25]. Previous studies in these areas indicated the effects of land use on the soil organic carbon and nutrient stocks [10], however, a few studies have used composite indices to determine overall soil functionality. This suggests that there are limited preceding works in the mid-hill regions of Nepal that have assessed soil health in the agricultural and barren lands using integrated indices. Thus, the present study was carried out with the aim of assessing the major physicochemical characteristics and soil health in the two mid-hill districts (Dhading and Kavrepalanchok) using SQI. The findings of this study may be useful for agriculture scientists, farmers, policy and decision makers, and different tier of governments for sustainable management of agroecosystem.

2. Materials and Methods

2.1. Study area

The research was carried out in two mid-hill districts encompassing four municipalities, i.e. Benighat Rorang and Dhunibesi from Dhading District, and Banepa and Panauti from Kavrepalanchok District of the Bagmati Province, Nepal (Figure 1). The study area ranges from 500 to 2,000 m above the sea level with rugged topography, subtropical and temperate climate, and heterogeneous land use, such as cropland, forest, grassland, and urban settlements [10]. The barren land was slopy with less vegetation coverage. The climatic parameters such as temperature and precipitation are increasing over the period of time which are also projected to increase in future in both the districts [26]. Dhading District is characterized by an alluvial and colluvial soils, which are usually loamy to sandy loam, with low levels of nitrogen and organic matter due to high rainfall and common erosion [10]. The rapid urban growth and intensification of land use in Banepa and Panauti of Kavrepalanchok District are also propelling to land degradation and loss of agricultural land [27]. The soil of the mid-hill regions shows higher variation in fertility depending on the land use, where forest soil generally has higher organic carbon and nitrogen than the intensive cultivated soil [28]. The land use and land cover (LULC) of Bagmati Province shows that the share of built up area and agricultural land has decreased significantly over the last two decades and requires systematic monitoring of the soil quality [29]. These varied environment and human-induced conditions suggest the selected study area to be ideal for assessing the effects of land management on soil quality following the integrated SQI approach.

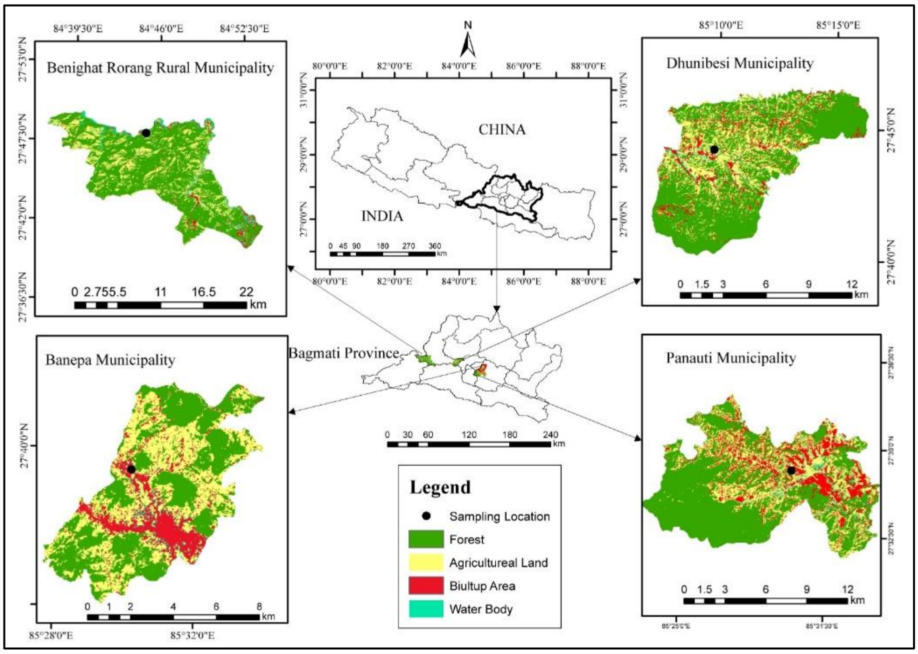

Fig. 1: Study Sites for Soil Health in Mid-Hills of Bagmati Province, Nepal.

2.2. Methods

2.2.1. Sample collection

The soil samples were collected in dry seasons (April and June, 2023; February, 2024) from agricultural and barren lands. A full factorial sampling strategy (2 districts x 2 municipalities x 2 locations x 2 quadrates x 3 samples) was applied while collecting samples [30]. Two quadrates of 5 m x 5 m were established in each location considering purposive sampling technique. Three triangle-shaped sampling plots were established in each quadrate for composite sample collection. Three samples were collected from each sampling point using the stainless steel soil auger (0–30 cm). The three samples were mixed together thoroughly to prepare a composite sample. The collected samples were packed immediately in air-tight zip-lock polyethylene bags and transported to the laboratory of the Central Department of Environmental Science, Tribhuvan University, Nepal. The pieces of stones, wood, grasses, and residual roots were removed from the collected samples and air-dried for 24 hours. The samples were crushed and sieved using 2 mm sieving mesh. The fine soil samples were then packed into air-tight zip-lock bags for laboratory analysis.

2.2.2. Physicochemical characteristics

The physical (soil texture) and chemical parameters (pH, EC, OM, TKN, AP, K) were measured for agricultural and barren lands using standard analytical procedures in the laboratory of the Central Department of Environmental Science, Tribhuvan University. The soil textures were determined with the help of Bouyoucos hydrometer method using hydrometer (ASTM 152H, Model 55, calibrated at 20 °C (68/68 °F), surface tension 55 mN m^{-1}) [31 - 33]. The soil electrical conductivity and pH were determined using a 1:5 soil–water suspension, where soil pH was measured with a glass-electrode pH meter (Milwaukee pH 55 PRO) calibrated using standard buffer solutions of pH 4.0 and 7.0 [34]. The soil organic matter was determined using Walkley and Black method [35]. Total Kjeldahl nitrogen was determined using the Kjeldahl digestion–distillation method [36 - 38]. The exchangeable potassium was determined using microprocessor-based flame photometer (model-1382/1385) [39]. The available phosphorus was determined using Bray and Kurtz No. 1 extraction method [40].

2.2.3. Soil quality index

The Soil Quality Index was determined by integrating the physical and chemical characteristics of the soil into a single quantitative measure of overall soil health [21]. Indicators such as pH, electrical conductivity, organic matter, total Kjeldahl nitrogen, available phosphorus, exchangeable potassium, sand, clay, and silt were selected for calculating the SQI. For this purpose, each soil indicator was transformed into a dimensionless score (S_i) using linear scoring functions by following the Andrews et al. [21], and Mukherjee and Lal [41]. The direction of scoring was determined by known soil quality relationship. The indicators with higher values associated with better soil function were normalized using a "more is better" function including EC, OM, TKN, AP, and K. However, pH was defined as an "optimum is better" function with the range of 6.0–7.0, as very low and very high pH values have negative effect on nutrient availability and microbial activity [21]. The "less is better" scoring method was used for soil texture (sand, silt, clay), although intermediate textures are known to use for better water retention and aeration [41]. The weights (W_i) assigned to the indicators were according to the relative contribution to overall soil fertility and function based on previously published weights for tropical and subtropical agroecosystems [20], [21]. The weights for the indicators (OM, TKN and AP) closely related to the plant productivity and biological activity were assigned higher. However, as textural components are more stable, they were assigned with lower weights. The weighted additive method was used to calculate the SQI using the following equation [41].

$$\mathrm{SQI} = \sum_{i=1}^{n}(Wi \text{ x } Si)$$

Where, W_i represents the assigned weight and S_i is the normalized score for the i^{th} soil parameter.
The t-test was used to compare the SQI between agricultural and barren lands. Furthermore, the correlation heat map was used to compare the relationship among analyzed soil physicochemical parameters.

3. Results and Discussion

3.1. Soil texture

The overall soil properties and productivity are the functions of soil nutrient and moisture contents, which are, in turn, affected by the soil texture. Therefore, the textural composition of both agricultural and barren lands of Dhading and Kavrepalanchok districts were assessed and presented in Table 1. In Dhading, sand content in agricultural land ranged from 63.35 to 80.02% (70.15 ± 6.62%), increasing slightly as compared to the barren land (62.35–84.02%; 72.78 ± 8.28%). A comparable trend was observed in Kavrepalanchok where sand content varied between 54.90 and 80.53% (68.72 ± 9.68%) in agricultural land, 54.90 and 77.90% (67.22 ± 9.54%) in barren land. The second dominant fraction was silt, which was widely spread in Kavrepalanchok (up to 41.33%) than in Dhading, with mean value ranges from 18.31 ± 4.86% to 26.07 ± 8.89%. Conversely, the clay content was very low throughout the sampling units (2.87–15.10%), with a mean value lower than 7.07% , but a little higher variance was found in barren land. These findings suggest that soils of the two districts have a similar composition of mostly coarse-textured soils with minimal fine fractions, and higher intra-site variability in Kavrepalanchok.

Table 1: Soil Textures of Agricultural and Barren Lands (%) in Dhading and Kavrepalanchok Districts

Textural Component	Dhading District				Kavrepalanchok District			
	Agricultural Land		Barren Land		Agricultural Land		Barren Land	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
Sand	63.35 - 80.02	70.15 ± 6.62	62.35 - 84.02	72.78 ± 8.28	54.90 - 80.53	68.72 ± 9.68	54.90 - 77.90	67.22 ± 9.54
Silt	14.50 - 28.20	21.94 ± 5.21	12.33 - 24.58	18.31 ± 4.86	16.27 - 41.00	25.38 ± 8.09	18.70 - 41.33	26.07 ± 8.89
Clay	5.15 - 9.45	6.88 ± 1.65	3.65 - 14.12	7.07 ± 4.05	2.87 - 13.43	5.90 ± 3.95	3.40 - 15.10	6.72 ± 4.54

The prevalence of sand has significant effects on the soil hydraulic and fertility properties where coarse textured soil is normally linked to high infiltration rates, low water holding capacity, and decreased cation exchange capacity. Contextualized in the mid-hill of the central Nepal, the current results show the existence of a significantly coarser soil texture in comparison to the previously published works. For example, the soils of Darechok, Chitwan (56.30%), Sarangkot, Kaski (42.60%), and Tilhar, Parbat (60.60%) have considerably lower sand fractions [42], and Daman-Palung, Makawanpur has 45.67% sand [42]. On the other hand, the record of previous research has relatively higher silt (44.00%) and clay content (18.49%), which indicates finer textured soils in comparison to the current research (Table 2).

Table 2: Soil Textures of Different Regions of Nepal (%)

District	Soil Textures (%, mean)			Reference
	Sand	Silt	Clay	
Kavrepalanchok	68.72	25.38	5.90	This study
Dhading	70.15	21.94	6.88	This study
Chitwan	56.30	32.00	11.70	[42]
Kaski	42.60	44.00	13.40	[42]
Parbat	60.60	24.00	15.40	[42]
Makawanpur	45.67	35.65	18.49	[43]

The relatively low clay content (<7%) in Dhading and Kavrepalanchok signifies that there is little soil structure development and physicochemical buffering capacity. Such a difference can be explained by site specific controls, such as lithological variability, erosional processes associated with slope, and the history of land use. Specifically, the fact that the variability of silt and clay fractions is slightly larger in barren land could be attributed to the selective nature of erosion, with smaller particles being selectively eroded and redistributed, thus increasing the spatial heterogeneity. These processes are highly recorded in weak mid-hill terrains, whereby anthropogenic unrest and topographic gradient interact to enhance soil erosion.

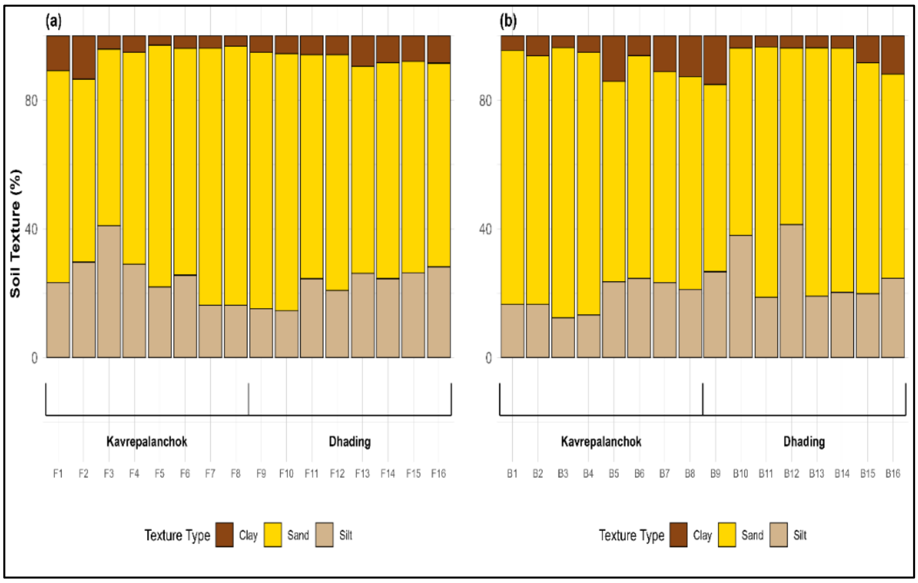

Fig. 2: Textural Distribution of the Soil (A) Agricultural Land; (B) Barren Land.

Most of the soils are sandy loam and loam in nature. The previous studies have also found that the soil textures of hilly regions are mostly sandy and loamy sand [42], [43]. The Wilcoxon rank-sum test revealed there is no significant change ($W = 133$, $p = 0.865$) in textural characteristics like sand, silt, and clay suggesting both agricultural and barren lands have similar soil textures (Figure 2). The textural distribution suggests that the general effect on the management of agricultural land seems to increase soil fertility, but not considerably change inherent soil texture [44].

The higher proportion of sand and lower proportion of clay fractions found in Dhading and Kavrepalanchok districts as compared to the other hilly districts (Kaski and Makawanpur) of Nepal are due to site specific geological and pedogenic conditions. The soils of Dhading are mainly alluvial and colluvial deposits that come from the quartzite, schist and phyllite of the Mahabharata range, which tends to have coarse soil texture [45], [46]. The weathering of these rocks occurs slowly and produces sandy, low clay soils against the finer textured soils of Terai. Besides, in the Banepa and Panauti sections of Kavrepalanchok District, the soils are affected by the lacustrine deposits from the paleo-Kathmandu lake basin where silt fractions might be slightly higher than Dhading. In addition, the sharp slopes in both the districts cause physical erosion leading to the loss of fine particles making soil more sandy [10], [14]. This results into low cation exchange capacity, water holding and buffering capacity against pH and nutrients fluctuations. This explains the high inter-sites variability among the chemical parameters.

3.2. Chemical characteristics

The physicochemical characteristics of the soils varied by district and land use types. The electrical conductivity, organic matter, nitrogen, phosphorus and potassium were higher in Kavrepalanchok as compared to Dhading (Table 3). The pH in Dhading was slightly acidic to nearly neutral (6.55 ± 0.35 in agricultural land; 6.80 ± 0.35 in barren land). However, soil in Kavrepalanchok was more acidic, especially in barren land (5.40 ± 0.80). By land use type, the EC value in agricultural land was very high in both the districts (Kavrepalanchok: 1,067.62 ± 665.50 µS cm^{-1}; Dhading: 157.64 ± 99.53 µS cm^{-1}) as compared to the Barren land (Kavrepalanchok: 109.75 ± 42.22 µS cm^{-1}; Dhading (32.70 ± 17.28 µS cm^{-1}) (Table 3). Likewise, in both the districts, agricultural land revealed higher nutrient contents as compared to the barren land due to nutrients input during farming activities.

Table 3: Chemical Characteristics of Agricultural and Barren Lands (Mean ± SD)

Physicochemical parameter	Unit	Dhading District Agricultural Land	Barren Land	Kavrepalanchok District Agricultural Land	Barren Land
pH	-	6.55 ± 0.35	6.80 ± 0.35	6.33 ± 0.49	5.40 ± 0.80
Electrical Conductivity	µS cm^{-1}	157.64 ± 99.53	32.70 ± 17.28	1,067.63 ± 665.50	109.75 ± 42.22
Organic Matter	%	2.36 ± 0.71	2.21 ± 0.71	5.28 ± 1.54	5.62 ± 1.02
Nitrogen	%	0.12 ± 0.05	0.12 ± 0.02	0.25 ± 0.14	0.14 ± 0.06
Phosphorus	kg ha^{-1}	419.55 ± 284.54	75.07 ± 52.32	862.74 ± 465.55	128.59 ± 51.61
Potassium	kg ha^{-1}	207.11 ± 309.51	101.74 ± 108.31	727.70 ± 450.26	441.47 ± 226.70

The comparative analysis of physicochemical characteristics between agricultural and barren lands (Figure 3, a–f) demonstrates that there are significant differences in soil fertility and nutrient contents. The soil pH was moderate to slightly acidic in both types of land, however agricultural land revealed less variation (5.53–7.13) as compared to the barren land (4.07–7.10). This can be attributed to sloppy land with less vegetation cover and possibility of cation leaching. Moreover, there could be liming and organic amendments in agricultural land that help to maintain soil pH.

In agricultural land, the EC was significantly higher (>2,000 µS cm^{-1}) than the barren land. This means, the soluble salts are more concentrated in cultivated soils, which is probably due to the excessive use of fertilizers and irrigation activities. These high EC levels have further been detected in highly managed soils in Sanga, Kathmandu where salinity is correlated to a high level of nutrient loading [5]. On contrary, low EC of barren soil indicates low nutrient inputs which supports biological activities. The agricultural soils with higher EC and nutrient contents may cause high variance and inconsistent correlation between physicochemical parameters suggesting decoupling natural functioning in the agroecosystem [47], [48]. Furthermore, the frequent use of chemical fertilizers can increase EC which may cause reduced microbial diversity and enzymatic activities [49].

There was a consistent increase in the levels of macronutrients (N, P, K) in agricultural soils as compared to the barren land that illustrates how land use impacts the soil fertility. Nitrogen concentrations in agricultural land (mean, 0.16 ± 0.12%) were higher than those of barren land (mean, 0.12 ± 0.05%). These differences show that there is spatial heterogeneity in the availability of nitrogen, which may be affected by the level of cropping and the presence of organic matter. Nevertheless, the concentrations of nitrogen in this present study are higher than those in Palung, Makawanpur (0.22 ± 0.01%) [43], and Sanga, Kathmandu (0.22 ± 0.01%) [5], implying that the soil has enriched with the nitrogen content.

The level of phosphorus in the soils of agricultural land (usually >500 kg ha^{-1}) was much higher in comparison with the barren land (<200 kg ha^{-1}), which pointed accumulation of phosphorus under the influence of long-term fertilizer use. The phosphorus level at Kavrepalanchok (862.74 ± 465.55 kg ha^{-1}) and Dhading (419.55 ± 284.54 kg ha^{-1}) are higher as compared to other areas, whereas the lower value of phosphorus (545.82 ± 122.12 kg ha^{-1}) has been reported in Sanga, Kathmandu, and also in the Putalibazaar, Syangja (44.60 ± 3.50 kg ha^{-1}) [5], [50]. This difference underscores the contribution of site-specific management activities and parent material to regulate phosphorus availability.

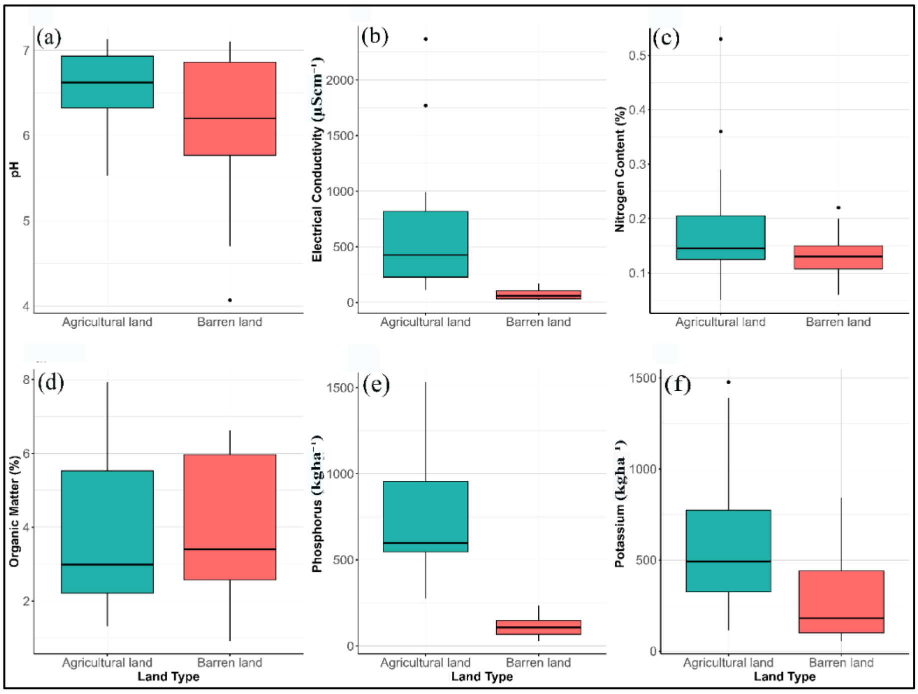

Fig. 3: Chemical and Fertility Profile of the Agricultural and Barren Lands.

In the same way, the concentration of potassium in agricultural soil was higher with a significant variation (up to 1,500 kg ha^{-1}) and barren soil has lower values consistently (Table 4). The average potassium level in Kavrepalanchok (727.70 ± 450.26 kg ha^{-1}) was also more than Dhading (207.11 ± 309.51 kg ha^{-1}), which indicated regional variations in the soil fertility. In comparison with other studies, the concentration of potassium in the study area is lower than Sanga, Kathmandu (1,411.78 ± 222.34 kg ha^{-1}) but higher than in Palung, Makawanpur (194.80 ± 140.08 kg ha^{-1}) and Putalibazaar Syangja (261.30 ± 66.80 kg ha^{-1}) [5], [43], [50]. The potassium variability could be explained by variations in mineral weathering, fertilizers and crop uptake. The organic matter also confirms the evident trends in nutrients with agricultural soils exhibiting comparatively less stable than the barren land. This is a sign of better soil structure and retention capacity of nutrients in the cultivated regions through the incorporation of the organic residues and manure. Conversely, soils in barren land, which have no vegetation cover and organic matter, have higher chances of nutrients deficit due to erosion and leaching. Additionally, the climate-induced drought and monsoon variability may enhance nutrient leaching in sandy soils under the present climate scenarios [26].

Table 4: Macronutrients in Agricultural Soil of Different Regions of Nepal

Place/District	Macronutrients (mean ± SD)			Reference
	Nitrogen (%)	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	
Kavrepalanchok	0.25 ± 0.14	862.74 ± 465.55	727.70 ± 450.26	This study
Dhading	0.12 ± 0.05	419.55 ± 284.54	207.11 ± 309.51	This study
Palung, Makawanpur	0.22 ± 0.01	461.16 ± 171.22	194.80 ± 140.08	[43]
Putalibazaar, Syangja	0.07 ± 0.03	44.60 ± 3.50	261.30 ± 66.80	[50]
Sanga, Kathmandu	0.22 ± 0.01	545.82 ± 122.12	1,411.78 ± 222.34	[5]

The correlation heatmap of physicochemical parameters revealed interrelations among the soil parameters in both the agricultural and barren lands (Figure 4). In both land use types, organic matter showed strong positive correlations with electrical conductivity and potassium. However, the strength of these correlations varies between two land use types. Similarly, nitrogen showed a weak positive correlation with OM in agricultural land while it has strong positive correlation in barren land. In contrast, pH and OM are negatively correlated. These findings suggest that nitrogen, potassium and phosphorus tend to increase with the increase in organic matter in acidic environment. The correlation between pH and EC in both the land use types reflects fundamental principle of soil chemistry, where dissolved ions increase EC and pH in soils [51]. Overall, the higher EC values observed in agricultural land (380.93 ± 650.04 µS cm^{-1}) as compared to the barren land (57.88 ± 49.26 µS cm^{-1}) indicate salt accumulation resulting from agricultural inputs such as fertilizers and pesticides. This also contributes to elevate soil salinity associated with agricultural intensification [52].

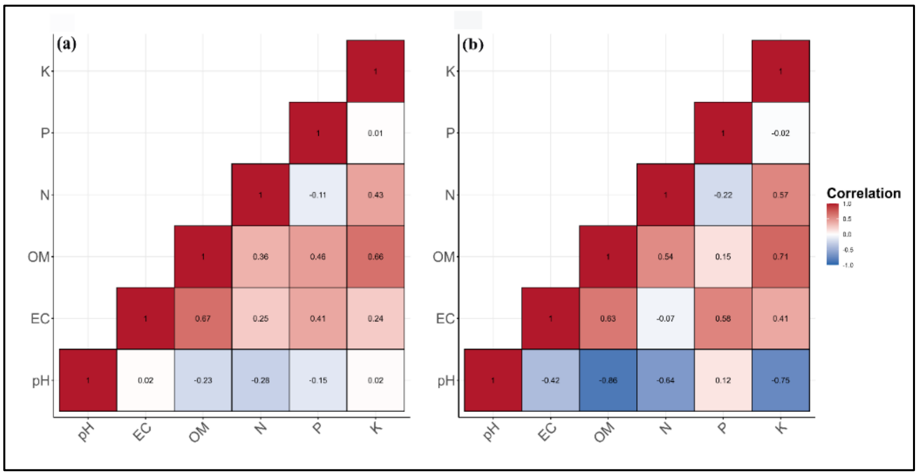

Fig. 4: Inter-Relation between Physicochemical Characteristics in Different Land Uses (A) Agricultural Land; (B) Barren Land.

3.3. Soil quality

Both Kavrepalanchok and Dhading districts revealed a clear variation in their SQI values with the land use types (Figure 5). According to the classification criteria of the thresholds, low (SQI < 0.55), intermediate (0.55 ≤ SQI ≤ 0.70) and high (SQI > 0.70) [53]. In both the districts, the SQI values of agricultural land range between 0.42 and 0.81 with seven sites (F1, F11-F16) in low category, eight sites (F2, F4-F10) in intermediate, and one site (F3) in high category (Figure 5a). These results show most of the soils of agricultural land belongs to low to intermediate categories. Similarly, the SQI values of barren land range from 0.46 to 0.64 with eleven sites (B5-B9, B11-B16) in low and five sites (B1-B4, B10) in intermediate categories (Figure 5b). By districts, Kavrepalanchok exhibits relatively good soil quality as compared to the Dhading. However, the SQI values between the agricultural (0.616) and barren land (0.578) are not significantly different (t = 1.10, df = 30, p = 0.28). The better SQI in agricultural land may be due to the small effect of Cohen's value, d = 0.39.

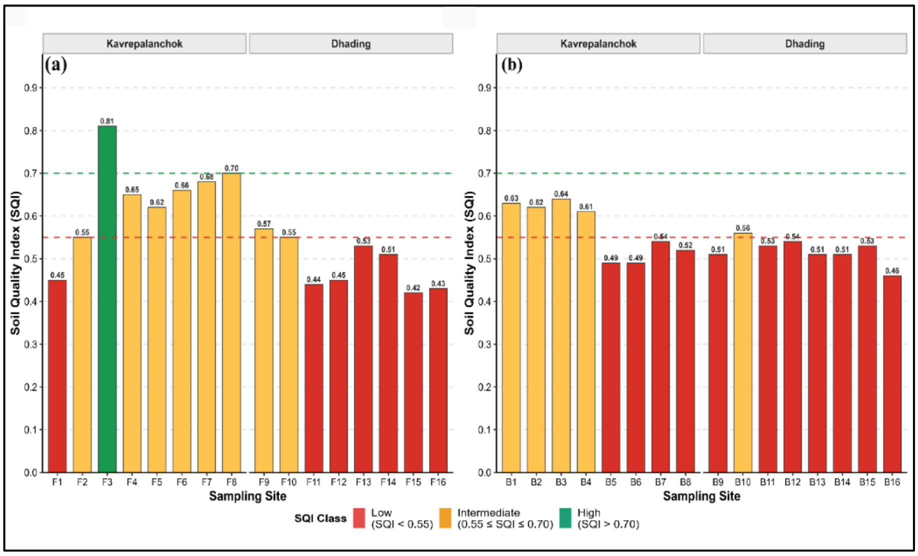

Fig. 5: Soil Quality Index Under the Different Land Uses (A) Agricultural Land (Kavrepalanchok: F1-F8; Dhading: F9-F16); (B) Barren Land (Kavrepalanchok: B1-B8; Dhading: B9-B16).

4. Conclusion

The soils of Dhading and Kavrepalanchok districts are mostly sandy in both the agricultural and barren lands. Although, there is no significant difference in SQI between the land use types, the agricultural land with higher EC and enriched nutrients like nitrogen, phosphorus and potassium reflects the influence of fertilizers and other chemical inputs making the soil prone to salinization. The present study classified soils based on the SQI value which used only physicochemical characteristics of limited spatial coverage. However, biological, ecological, and hydrological aspects of soil also play an important role in soil quality determination. Thus, further extensive research is required to be carried out with due consideration of biological, ecological, and hydrological aspects covering wider spatial range.

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Conflict of Interest

Authors declare that there is no conflict of interest for the publication of this manuscript.

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