

Original Research

Mapping of Soil Properties under Different Land Uses in Lesser Karakoram Range, Pakistan

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Abstract

The vulnerability to environmental changes requires appropriate management of mountainous soils to harmonize agriculture productivity and health of agro-ecosystem. Information on spatial analyses in land uses is important for site-specific nutrient management. The current study investigates and maps soil properties in two land use types (agriculture and orchard) through geostatistical analyses of selected parameters using Inverse Distance Weighting (IDW). Geo-referenced soil samples were collected at 0-15 cm depth. Overall, silty loam soils were observed with slightly alkaline pH, normal electrical conductivity and adequate organic carbon in both land use types. Macronutrient results indicated that nitrate-nitrogen was medium while phosphorus and potassium were higher in both land uses. The two-way ANOVA indicated that the EC ($p < 0.05$), $\text{NO}_3\text{-N}$, Av. P and Ex. K ($p < 0.001$) differed significantly across the land use types. Whereas with respect to various study locations the EC and Av. P differed significantly ($p < 0.01$), while pH, SOC, $\text{NO}_3\text{-N}$, Ex. K and saturation did vary. Higher Soil quality index (SQI) in agriculture soil indicating better quality or health than the orchard. The findings provide useful insights for soil fertility management in mountainous agro-ecosystems.

Keywords: fertility management, Karakoram, land use, spatial analyses, Soil Quality Index

Introduction

The interactions of soil chemical, physical and biological properties define a particular soil's quality and determine how effectively the soil performs ecosystem functions [1]. The anthropogenic conversion of forest and rangelands into agricultural lands greatly alter ecological functions of soils. Fertility and quality of soil also depend upon the cropping system and farming practices, which affect the fertility quality and yield production [2]. Constant tillage in soil and the use of diverse agro-chemicals has severe effects on soil biodiversity and its habitats [3]. For assessment of soil quality, scientists have proposed some parameters such as Soil organic carbon (SOC), soil pH, nitrate-nitrogen ($\text{NO}_3\text{-N}$), available P (Av. P), exchangeable K (Ex. K) and electrical conductivity (EC) [4-6]. Soil organic matter (SOM) has positive effects on soil chemical and physical properties as it plays a role in the supply of SOC and is the main energy source for the soil microorganism to perform their biological soil practice [7].

Geospatial tools and techniques are increasingly in use by soil scientists to map soil properties across wide ranges of geographic and topographic region. Such mapping is important for land use planning, fertility management, better yields and sustainable agro-ecosystem management. The maps generated through the geostatistical analysis also help in the monitoring of the nutrient status of soil [8]. Spatial analysis of soil properties provides information about nutrient availability and its management, which will help in the application of fertilizer use in the area. It is also beneficial for farmers to get more crop yields [9].

Land cover is one of the most important data used to demonstrate the effects of land use changes, especially human activities. Production of land use maps can be done by using different methods on satellite images. Some studies have produced land cover maps of the controlled classification technique over Landsat satellite imagery. By using land cover maps, the changes in urban development and green areas over time have been evaluated. At the same time, the relationship between changes in the land cover over time and changes in the urban population has been examined. Agriculture planning has many benefits in terms of the environment. Agricultural landscape planning means making decisions about the future situation of agriculture land. In this case, it is necessary to predict how the land has changed over time and the effects of natural factors and human activities on the land. In this way, successful and sustainable landscape planning studies can be accomplished [10-14]. Different land use type has a deep effect on SOC storage because it affects the amount and quality of litter input, decomposition rate, and stabilization of SOC [15]. Nitrous oxide (N_2O) is a major greenhouse gas produced from these factors [16] which also affects ozone [17].

Land use change practices have a great effect on the distribution and supply of soil nutrients. SOM gains or

losses in a short time is difficult to measure because of a large amount of organic matter in soils and spatial analysis of soil, especially in forest soils. Such kind of changes in soil properties lead to soil erosion [18]. Land use changes have major effect on the diversity and the amount of biomass returned to the soil, which also disorders the richness of nutrients restored to the soil. The change in forest cover to other forms of land such as grasslands and plantation results in great variation of canopy cover, this affects the supply of SOC, due to change in soil temperature and moisture regimes [19].

Population growth and economic factors are the two main forces behind the demand for food production, crop production and fertilizers use in Nepal [20]. [21] Reported that OM in forest and pastures is higher than arable land in Bagrot valley, Gilgit, Pakistan. Due to the higher use of animal dung and green manure, chemical properties like SOC and $\text{NO}_3\text{-N}$ was found higher in Shiskat valley [22]. According to [22] the SOC and fertility status in Altit valley was ideal due to the use of organic fertilizers. There was a great variation in the SOC content in different forest catchments of Bagrot forest [23].

Mountainous landscapes have serious problems of soil degradation and in the last few years, the problem has been escalating due to the increase in population growth leading to land scarcity in the fragile mountains. With increase in population, human settlements on slopes, overgrazing and deforestation natural habitats have depleted. Mountainous soils are vulnerable to environmental changes; therefore, their fertility management is essential to enhance agricultural productivity and sustain agro-ecosystems [23, 24]. The present study seeks to investigate and map soil properties under different land use types across different geographic locations at a selected site in Karakoram Mountain of northern Pakistan.

Objects and Method

Study Area

Gilgit-Baltistan (GB) encompasses between $35^\circ\text{-}37^\circ\text{N}$ and $72^\circ\text{-}75^\circ\text{E}$ of Pakistan bordering with China through Xinxiang province. It has mountainous landscape elevation ranging between 1500 m-4,500 m sea level and the place where world three famous mountain ranges Hindukush, Himalaya and Karakoram meet. It covers an area of 72496 km^2 , with approximately 1.5 million people, with the density of 10 persons/ km^2 . About 0.96% of land is cultivable whereas, approx. 60,000 hectares is barren, which could be cultivable land if irrigation available and the rest is comprised of mountains, rangeland, lakes/rivers and forests etc [25]. The study area comprised of two villages of Karakoram mountains in northern Pakistan, namely Jalalabad and Oshikhandas, located at the elevation of 1503 m and 1475 m having latitude and longitude of 35.8815° ,

74.498°, and 35.8846°, 74.4649°, respectively (Fig. 1). The major land use types in the investigated area are cultivated cropland, orchards, forest plantation at the hill slope and barren land where irrigation is not possible. The natural vegetation of Jalalabad and Oshikhandas consists of trees, grasses and bushes. The major dominated tree species in the study area are willow (*Salix* spp), poplars (*Populus* spp), mulberry (*Morus* spp), apricot (*Prunus* spp), and Russian olive (*Elaeagnus* spp). The farming system in both the villages are mixed type, which comprises of crop production and livestock rearing. Crop residues and leaf litter used for livestock bedding that undergoes composting along with animal dung, which is later applied to agriculture land as cattle manure. Both villages have snow and glacial fed irrigation system and network of channels to the agriculture land. The areas fall in double cropping zone and grow wheat and maize as major crop, further, they produce vegetables such as potato, mustard, pulses, beans, onion, cabbage and tomato in summer. Cattle manure along with chemical fertilizers are applied in agriculture land once in the month of December and January. The community use both tractor and traditional ox plowing to prepare the lands for cultivation.

Sampling and Analysis

Eighty soil samples were randomly collected from two land use types (40 * 2 = 80 agriculture and orchards). Samples were collected from a depth of 0 to 15 cm with the help of small spade and hand trowel. The samples were air-dried and passed through a 2 mm sieve for further laboratory analysis. pH was measured through a pH probe by 1:1 (soil: water) suspension with OAKTON PC 700 meter [26]. EC was measured by 1:5 (Soil: water) with Milwaukee EC meter (SM 302) [27]. SOC was measured by dry combustion method [28, 29]. Saturation % was determined as described by [30]. Fertility status of soil NO₃-N, P, K was determined

by Ammonium bicarbonate diethylene triamine penta acetic acid (AB- DTPA) extractable method [31]. Interpolation with Inverse distance weighting (IDW) in ArcGIS 10.3 was selected for mapping in this study [8]. IDW is used when sampling points are separated by large distances. Soil Quality Index (SQI)

The method was adapted from [32] and [33]. All the SQI values of each parameter of their ranges are summed to get a total SQI [32].

$$\text{Total SQI} = \sum \text{individual soil properties index values.}$$

The total SQI is then expressed as a percentage of the maximum possible value of the total SQI for the soil properties that are measured by using following equation.

$$\text{SQI}\% = \frac{\text{Total SQI}}{\text{maximum possible total SQI for properties measured}} \times 100$$

Statistical Analysis

Two-way factorial ANOVA was applied to find any significant variation in soil quality between locations and among land uses. Pearson's correlation test was applied to determine the relation between investigated soil properties. Statistical analysis was performed using SPSS 20.

Results and Discussion

Influence of Location and Land Use Change on Soil Physio-Chemical Properties

EC ($p < 0.05$), NO₃-N, Av. P and Ex. K ($p < 0.001$) differed significantly across the land use types. With respect to locations EC and Av. P differed significantly ($p < 0.01$), ($p < 0.001$) whereas pH, SOC, NO₃-N, Ex.

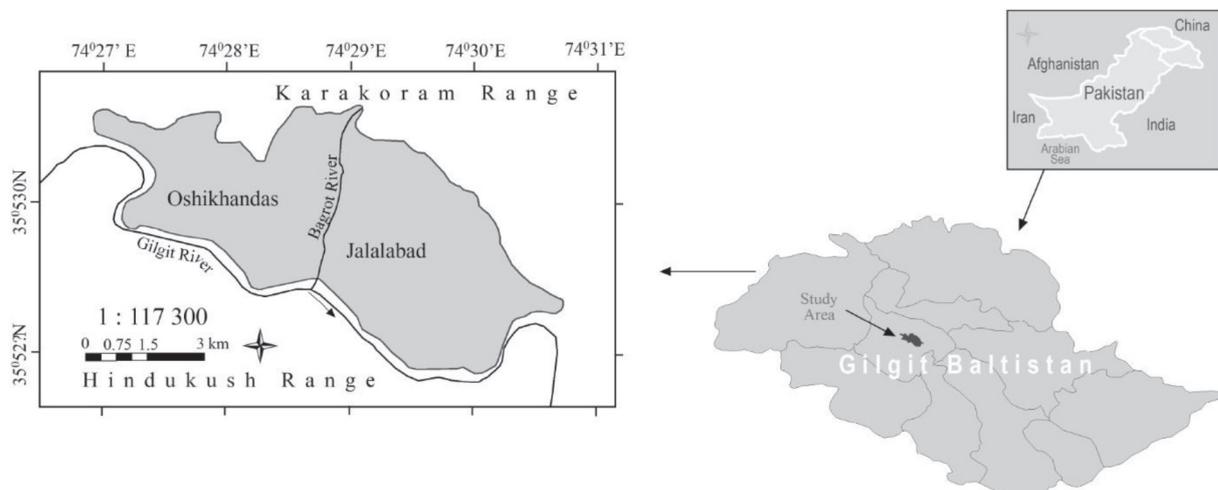


Fig. 1. Location map of Jalalabad and Oshikhandas.

Table 1. Two-way Factorial ANOVA of relevant parameters by land use and location.

	pH	EC	SOC	NO ₃ -N	Av. P	Ex. K	Saturation
Location	.633 ^{ns}	.009 ^{**}	.667 ^{ns}	.200 ^{ns}	.000 ^{***}	.461 ^{ns}	.435 ^{ns}
Land Use	.210 ^{ns}	.026 [*]	.270 ^{ns}	.000 ^{***}	.000 ^{***}	.000 ^{***}	.846 ^{ns}

Note: *, **, ***, & “ns” indicate p<0.05(5%), p<0.01(1%), p<0.001 and “ns” non-significant respectively

Table 2. Comparative soil properties among agriculture and orchard (land uses).

Land Use	Variable	Unit	Mean	S.D.	Min	Max	Variance	Skew	Kurt
Agriculture	pH		7.75	.12	7.50	7.90	.015	-.687	-.016
	EC	mS/cm	1.17	.24	1	1.50	.060	.681	-1.71
	SOC	%	2.64	1.30	.83	4.97	1.71	.549	-1.024
	NO ₃ -N	ppm	19.47	2.61	12.97	24.67	6.84	-.561	1.009
	Av. P	ppm	16.62	3.38	10.46	21.73	11.46	-.130	-.030
	Ex. K	ppm	360.90	61.36	252	468	376	-.119	-.538
	Sat	%	40.05	3.60	35	48	12.99	.621	-1.199
Orchard	pH		7.69	.19	7.30	7.90	.037	-.690	-.860
	EC	mS/cm	1.47	.52	1	2.50	.276	1.01	.068
	SOC	%	3.04	.93	1.29	4.42	.875	-.223	-.784
	NO ₃ -N	ppm	13.16	2.46	9.17	13.40	6.09	.082	-.896
	Av. P	ppm	10.07	4.49	4.43	17.71	20.16	.475	-1.176
	Ex. K	ppm	252.40	50.40	192	374	254	.993	.796
	Sat	%	40.25	2.80	35	45	7.88	-.491	-2.269

Min: minimum value; Max: maximum value; S.D.: standard deviation; Skew: skewness; Kurt; Kurtosis

Table 3. Comparative soil properties among Jalalabad and Oshikhandas (locations).

Location	Variable	Unit	Mean	S.D.	Min	Max	Variance	Skew	Kurt
Jalalabad	pH		7.71	.17	7.30	7.90	.029	-1	.409
	EC	mS/cm	1.50	.51	1	2.50	.263	.975	.112
	SOC	%	2.92	1.33	.83	4.97	1.79	.061	-1.4
	NO ₃ -N	ppm	17.14	4.66	9.17	24.67	21.79	-.377	-.973
	Av. P	ppm	10.29	4.54	4.43	19.92	20.65	.409	-.846
	Ex. K	ppm	297	79.19	192	468	627	.395	-.632
	Sat	%	40.55	2.79	35	45	7.83	-.219	-.474
Oshikhandas	pH		7.73	.15	7.40	7.90	.024	-.835	-.421
	EC	mS/cm	1.15	.23	1	1.50	.055	.945	-1.24
	SOC	%	2.76	.93	1.29	4.42	.869	.120	-.809
	NO ₃ -N	ppm	15.48	3.26	10.12	20.56	10.64	.190	-1.22
	Av. P	ppm	16.40	3.73	9.66	21.73	13.92	-.518	-.602
	Ex. K	ppm	315.90	77.78	196	452	604	.280	-1.16
	Sat	%	39.75	3.56	35	48	12.72	.614	.158

Min: minimum value; Max: maximum value; S.D.: standard deviation; Skew: skewness; Kurt; Kurtosis

K and saturation did not vary across the locations (Table 1).

Soil pH was slightly higher in agriculture (Table 2) while with respect to the location it was found to be slightly higher in Oshikhandas (Table 3). Mapping of pH by GIS technique showed that above 83.16% area contained pH concentration of agriculture in the range of 7.63-7.81; while in orchards 62.9% area fall in ranges of 7.63-7.81 (Fig. 2). Soil pH is the sign of acidity and alkalinity in the soil, the availability of nutrients to plants depends upon it [6, 34]. The majority of the soil nutrients are present in slightly acidic soils as compared to neutral and alkaline soils. The

mean soil pH of two land use types in Jalalabad and Oshikhandas showed a slight variation. pH was slightly alkaline in nature; this may be due to an accumulation of soluble salts, classified as alkaline soil [35]. Soils in agricultural and orchards slightly varied pH, possibly due to the presence of different nutrient cycling and slightly different vegetation cover [36]. Soil EC is higher in orchards as compared to agriculture (Table 2); it is higher in Jalalabad as compared to Oshikhandas (Table 3). Mapping of EC by GIS technique showed that about 76.21% of the agriculture area contains EC in the range of 1.15-1.35 mS/cm; while in orchards, 77.42% area contains the range of 1.15-1.60mS/cm (Fig. 2).

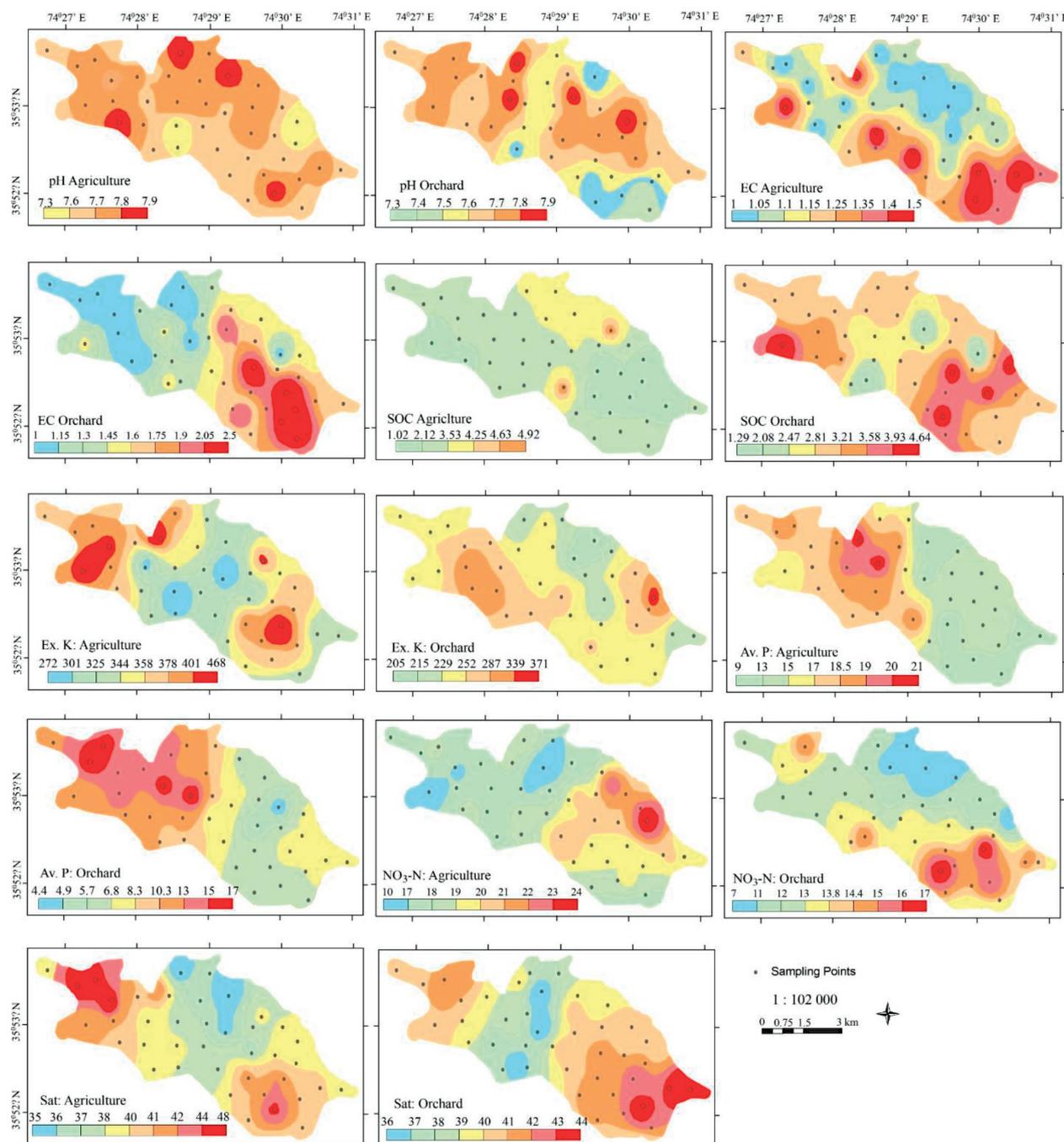


Fig. 2. IDW maps of pH, EC, SOC, NO₃-N, Av. P, Ex. K and saturation in both land uses and locations.

Pearson's correlation indicated that EC was significantly correlated with Av. P ($p < 0.01$), Ex. K ($p < 0.05$) and soil saturation ($p < 0.05$) (Table 4).

EC is an important indicator of soil health and is a measure of different salts in soil that affects the crop yields [37]. Mean Soil EC in Jalalabad orchards was higher as compared to agriculture, this could be attributed to high $\text{NO}_3\text{-N}$, SOC and base saturation in the soil [35]. One major reason for increasing salts in cultivated lands is due to the use of chemical fertilizers [38]. The mean readings of both soils are 1.4mS/cm, which indicates the soil is good in the form of nutrient availability and microbial activity, which helps plant growth. SOC is higher in the orchard as compared to agriculture (Table 2) while it is higher in Jalalabad as compared to Oshikhandas (Table 3). Spatial analysis of SOC showed that above 73.9% area contains SOC concentration of agriculture in the range of 2.12-4.62% while in orchards 65.41% area contains SOC concentration in the range of 3.57- 5% (Fig. 2). SOC is the main resource of energy to the microorganisms present in soil and also affects nutrient availability and the soil health also depends upon it [39], and used to mitigate consequences of climate change [40]. A higher amount of SOC content in orchards may be due to the maximum amount of litter fall and its decomposition as it was noticed during soil sampling. The amount of soil organic carbon content depends upon the organic matter presents in soil [41]. SOC in agriculture was normal in range; it can be affected by use of fertilizers and animal manure that can increase the SOC levels [42, 43]. Another reason may be due to the agricultural management and rotation of the crops in the fields including maize, wheat and potato, which affects the accumulation rate of SOC. The farming management system and soil type also have a great influence on SOC content [44].

$\text{NO}_3\text{-N}$ was higher in agriculture as compared to the orchard (Table 2) while it was higher in Jalalabad as compared to Oshikhandas (Table 3). Spatial analysis of $\text{NO}_3\text{-N}$ showed that above 65.89% area contains $\text{NO}_3\text{-N}$ concentration of agriculture in the range of 16.95-20.55 ppm; while in orchards, 60.47%

area contains $\text{NO}_3\text{-N}$ concentration in the range of 10.98-13.89 ppm (Fig. 2). Nitrogen was applied in the form of ammonium nitrate in agriculture and is an important indicator that is used for the evaluation of soil fertility [45]. Decay and accumulation of leaf litter in orchards due to trees could have possibly resulted in high fertility in the orchards [46], while in agriculture it may be due to the application of commercial fertilizers and animal manure. As both agriculture and orchards fall in the medium category of soil fertility levels. The amount of $\text{NO}_3\text{-N}$ in agriculture was slightly higher than orchards. Forest and grasslands store the maximum amount of SOC and nitrogen [47]. From geographical perspective [22] found higher results of $\text{NO}_3\text{-N}$ in agriculture soil of Altit valley Hunza, while [35] held that Gilgit soils are deficient of nitrogen having 0.08% only.

Av. P was significantly higher in agriculture as compared to orchards (Table 2) while it was significantly higher in Oshikhandas as compared to Jalalabad (Table 3). Spatial analysis of Av. P showed that about 60.03% area contains its concentration of agriculture in the range of 13.75-18.56 ppm; while in orchards, 52.06% area contains phosphorus concentration in the range of 5.75-10.33 ppm (Fig. 2). Pearson's correlation indicated that Av. P was highly correlated with EC ($p < 0.01$), $\text{NO}_3\text{-N}$ ($p < 0.01$) Ex. K ($p < 0.01$) (Table 4). Due to the use of fertilizers, the phosphorus accumulates in the surface of the soil in cultivated lands. One major reason for the higher values of Av. P in agriculture is due to the use of commercial fertilizers [22]. Agricultural phosphorus properly falls in the high category having a mean 16 ppm; which means that the soils of both villages have the required amount of Av. P, which is suitable for crop growth. Good enough amount of Av. P in agriculture may be due to the application of synthetic fertilizers and animal manure while in orchards it may be due to decay of leaf litter and organic matter [22], who reported similar results of Av. P in Altit valley of the Karakoram Range in Gilgit.

Ex. K was also significantly higher in agriculture as compared to orchards (Table 2) while it was higher in Oshikhandas as compared to Jalalabad (Table 3).

Table 4. Pearson's correlation among measured soil properties.

	pH	EC	SOC	$\text{NO}_3\text{-N}$	Av. P	Ex. K	Sat
pH	1						
EC	-.180	1					
SOC	.074	.038	1				
N	.029	-.139	-.158	1			
Av. P	.144	-.492**	-.167	.426**	1		
Ex. K	.189	-.315*	-.219	.522**	.495**	1	
Sat	.092	.354*	-.241	.086	-.062	.151	1

* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01 level (2-tailed)

Spatial analysis of Ex. K showed that about 53.89% area contains its concentration of agriculture in the range of 325.27-378.36 ppm; while in orchards 83.52% area has a concentration in the range of 215.04-287.07 ppm (Fig. 2). Pearson's correlation indicated that Ex. K was significantly correlated with EC ($p < 0.05$), $\text{NO}_3\text{-N}$ ($p < 0.01$) and Av. P ($p < 0.01$). $\text{NO}_3\text{-N}$ was highly correlated with Av. P ($p < 0.01$), Ex. K ($p < 0.01$) (Table 4). Soil Ex. K was higher in agriculture than orchards. [7, 25] also noted similar findings of higher $\text{NO}_3\text{-N}$, Av. P and Ex. K in agriculture soil than the other land uses reported in Karakoram soils of Gilgit-Baltistan. [34] Also reported similar concentrations of potassium in forest and farmlands in Ethiopia. Good enough amount of Ex. K in agriculture may be due to the use of fertilizers while in orchards it may be due to the relative pumping of potassium from the subsoil by the vegetation in the orchards [34]. The current concentration of potassium in both land uses is good enough for soil fertility. [48] Observed a decrease in potassium concentration as the growing season progresses from summer to autumn. Soil texture controls the presence of nutrients in the soil, its water holding capacity also depends upon it [8]. Saturation percent has around the same percentage in both agriculture and orchard (Table 2) while on location it has the same results as land uses (Table 3).

The percentage of stones in the soil profile of agriculture and orchards is 1-2% and 5-6% respectively. The depth of soil respect to bedrock varied in both sites, being a mountainous region and the soil depth solely depends on the land formation and deposition of soil is different in different sampling locations so the average soil depth is 3-6m. Spatial analysis of Sat. percentage showed that above 71.60% area contains soil saturation of agriculture in the range of 37.64-42.67%;

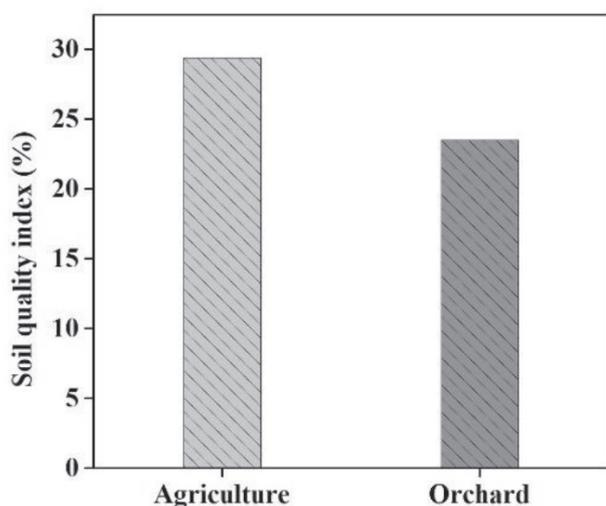


Fig. 3. Variation of soil quality index (SQI) in agriculture and orchards.

while in orchards 68.28% area contains soil saturation in the range of 39-43% (Fig. 2). Pearson's correlation indicated that saturation was positively correlated with EC ($p < 0.05$) as expected (Table 4). In the present study, the range of the soil saturation varied from 35%-48%. The textural class of Gilgit soil varied from silt loam to silt clay [35]. Similar results were found by [22, 23] in different sites of Gilgit Baltistan.

Soil Quality Index (SQI)

SQI is used to examine the status of soil quality in both land uses. The average SQI values of agriculture and orchards are 29.41% and 23.49% respectively (Fig. 3). It is evident that there is an increase of 5-6% in the soil quality in agriculture soil as compares to orchards, possibly attributed to the application of cattle manure along with chemical fertilizers. [33] Suggested that soil pH and organic matter has a great influence on the SQI yield. Soil EC and texture also had a great influence on the soil quality, as the texture of the area is silty loam; both the parameters are not considered in this SQI.

Conclusions

From the results, it is concluded that soil in both land uses is slightly alkaline in nature, silty loam with adequate SOC and good enough concentration of macronutrients. Higher soil quality index in agriculture soil showed better soil health compared to that in orchards. Spatial distribution maps developed through the IDW tool in GIS will be helpful for the policy makers and land manager in designing policy or taking fertility management decision for sustainable management of agro-ecosystem. Further research is required to understand the sustainable crop intensification on soil properties considering soil biodiversity and carbon stock under different cover crop for the sustainable management of agro-ecosystem and food security in the mountainous landscape.

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Conflict of Interest

The authors declare no conflict of interest.

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