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Assessment of the Sustainability of Land Use Systems through Sensitive Indicators of Soil Quality and Biophysical Properties in Temperate Ecosystem

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GOOD SOIL can raise the quantity and quality of food. However, the land quality has worsened due to various anthropogenic activities. The present study aimed to assess the effects of land use systems on soil quality over time through specific indicators. A top 30 cm soil sample from six land uses (forest, pasture, orchard, vegetable, maize, and paddy) was analyzed for soil quality index using Principal Component Analysis. The results revealed the highest organic carbon (20.94±1.85 g kg^{-1}), N (537.50±16.7 kg ha^{-1}), and P_2O_5 (36.51±1.62 kg ha^{-1}) in paddy-based land uses while the minimum OC (8.63±1.23 g kg-1), N (290.30±1.8 kg ha^{-1}) and K_2O (201.36±6.2 kg ha^{-1}) respectively with lowest P2O5 (24.22±1.21 kg ha-^{1}) in maize. The forest system showed dense macrofauna (1498 ind. m-2). The microbial population was found in the order of paddy>maize>vegetable>apple>pasture>forest. Particle size distribution of studied land uses varied from silty loam to clay loam. The following order of soil quality: forest>pasture>apple >vegetable>maize>paddy was found after the indexing procedure. It is concluded that further extension and turning of natural forests to agriculture will lead to a more significant loss of stored carbon from soils.

Keywords: Land uses; Biophysical properties; Soil-quality index; Temperate ecosystem.

1. Introduction

The soil quality parameters reflect land use patterns and management approaches (Masto et al., 2008a; Olateju et al., 2015). Soil quality is the soil's potential to raise adequate food while safeguarding humans (Vinhal-Freitas et al., 2017; Lal, 1997). A sustainable land use system is essential to prevent the extinction of species and the climate from changing (Martin et al., 2022; Baligar, 1997). Environmental and land degradation caused by humans was a significant global problem during the 20th century, and it continues to be a top priority today (Ikraoun et al., 2021; Bhowmik et al., 2019; Trivedi et al., 2016). Land management practices typically impact changes in land use through economic metrics, engineering, land management policies, and institutions. The transitions and management of land can contribute to balancing the regional land use morphological pattern (Long and Qu, 2018). Production is primarily controlled by

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the physicochemical qualities of soil, climatic variables, and management strategies; improper land use exacerbates the degradation of the physicochemical and biological characteristics of soil (He et al., 2003)

Land use system affects water storage and movement within the soil, thus affecting soil hydraulic properties by poorly connecting the macropores (>30µm) (Fu et al., 2021). Evaluating soil attributes is essential for illustrating and comprehending the status and characteristics of the significant additives in soils (Geissen et al., 2009). Physicochemical properties are analyzed to determine the nutrient status of soils under various land uses (Geissen et al., 2009).

Land use systems with minimum disturbances have been beneficial for developing better soil structure. Grasslands and orchard land use systems have > 5mm aggregates which contribute to the soil nutrients, while upland soils have only 0.25-0.053 mm aggregates that make a significant contribution to soil nutrients (Liu et al., 2010; Wang et al., 2014; Bhuyan et al., 2013). Soil organic carbon (SOC) is an essential indicator of soil quality and is greatly influenced by land use systems (Kaur et al., 2021; Everest et al., 2022). United Nations Blueprint for Sustainable Development Goals (SDGs) also involves the accessibility of macro and micronutrients with various land use systems (Keesstra et al., 2018). Dynamics of land use systems are pervasive and significantly impact the ecosystem architecture and services (Adeel et al., 2008; Adelana et al., 2022; Paz-Kagan et al., 2014). Due to land use changes during the past few decades, a significant percentage of the temperate terrestrial surface has transitioned from a natural to a human-dominated system, having a considerable impact on the soil ecosystem's health (Alemayehu and Sheleme, 2013; Paz-Kagan et al., 2014).

The quality of soil relies on the physicochemical characteristics of soil, which are primarily affected by land use systems. Natural and anthropogenic activities, as well as incredibly intensive management practices, have destroyed soil quality. The combined effect of conventional tillage, mono-cropping, and overgrazing has degraded 20% of agricultural land worldwide (Angon et al., 2023. The cropping system and soil quality have a complex and interactive relationship (Sithole et al., 2018; Everest et al., 2022a). Land use and cropping practices alter the soil's physicochemical makeup, impacting plant growth and harvest yields (Moraes et al., 2020).

The research area's nutritional status and organic carbon levels have not yet been linked to land uses and management practices. Soil quality parameters assessment concerning land uses and soil management techniques is intriguing to integrate into the study area. To compare soil quality across different land uses, investigate relationships between different soil features, and assess the soil quality across different land use types, the soil's physico-chemical and biological parameters were examined.

2. Materials and methods

2.1. Description of Study Area

The study was performed in the area (34.42^o N and 74.65^o E) that falls under the temperate region of Jammu and Kashmir-India (Fig 1). It has a surface area of 345 km^2 and lies at an altitude of 1578-1581m AMSL, spreading towards the north of the Indian Himalayan region. At the experimental site, the annual mean temperature is 15.6°C, and the annual precipitation is 2200 mm. The major soils of the region are silty clay loam and sandy soil, comprising about 70% and 30%, separately. By and large, the soils of the study area are medium in nutrients (NPK) and organic carbon. Apart from microclimatic differences, no significant climatic variation between the different land use systems affects soil quality parameters. Agriculture, such as the small-scale and commercial cultivation of paddy, maize, and vegetables, is the most significant economic activity in the studied area. In the study region, horticulture crops such as apples, walnuts, pears, and cherries are also grown. The Pohru group of rock formations, which comprise agglomeratic slates from the Upper Carboniferous period and limestone, siltstone, shale, and arenite from the Cambrian-Silurian, cover the study area on its far northern side (Razdan and Raina 1986; Thakur and Rawat 1992). Quaternary Karewa deposits and recent alluvium are located on its southwestern, southeastern, and southwestern sides. The northeastern and northwestern sides are exposed to Panjal volcanics and Triassic limestone formations (Sarah et al. 2011). The Permian-aged Panjal volcanic comprises layers of andesitic to basaltic lava flows that range in color from dark grey to green. It is significant to note that the volcanic basalt and limestone rocks are mined in the area for building stone and road construction. Karewa group sediments and recent alluvium are abundant in low-lying areas (De Terra and Paterson 1939; Bhatt and Chatterji 1976). According to Wadia (1931), Burbank and Johnson (1982), Singh (1982), and Agarwal and Agarwal (2005), the Karewa are fluvial-glacial-lacustrine deposits from the Plio-Pleistocene epoch that are made up of fine silty clays with sand and boulder gravel conglomerates and embedded moraines. The recent alluvium comprises fine silt, clay particles, and more extensive sand and gravel.

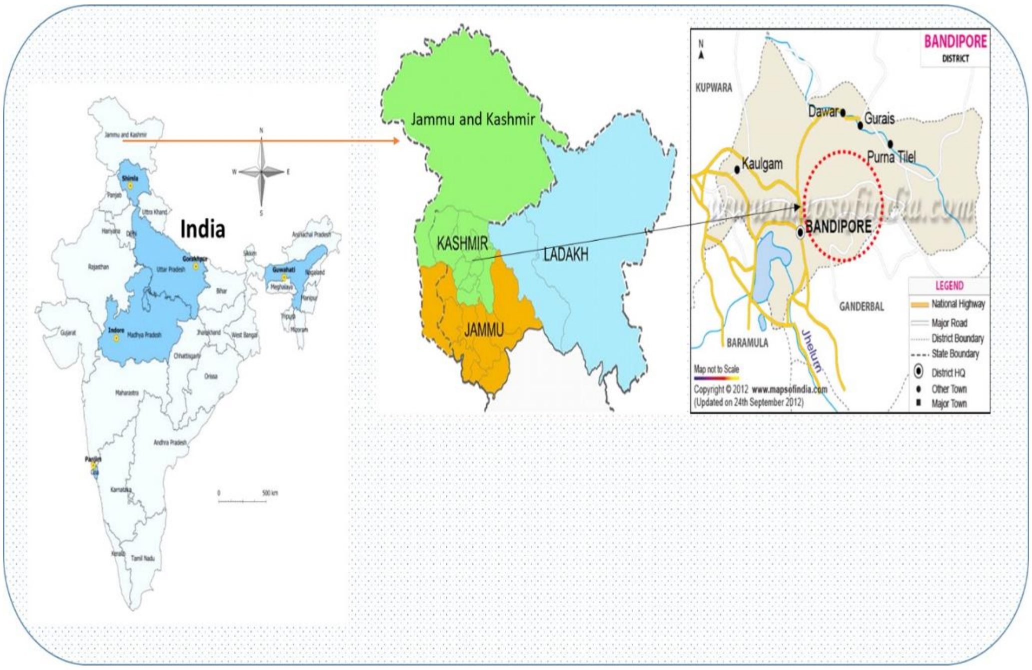

Fig. 1. Map of the study area.

2.2. Experiment

The study is based on two methodological approaches: (1) determination of sampling locations and (2) soil sampling and analysis. The soil quality database relies upon land uses, soil, landscape, and environmental conditions. The sampling sites were selected considering the variations in land use, soil type, management practices, fertilization, and other parameters expected to affect soil quality. Topsoil samples (0-30 cm) from 30 different land use systems, such as temperate forests, pasture, apple orchards, seasonal vegetables, maize, and paddy fields, were collected and analyzed for other soil characteristics. Bulk density (g cm^{-3}) and particle density (g cm^{-3}) were estimated using core sampler and pycnometer methods. The hydrometric technique was used to determine particle size, as Bouyoucos (1962) showed. With the help of a glass cathode pH meter, the soil reaction was resolved in 1:2.5 soil-water suspension. Electrical conductivity (dS m^{-1}) was measured by the Solubridge conductivity meter, as depicted by Jackson (1973). Organic carbon (g kg^{-1}) was estimated using the rapid titration method and cation exchange capacity using a technique given by Jackson (1973). Available macro-nutrients (kg ha^{-1}) like nitrogen and phosphorus were estimated according to alkaline $KMnO_4^-$ (Subbaiah and Asija 1956) and Olsen (1954), respectively. Potassium (kg ha^{-1}) extraction was carried out with 1N ammonium acetate solution at pH 7.0 and sulfur by turbidity metric method, given by Williams and Steinberg (1959). Micronutrients (manganese, iron, zinc, and copper) were estimated using an atomic absorption spectrometer (AAS) (Lindsay and Norvell, 1978). Chloroform fumigation and incubation were used for determining soil microbial carbon. The soil microbial nitrogen and phosphorus were estimated by direct incubation (Keeney and Nelson, 1983) and the Fumigation-extraction technique (Brookes et al., 1982), respectively. The total viable bacteria and fungi counts were estimated using the standard plate
count method (Aneja, 2002).

2.3. Soil Organic Carbon Fractions

The hot-water extractable C (HWC) was determined on fresh field samples by a modified method developed by Haynes and Francis (1993). The extraction of HWC was conducted in two simple steps. The first step involved the removal of readily soluble C from the soils that may have come from animal dung and soluble plant residues. The second step involved extracting labile components of soil carbon at 80^{o}C for 16 h. This is subsequently referred to as hot-water extractable carbon (HWC). The particulate organic carbon (POC) was determined using the method given by Cambardella and Elliotte (1992), and the mineral-associated organic carbon was determined using the technique of Plante *et al*. (2006). A 10 gm soil sample was dispersed in 30 mL of 5 g L^{-1} sodium hexametaphosphate by shaking for 15 h on a reciprocal shaker. The dispersed soil samples were passed through a 53 µm sieve, and after rinsing several times with water, the material retained on the sieve was dried at 50 °C overnight. The soil slurry passing through the sieve contained the mineral-associated C.

2.4. Soil quality assessment

Soil quality assessment was carried out in three steps: i) selection of indicators for minimum data set (MDS), ii) scoring of selected indicators, and iii) soil quality report by integrating individual indicator scores (Andrews et al., 2004). Followed by a modified approach from Askariand Holden principal component analysis (PCA) (Askari and Holden, 2014) was utilized to recognize a base dataset (MDS) of soil-quality markers followed by building up of soil quality index under different land use types (Fig 2.).

2.5. Determination of Indicators

Critical parameter identification was done using expert opinion and principal component analysis. Each data set's principal components (PCs) were examined, and those with high Eigenvalues>1 were thought to strongly contribute to the overall variability (Askari and Holden, 2014). The most suitable soil indicators for the MDS in each PC were those whose values fell within 10% of the factor loading with the highest value. By dispersing the variance, Varimax rotation was used to maximize the correlation between PC and the soil parameters (Kaiser, 1960). Multivariate correlation was used to examine the duplication of variables when more than one variable was kept in a single PC. The SQI was chosen to have the highest loading factor (absolute values) among variables that demonstrated a positive relationship (Waswa et al., 2013).

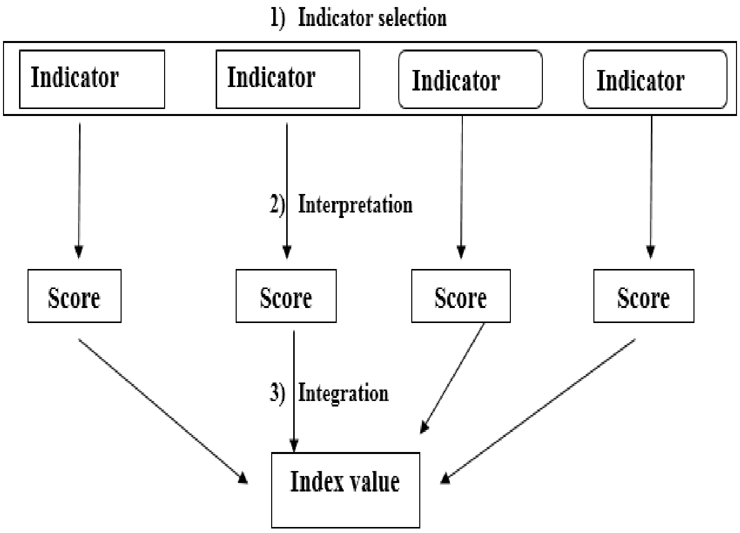

Fig. 2. Flowchart of soil quality indexing procedure.

2.6. Scoring the Soil Quality Indicators

The transformation of data into unitless values (0 to 1) was according to the Linear Scoring Method (Waswa et al., 2013). According to whether a higher value was deemed "good" or "poor" in the context of soil functions, soil attributes (indicators) were organized to assign scores. Since almost all of the MDS indicators were deemed suitable based on their qualities in this study, the "more is better" approach was used, except bulk density, where the "lesser is better" approach was taken into consideration (Andrews et al., 2002).

2.7. Indicator Integration into Soil Quality Indices

For each land use, the following soil quality indexes were calculated.

- Un-screened additive index
- Regression equation-based soil quality index
- PCA-based soil quality index

2.8. Un-screened additive index

The un-screened additive index was calculated using the following formula (Velmurugan, 2000).

$$SQI = \sum_{n=1}^{i} \frac{S}{n} \ldots\ldots\ldots (1)$$

Where, SQI represents the soil quality index, n represents the number of indicators, and S represents a score of indicators.

2.9. Soil biology

The sampling was performed according to Anderson and Ingram's (1993) method, based on excavating five soil monoliths of 25 cm x 25 cm x 30 cm. The three soil layers were then differentiated: litter, 0–10 cm, 10–20 cm, and 20–30 cm. There was a 5-meter distance between the two monoliths. The soil samples were analyzed in a microbiological laboratory for microbial studies. The macrofauna was manually sorted in the field, and invertebrates were numbered, weighed, and identified down to the order level. After that, the density and biomass of earthworms, termites, ants, Coleoptera, Diplopoda, Isopoda, Gastropoda, Arachnida, Hemiptera, and Homoptera, in total, were recorded.

2.10. Regression equation-based soil quality index

In this instance, a stepwise multiple linear regression equation (MLR) was established between total soil organic carbon and quality indicators. The Soil Quality Index (SQI) was established using the following equation.

$$SQI = \sum_{1}^{n} \quad Sx\,(beta) \ldots \ldots \ldots \quad (2)$$

Where S= linear scores,

n = tally of indicator parameters held on in multiple linear regression (MLR)

And "Beta" = coefficients (standardized) of the hold on indicator parameters.

2.11. PCA based on SQI

Generally, normalized PCA of all soil parameters is performed, which shows statistically significant differences between management systems. The principal components with Eigenvalues≥1 were investigated. Furthermore, PCs that clarify ≥ 5% of the fluctuation in the soil information are incorporated when less than three PCs have Eigenvalues≥1. Every factor in a specific PC is given a weight that represents its contribution to the structure of the PC. Every PC holds the exceptionally weighted factors for the MDS. Factor loadings with absolute values within 10% or ≥0.40 are classified as highly weighted variables (Saikh et al., 1998). If two or more variables are held in a solitary PC, the multivariate relationship is utilized to decide whether the factors can be retained (Andrews et al., 2004). On the off chance that the highly weighted variables are not correlated (correlation coefficient <0.60), at that point, every one of them is viewed as significant and, therefore, can be held in the MDS. Among many correlated factors, the variable with the most elevated factor loading (absolute values) is picked for the MDS. The percentage of variation explained by each PC influences the weight of parameters selected in different PCs. The equation used in the principal component analysis is given below.

$$SQI = \sum_{n=1}^{i} \quad WixSi \ldots \ldots \ldots \ldots \ldots (3)$$

The weight of factors is represented by "W" under a specific PC, and the score of indicators is measured by "S." After the SQI calculation, the values are normalized to get a maximum score of 1.

3. Results

3.1. Descriptive statistics of soil parameters under different land-use types.

The soil qualities were influenced by land use (Table 1). Land uses under study were classified as silt loam, silty clay loam, clay loam, and sandy loam based on soil texture. Most sites exhibited silt loam texture followed by silty clay loam and loam. The highest sand content (48.52±1.68 %) was found in forest soils, followed by maize (40.53±1.68) > paddy (36.07±4.17) > pasture (30.98±2.81) > apple (30.80 ±3.71) > vegetable (21.22±0.58). while as highest silt content (55.87±3.67 %) was found in vegetables and the lowest (28±2.81%) in paddy. The highest clay content (35.92±2.33 %) was found in paddy fields. The highest bulk and particle densities of 1.48 g cm^{-3} and 2.60 g $cm^{-3,}$ respectively, were recorded in paddy soils, and the least of them, 0.75 g cm^{-3} and 2.31 g cm^{-3} in forest soils.

Under diverse land uses, soil pH ranged from moderately acidic to slightly alkaline, with paddy soils having the highest pH of 7.34 and forest soils having the lowest pH of 6.46, followed by pasture soils (6.70). It is evident from Table 1 that pH shows a regular trend: forest < pasture < apple < vegetable < maize and paddy in all locations. All the studied land uses have electrical conductivity values well below 1 dSm^{-1}, indicating no salinity hazard. Forest land use systems had the highest content of SOC (20.94 g kg^{-1}), followed by pastures (16.37 g kg^{-1}). The cultivated land-use system had a lower percentage of organic carbon, which could be attributed to intensive cultivation, high mineralization rate, and crop uptake (Selassie et al. 2015 and Soleimani et al. 2019). The cation exchange capacity followed the order of forestry > vegetable=pasture > apple > paddy > maize.

The highest mean value (21.97 Cmol (p^{+}) kg^{-1}) was found in forest and lowest in maize (9.87 Cmol (p^{+}) kg^{-1}). The availability of macronutrients in terms of nitrogen and phosphorus under different land uses showed considerable variation, with the highest N and P_2O_5 content of 537.50 (kg ha^{-1}) and 36.51(kg ha^{-1}), respectively, recorded in forest soils and a minimum of 290.30 N (kg ha^{-1}) and 24.22 P_2O_5 (kg ha^{-1}) in paddy and maize soils. Forest soils had the highest potassium availability, 289.60 (kg ha^{-1}), while the lowest, 201.36 kg h$^{-1,}$ was observed in paddy soils. The forest land use system was found to have the highest available sulfur, 29.68 (kg ha^{-1}), while vegetable soils from different locations showed the lowest available sulfur, 16.50 (kg ha^{-1}).

Table 1. Descriptive statistics of soil parameters under different land uses.

Parameter	Forest	Pasture	Apple	Vegetable	Maize	Paddy
Physico-chemical properties						
BD (g cm^{-3})	0.75±0.12	1.20±0.05	1.28±0.05	1.32±0.04	1.35±0.02	1.48±0.01
PD (gcm^{-3})	2.31 ± 0.06	2.50 ±0.05	2.44 ±0.04	2.58 ±0.04	2.52 ±0.04	2.60 ±0.01
Sand (%)	48.52 ± 3.89	30.98 ±2.81	30.08 ±3.71	21.22 ±0.58	40.53 ±1.68	36.07 ±4.17
Silt (%)	38.51 ± 5.73	49.48 ±3.96	50.64 ±3.42	55.87 ±3.67	36.71 ±2.32	28.00 ±2.81
Clay (%)	13.17 ± 4.07	18.74 ±2.65	19.28 ±1.81	22.91 ±3.96	22.76 ±2.50	35.92 ±2.33
pH	6.46 ±0.14	6.70 ±0.11	6.78 ±0.11	6.86 ±0.07	7.06 ±0.16	7.34 ±0.15
EC (dSm^{-1})	0.09 ±0.01	0.12 ±0.02	0.14 ±0.01	0.17 ±0.01	0.22 ±0.02	0.26 ±0.02
OC (kg^{-1})	20.94±1.85	16.37 ±2.66	14.94 ±0.84	10.95 ±1.99	11.42 ±2.33	8.63 ±1.23
CEC (meq100g^{-1})	21.97±1.52	16.38±0.73	15.43±0.52	16.49±0.87	9.87±0.68	14.95±0.94
Nitrogen (kg ha^{-1})	537.50 ±16.7	416.60 ±18.0	399.90±20.00	336.20 ±24.5	299.20 ±18.	290.30 ±1.8
Phosphorus (kg ha^{-1})	36.51±1.62	35.28 ±1.70	29.63 ±1.46	27.19 ±1.52	24.22 ±1.21	27.35 ±2.12
Potassium (kg ha^{-1})	289.60 ±13.60	275.8 ±12.70	243.68 ±7.99	259.22 ±9.63	226.84 ±5.2	201.36 ±6.2
Sulphur (kg ha^{-1})	29.68 ±3.05	26.93 ±2.13	23.82 ±1.86	16.50±0.99	18.47 ±1.32	20.21 ±1.30
Zinc (ppm)	1.57 ±0.08	1.51 ±0.08	1.19 ±0.06	0.98 ±0.03	0.76 ±0.03	1.12 ±0.03
Copper (ppm)	3.73 ±0.23	3.37 ±0.14	3.01 ±0.11	2.57 ±0.15	1.95 ±0.08	2.35 ±0.13
Iron (ppm)	30.04 ±2.16	26.16 ±1.56	24.02 ±1.92	22.75 ±1.62	15.29 ±1.53	18.93 ±1.71
Manganese (ppm)	8.05 ±0.47	5.97 ±0.49	3.59 ±0.32	2.78 ±0.31	1.39 ±0.19	1.71 ±0.26
MBC (µg g^{-1}soil)	252.07±4.82	234.77±4.08	190.15±8.10	152.22±4.80	121.87±4.1(	75.25±7.19
MBN (µg g^{-1}soil)	36.00±0.68	33.53±0.58	27.16±1.16	21.72±0.68	17.494±0.5	10.74±1.03
MBP (µg g^{-1}soil)	5.98±0.12	5.59±0.09	4.52±0.19	3.58±0.12	2.91±0.09	1.78±0.17
BC (cfu*10^{6} g^{-1}soil)	76.20±4.00	67.80±3.09	67.20±3.35	69.00±3.11	63.60±4.39	65.40±3.61
FC (cfu*10^{5} g^{-1}soil)	30.00±2.77	28.00±3.08	21.00±4.46	24.00±3.83	18.20±3.48	12.60±2.06

Values are the average of triplicates. $\pm$ = standard deviation

High levels of OM also increase phosphorus availability by forming organo-phosphate complexes that are more readily available to plants. The same results were also reported by Selassie et al. (2015) and Kaur and Bhat (2017). The highest mean values (ppm) of 1.57, 3.73, 30.04, and 8.05 for Zn, Cu, Fe, and Mn, respectively, were observed in forest soils, and with minimum respective values (ppm) of 0.76, 1.95, 15.29, and 1.39 for maize-based land use system.

3.2. Biological characteristics of soil

The biological properties (µg g^{-1} soil) such as microbial biomass's carbon, nitrogen, phosphorus, and viable bacterial (cfu*10^{6} g^{-1} soil) and fungal count (cfu*10^{5} g^{-1} soil) were found to be the highest in forest soils as compared to cultivated soils. The maximum bacterial count of 76.20 cfu g^{-1} soil and fungal count of 30.00 cfu g^{-1} soil were recorded in forest soils Fig. 3). The MBC was found in the order of paddy> maize> vegetable> apple >pasture and> forest with a mean value of 75.25±7.19, 121.87±4.10, 152.22±4.80, 190.15±8.10, 234.77±4.08 and 252.07±4.82 µg g^{-1} soil, respectively. Soil microbial nitrogen and phosphorus were found in the same order in the studied land uses as microbial carbon like forest, pasture, apple, vegetable, maize, and paddy, with the highest mean value of all the experimental sites for microbial nitrogen as 36.00 µg g^{-1} soil and microbial phosphorus as 5.98 µg g^{-1}. The highest mean value for the bacterial count was found to be 76.20 cfu g^{-1} soil in forest tracked by pasture as 67.80±3.35 cfu g^{-1} soil, and the minimum count of bacteria was found in paddy as 65.40±3.61cfu g^{-1} soil. Similarly, a maximum fungal count of 30.00±2.77cfu g^{-1} soil was recorded in forest soils, followed by pasture (28.00±3.08), vegetable (24.00±3.83), apple (21.00±4.46), maize (18.20±3.48) and paddy (12.60±2.06). In contrast, the total opposite happens in cultivated lands.

3.3. Soil macrofauna under different land use systems

Forest soil and pasture had the lowest density values of total macrofauna compared to those determined from paddy, maize, and vegetable fields, 1,312, 1,445, and 1,461 individual m^{-2}. The abundance of termites and ants was the cause of the high density in the forest (567 and 678 individuals m^{-2}), followed by pasture (490 and 610 individuals m^{-2}). It is crucial to note that the latter technique favored specific termite groups because the macrofauna was collected right after harvest when agricultural leftovers were still in the soil. The pasture system contained abundant Coleoptera populations (409 individuals per m^{-2}). The pasture system had the highest total biomass (56 g m^{-2}) compared to other land-use systems (11 g m^{-2}). (Table 2).

3.4. Soil organic carbon fractions in different land uses

The soil organic carbon concentration varied greatly among various land uses, ranging from 7.27 to 27.03 g kg^{-1} and 6.13-23.66 g kg^{-1} in surface and sub-surface soils with mean values of 20.94 and 17.25 g kg^{-1}, respectively. Forest soils had the highest levels (8.63 g kg^{-1}) of organic carbon, compared to the lowest in paddy soils (6.94 g kg^{-1}).

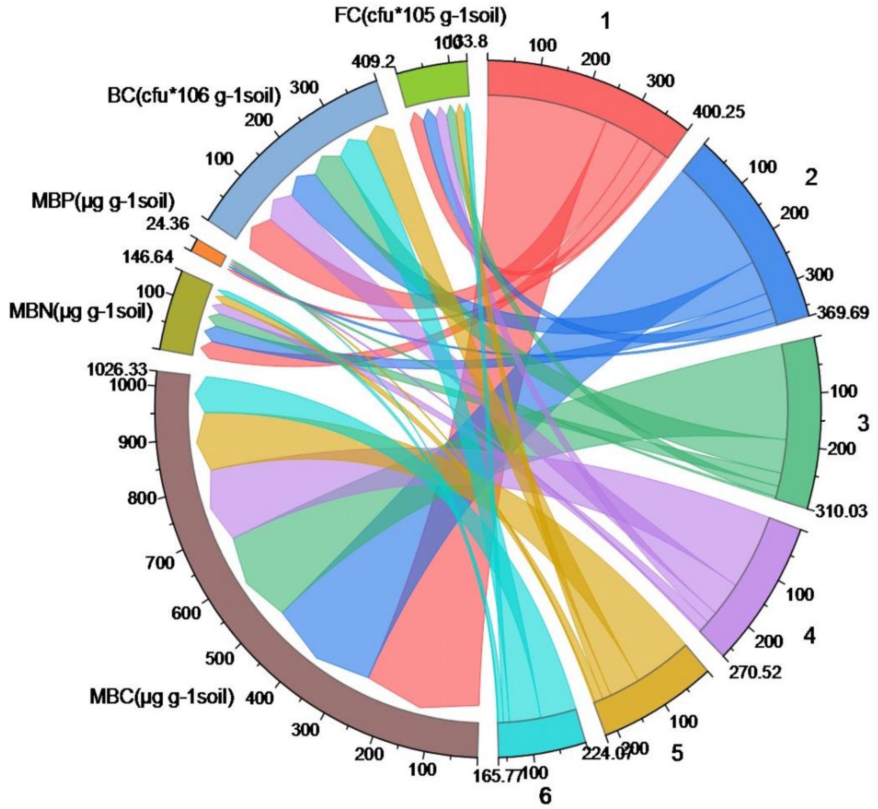

Fig. 3. Biological characteristics of soil samples under different land use systems.

BD- Bulk density, PD- Particle density, EC-Electrical conductivity, CEC- Cation exchange capacity, MBC- Microbial biomass carbon, MBN- Microbial biomass nitrogen, MBP- Microbial biomass phosphorus, BC- Bacterial count, FC- Fungal count.

Table 2. Distribution of macrofauna density (individual m^{-2}) in temperate Forest, Pastures, Apple, Vegetable, Maize, and Rice land-use systems.

Land uses	Arachnida	Coleoptera	Diplopoda	Gastropoda	Hymenoptera	Isoptera	Annelida
Forest	32	112	10	13	567	678	86
Pasture	45	490	15	32	490	610	108
Apple	55	126	11	24	480	596	128
Vegetable	62	90	15	33	455	543	133
Maize	25	86	9	14	310	412	118
Rice	11	10	10	12	220	225	85
SE(m)±	0.75	1.65	0.20	0.80	1.65	2.11	0.45
CD<0.5 %	2.15	6.35	0.93	2.12	8.10	8.55	2.98

In contrast to non-agricultural soil, which supports the accumulation of organic matter (OM), arable soils have lower SOC. In surface soils, the average hot water carbon (HWC) concentration for various land use systems ranged from 250.00 mg kg^{-1} to 765.00 mg kg^{-1} (Table 3), and with the increases in soil depth, the average HWC content for all land use systems showed a decreased trend from 651.00 mg kg^{-1} to 231.00 mg kg^{-1}. Forest samples had the highest intermediate HWC level (738.33 mg kg^{-1}), while paddy samples had the lowest average HWC content (279.33 mg kg^{-1}). As a result, samples with the highest SOC also had the highest MOC (Table 4).

When comparing the different land use regimes, soil samples from non-cultivated soils have significantly greater MOC contents than arable land. Subsurface paddy soils had the lowest mean value of MOC at 12.74 g $kg^{-1,}$ while the surface forest soils had the higher mean value of MOC at 28.06 g kg^{-1}. Forest land use significantly influences POC, with the highest concentrations of 5.65 g $kg^{-1,}$ whereas maize and paddy soil samples had the lowest concentrations of 2.14 and 2.04 g kg^{-1}, respectively (Table 5).

Table 3. Hot water extractable carbon (HWC) in different land uses (mg kg^{-1}).

Sampling sites	Depth (cm)	Land uses					
		Forest	Pasture	Apple	Vegetable	Maize	Paddy
Bandipora	0-20	692.00	687.00	658.00	597.00	411.00	250.00
Sumbal		765.00	745.00	621.00	637.00	456.00	276.00
Gurez		758.00	260.00	644.00	278.00	389.00	312.00
Mean		738.33	564.00	641.00	504.00	418.66	279.33
Bandipora	20-40	521.00	578.00	435.00	309.00	302.00	231.00
Sumbal		651.00	612.00	318.00	298.00	318.00	257.00
Gurez		622.00	267.00	321.00	275.00	323.00	332.00
Mean		598.00	485.66	358.00	294.00	314.33	273.33

Table 4. Contains mineral-associated organic carbon (MOC) in different land-use soils (g kg^{-1}).

Sampling sites	Depth (cm)	Land uses					
		Forest	Pasture	Apple	Vegetable	Maize	Paddy
Bandipora	0-20	23.12	24.1	21.12	20.03	16.46	14.42
Sumbal		32.3	25.15	20.38	22.37	20.17	14.63
Gurez		28.76	14.56	20.78	13.26	15.28	17.11
Mean		28.06	21.27	20.76	18.55	17.30	15.38
Bandipora	20-40	19.23	20.72	17.53	14.12	15.43	12.1
Sumbal		30.82	22.93	15.71	16.34	13.74	12.47
Gurez		23.61	13.21	16.42	15.54	12.54	13.67
Mean		24.55	18.95	16.55	15.33	13.90	12.74

Table 5. Particulate organic carbon (POC) content in different land uses (g kg^{-1}).

Sampling sites	Depth (cm)	Land uses					
		Forest	Pasture	Apple	Vegetable	Maize	Paddy
Bandipora	0-20	4.54	4.62	2.23	2.89	1.77	1.98
Sumbal		6.65	5.72	3.89	2.17	1.78	2.16
Gurez		5.76	2.97	1.79	2.56	2.87	1.99
Mean		5.65	4.43	2.63	2.54	2.14	2.04
Bandipora	20-40	3.78	3.85	2.97	1.36	2.01	1.2
Sumbal		6.16	4.18	2.07	2.65	1.47	1.28
Gurez		4.21	1.34	2.93	1.38	1.31	1.3
Mean		4.71	3.12	2.65	1.79	1.59	1.26

3.5. Integration Indicators into Soil Quality Indices

Three different approaches were followed to calculate soil quality indices for each land use, which are discussed below-

3.5.1. Un-screened additive soil quality index (SQI-un)

Unscreened additive SQI computed through linear scoring (SQI-*un*) function is presented in (Fig 4). The critical step in assessing the efficacy and value of SQI calculation is based on the scoring step. Setting the vital limits based on a range of essential limits with the function "more is better." These critical limits were based on the values found in the literature. The maximum value for SQI-*un* was observed to be (0.91) for forest soils, followed by pastures (0.84) and further decreased in the order of apple (0.74), vegetable (0.68), paddy (0.59), and the lowest (0.58) value was found in maize. As observed in this study, the maximum SQI for forests pertains to better physicochemical and biological properties.

3.5.2. Regression equation-based SQI

Stepwise multiple linear regression equation (MLR) was developed between the dependent variable (organic carbon) and independent variables (BD, PD, sand, silt, clay, pH, EC, CEC, N, P, K, S, Zn, Cu, Fe, Mn, MBC, MBN, MBP, BC, FC). The SQI for all the studied land uses was computed through a regression equation along with the scores of retained indicators (Fig. 5).

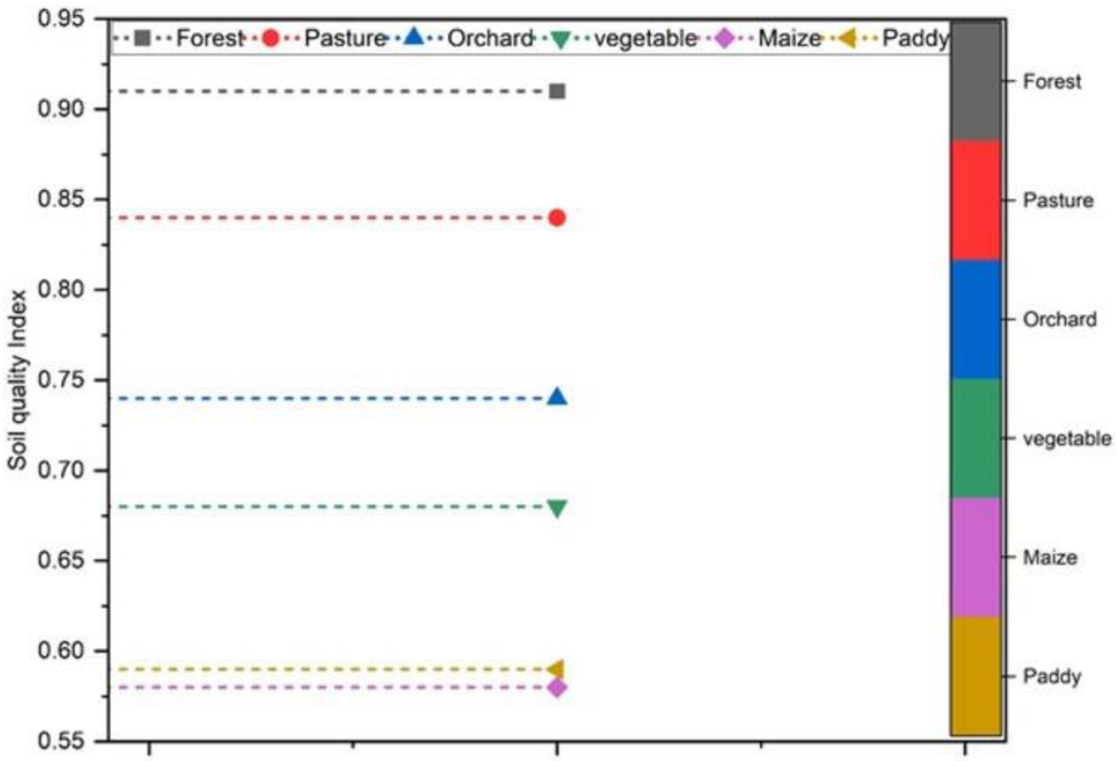

Fig. 4. SQI (*un*screened) of different land uses.

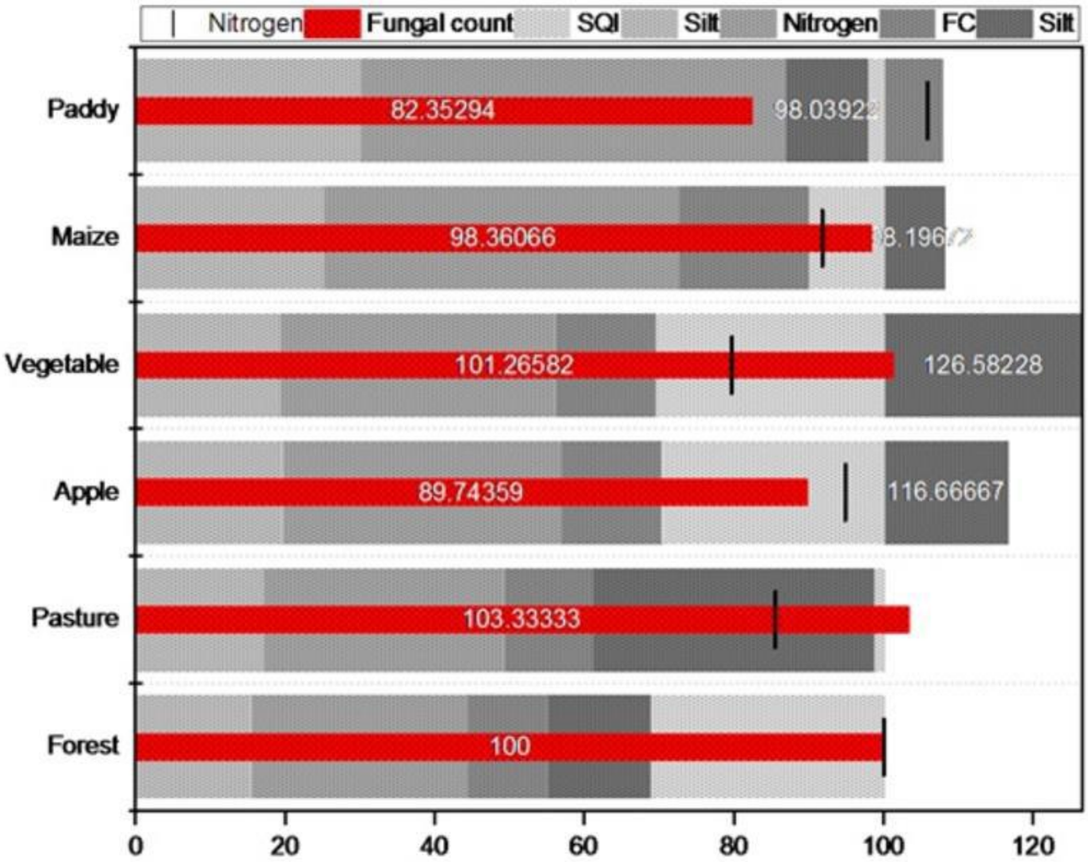

Fig. 5. Soil quality indices based on the regression equation.

3.5.3. PCA-based SQI

The data was subjected to PCA to develop SQI with the highest variability in the data set through PCA. This data reduction tool minimizes the number of indicator parameters retained without losing information. A normalized PCA was performed on all the data to extricate the MDS from 22 soil pointers (Table 7). Three PCs were picked based on Eigenesteem≥1, and cumulative variation was discovered to be 88.86% (Table 6). Inside every PC, just the most elevated weighted components were held for a minimum dataset.

As inferred from the data in Table 6, the principal component loading matrix indicated that the main PC (PC1) for MDS1 determination had twelve profoundly weighted factors inside 10.0% of the most noteworthy.

Factor loading. In any case, these factors were discovered to be very much correlated in the intercorrelation aside from bulk density, pH, and electrical conductivity, which corresponded with the rest of the indicators. Only those indicators with the highest loadings in the correlation study, like bulk density, organic carbon, nitrogen, iron, and MBC, were retained from PC1. From the second PC (PC2), only clay having the highest loading factor (0.871) was selected for MDS, and from the third PC (PC3), only sand having the highest loading factor (0.929) was retained (Fig 5). All in all, from PC1 and PC2, the indicators qualified and held for soil quality indexing were bulk density (BD), SOC, nitrogen, iron, microbial biomass carbon (MBC), clay, and sand (Fig 5).

The indicators selected and their respective scores and weights (variation percentage of respective PCs divided by cumulative variation percentage) (Table 7). After scoring and weighting, the derived values were applied to an additive model, which ultimately resulted in the evaluation of the numerical soil quality index for each land use and the determination of an aggregate score representing

the status of the soil (Table 6) with maximum soil quality in the forest (1.00) followed by pastures (0.79), apple (0.72), vegetable (0.62), maize (0.55), and paddy (0.51). The bi-plot has depicted the stability of selected parameters in the current experiment (Fig. 6).

The parameters OC, nitrogen, phosphorus, potassium, and zinc are substantially linked with Zn, Cu, CN ratio, MBC, and total organic carbon (TOC) in the first principal component, which can have mutual effects on mineralization and breakdown potential, with a cumulative variance of 66.89 % and high loading rate from PC first and second.

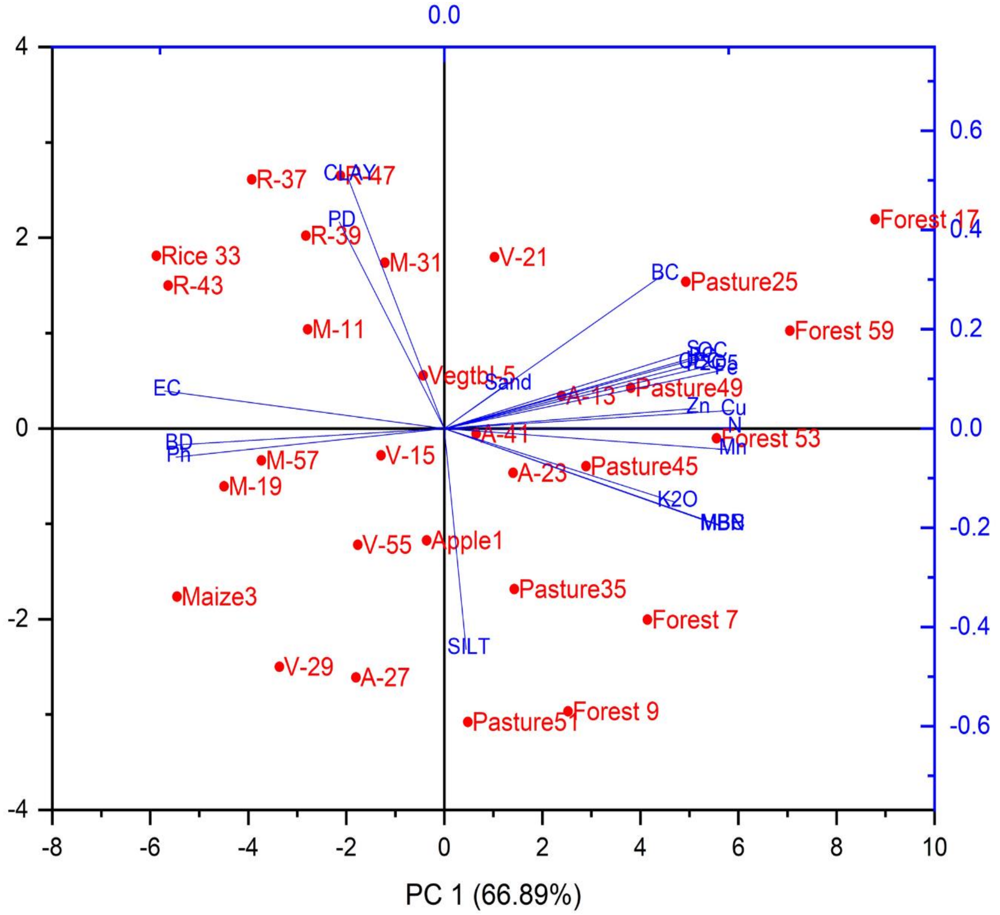

Fig. 6. The plot resulting from PCA was applied to indicators retained in the MSD. Labels of land use systems are depicted in red, with corresponding sites also indicated in red.

Table 6. Highest loaded variables that are retained (MDS*).

PC	Variance (%)	Cumulative variance (%)	Weight*	Retained indicators
1	66.89	66.89	0.75	Bulk density, Organic carbon Nitrogen, Iron, Biomass carbon
2	13.28	80.17	0.15	Clay
3	8.69	88.86	0.10	Sand

PC- Principle component, * Weight = Variance of PC/total cumulative variance, MDS*= Minimum dataset

Table 7. Selected indicators and their respective scores and weights.

Selected variables	Scores						Weights
	Forest	Pasture	Apple	Vegetable	Maize	Paddy	
Bulk density	1	0.62	0.58	0.57	0.55	0.5	0.75
Organic carbon	1	0.78	0.71	0.52	0.54	0.41	0.75
Nitrogen	1	0.77	0.74	0.63	0.56	0.54	0.75
Iron	1	0.87	0.79	0.76	0.50	0.63	0.75
Biomass carbon	1	0.93	0.75	0.6	0.48	0.29	0.75
Clay	0.37	0.52	0.54	0.64	0.63	1	0.15
Sand	1	0.64	0.62	0.44	0.84	0.74	0.10

4. Discussion

The present study aimed to assess the effects of land use systems on soil quality over time through specific indicators. Land uses under study were classified as silt loam, silty clay loam, clay loam, and sandy loam based on soil texture. Most sites exhibited silt loam texture followed by silty clay loam and loam. Tealab et al., 2024, Muche et al. (2015), and Pham et al. (2018) found that the texture of soils in plains varied from loam to sandy loam and had a more significant percentage of clay content due to a finer fraction of deposition from the uplands. The highest bulk and particle density, respectively, were recorded in paddy soils, and the least of them, in forest soils, which might be credited because of the expanded organic matter content in the forest when contrasted with cultivated lands where continuous removal of organic matter practices is followed (Abate and Kibre 2016 and Mehra et al. 2018). The paddy fields recorded increased bulk density, which might be attributed to the collapse of non-capillary pores during puddling operation. Moges et al. (2013) and Haile et al. (2014) came to similar conclusions.

Soil pH varied from moderately acidic to slightly alkaline across various land uses, with paddy soils having the highest pH of 7.34 and forest soils having the lowest pH of 6.46, followed by pasture soils (6.70). This may be caused by the bases taken up by tree biomass, the acidic character of the litter when it decomposes, the leaching of salts from top layers, which results in low pH as in forestry, and the buildup of salts in cultivated areas. Other studies reported similar findings (Muche et al., 2015; Negasa et al., 2017). All analyzed land uses had electrical conductivity values below 1 dS m^{-1}, suggesting no salinity risk. The usual range of electrical conductivity was also reported while studying the soils of Kashmir Valley (Kaur and Bhat, 2017; Maqbool et al., 2017).

The different land use systems also showed varied SOC. The Forest land presented the highest value of SOC, while cultivated land had the lowest value, which could be attributed to intensive cultivation, high mineralization rate, and crop uptake (Selassie et al. 2015 and Soleimani et al. 2019). Under different land uses, the availability of macronutrients displayed considerable variations, with forest soils showing the highest N and P_2O_5 content and minimum values for the same nutrients shown by paddy and maize soils, respectively. This may be due to higher organic matter levels, enhanced enzymatic activities, mineralization, and mobilization of available nutrients, including nitrogen. Elseedy et al. (2019) and Chauhan et al. (2014) reported a positive correlation between soil organic matter and nitrogen content. Panwar et al. (2013) and Paramanik et al. (2020) reported that forest soils had higher nitrogen availability than grassland, agricultural, and horticultural soils. The forest land use system also showed the highest available potassium and sulfur content, while paddy and vegetable soil had the lowest available potassium. Low soil organic matter levels in cultivated land may contribute to low macronutrient concentrations. Frequent tillage operations accelerate the mineralization of SOC and organic nitrogen, converting them into mineral nitrogen, carbon dioxide, and nitrogenous gases that escape into the atmosphere and are lost from the soils. High levels of OM also increase phosphorus availability by forming organo-phosphate complexes that are more readily available to plants. The same results were also reported by Selassie et al. (2015) and Kaur and Bhat (2017).

The micronutrient concentrations (Zn, Cu, Fe, and Mn) were the highest in forest soils, while lower concentrations were reported in maize-based land use systems. Organic matter advances the accessibility of micronutrients by providing solvent complexing specialists or natural acids that meddle with their fixation; they also act as a chelating agent by preventing leaching losses of micronutrients. Furthermore, organic matter acts as a good source of micronutrients (Kassahun et al. 2008 and Mehra et al. 2018), which might be the reason for the high availability of micronutrients in uncultivated land uses compared to that in cultivated land use systems, which is exceptionally correlated with microbial biomass (Chandel *et al*., 2018; Padalia et al. 2018).

When comparing forest soils to cultivated soils, the biological characteristics (µg g^{-1} soil) such as the microbial biomass carbon, nitrogen, phosphorus, and viable bacterial count (cfu*106 g^{-1} soil) and fungal count (cfu*105 g^{-1} soil) were found to be greater in the former. Root biomass, or more ground plant biomass, is the fundamental wellspring of soil organic matter microorganisms inhibiting trees by preventing the influence of heavy rains and promoting favorable fungal growth. In contrast, the total opposite happens in cultivated lands practicing intensive tillage operations, as known that fungi are heavily impacted by disturbances in soil and ecological conditions (Nwafor and Chibuike 2015; Wang F 2017). The study pattern observed supports the conventional tillage (CT) approach, which reduced HWC by roughly 24 % at 0–10 cm depth (Chen et al. 2009 and Vashisht et al. 2020).

When compared to the overall macrofauna density values measured from vegetable, paddy, and maize fields (m^{-2}), forest soil and pasture had the lowest values. Coleoptera populations were plentiful in the pasture system (per square meter). This was primarily a rhizophagous community, which was most likely brought about by the fact that these pastures produced and had a higher density of roots than forests.

The soil organic carbon content varied significantly among different land uses. The most significant levels of organic carbon were found in forest soils due to the accumulation of OM (Luna-Robles et al., 2024). In contrast, the lowest values were found in paddy soils as SOC declines with increasing soil depth, which may be attributed to the lower levels of OM and crop leftovers in the belowground layers (Chibsa and Asefa, 2009; Nguemezi et al., 2021). The average hot water carbon (HWC) concentration in surface soils across different land use regimes showed variation, with the highest value in forest samples and the lowest in paddy samples. Physical disruption of macro-aggregates encourages the microbial degradation of this C component, which has been linked to the CT system's detrimental effect on HWC concentration (Chemeda et al., 2017; Ghani et al., 2010).

POC is highly influenced by forest land use, with the most significant concentrations while the lowest quantities were found in soil samples from maize and rice fields, respectively (Table 5). Due to the continuous addition of fresh OM combined with soil particles and a slower decomposition rate, the surface layer in forests and pastures had higher levels of POC. In contrast to the 5% macro-aggregates in arable soils, uncultivated soils contain >30% macro-aggregates (Šeremešić et al., 2020). The highest POC content in samples from pastures and forests is ascribed to superior structural characteristics and better soil aggregation conditions since POC content is correlated with macro-aggregates. Similarly, the presence of hydrophobic materials in non-agricultural soils covers the aggregates, delays the entry of water into the soil, and guards against the degradation of those aggregates (Blair et al., 2006). POM was the portion of organic C that changed most due to land use, while changes in MOC may have resulted from long-term soil tillage and SOC background (de Moraes Sa et al., 2014).

Soil quality indices for each land use were calculated using three different approaches. 1) Unscreened additive SQI was computed through linear scoring (SQI-*un*) function, and forest soils displayed maximum value for SQI-*un with lower value in maize soils.* The evaluation of the impacts of various land uses and crop management strategies on soil quality was based on their roles in nutrient supply and storage capacity (Masto et al. 2008b). As observed in this study, the maximum SQI for forests pertains to better physicochemical and biological properties. 2) Regression equation-based SQI was also employed between the dependent variable (organic carbon) and independent variables (BD, PD, sand, silt, clay, pH, EC, CEC, N, P, K, S, Zn, Cu, Fe, Mn, MBC, MBN, MBP, BC, FC). 3) PCA-based SQI. Data was submitted to the analysis to create SQI with maximum variability in the data set using PCA. The higher soil quality of forests in contrast to cultivated soils like paddy might also be attributed to the extended period of paddy farming under flooded circumstances and the application of chemical fertilizers that breakdown the stable aggregates and deteriorate SOC (Chandel et al., 2018; Basak et al., 2021).

5. Conclusion and Future Prospective

This investigation examined the effects of six land uses on soil quality and evaluated the efficacy of six created SQIs to differentiate between various land use treatments. Uncultivated lands, such as forests, were shown to accumulate more organic carbon than cultivated soils, including those used for agriculture and horticulture. This finding suggests that further expanding and turning natural forests into farmland will result in a significant loss of carbon pools from soils. Forest soils' suitable physical, chemical, and biological properties are reflected in their higher OM levels. Since the unbroken soils (forest and pasture) developed more excellent properties than other land uses, long-term mono-farming negatively impacts the soils. The SQI created during the study revealed the following ranking of soil quality for various land uses: forestry > pasture > apple > vegetable > maize > paddy. Forests and pastures typically have high-quality soil, demonstrating that these land uses are advantageous for storing SOC and can function as larger sink pools for rising CO_2 levels.

The study establishes the foundation for future research initiatives to find sustainable solutions for soil quality losses and offers insightful information to support well-informed decision-making.

List of abbreviations

AAS- Atomic absorption spectrometer
BC- Bacterial count
BD- Bulk density
CEC- Cation exchange capacity
EC- Electrical conductivity
FC- Fungal count
HWC -hot-water extractable
MBC- Microbial biomass carbon
MBN- Microbial biomass nitrogen
MBP- Microbial biomass phosphorus
NPK – Nitrogen, phosphorus, and potassium
OC- Organic carbon
OM – Organic matter
PCA- Principal Component Analysis.
PCs - principal components
PD- Particle density
POC -particulate organic carbon
SOC – Soil organic carbon
SQI - Soil Quality Index
TOC - Total organic carbon

Declarations

Ethical Responsibilities of Authors
All the authors have complied with the statement on Ethical responsibilities of the authors. The work presented is original, has not been submitted in part/complete to any other journal, and is not under consideration in any other journal.
Conflict of interest
The authors declare no conflict of interest
Human participation
The research involves no Human Participants or Animals.
Data Availability
All the data is available in the manuscript file

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