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Spatial variability analysis of soil quality parameters in a watershed of Sub-Himalayan Landscape - A case study

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Abstract

Soil organic carbon (SOC) is a key component in maintaining soil quality. Mapping the local scale variations in the distribution and stratification of SOC and other soil quality parameters across different layers has always been a challenging task, in the current global scenario of changing climates. The study was aimed to investigate the spatial distribution of SOC and other soil quality parameters including SOC stratification ratio and CN ratio in a small hilly watershed (~ 10 km^2) located in the mid Himalayan region of Himachal Pradesh, India. Soil samples were collected in November 2015, from 75 points at two depths (0-15 cm and 15-30cm), along with their geographical coordinates using a Global Positioning System (GPS). The results revealed that SOC concentration (g kg^{-1}) decreased with increasing soil depth, throughout the study area and differed significantly (P<0.01) between the two depths in vertical soil profile. The SOC stratification ratio values were greater than 1.2 in major portion of watershed indicating a spatial improvement in soil quality. C: N ratio, another important soil quality attribute values were found to be <12:1, indicating high degree of soil quality and increased rate of organic matter mineralization. The spatial distribution maps of SOC content (g kg^{-1}), SOC stratification ratio as well as CN ratio of study area were generated using Inverse Distance Weighted (IDW) interpolation approach. Additionally soil quality index (SQI) was also computed using various soil quality parameters based on Analytical Hierarchy Process (AHP) and their spatial distribution was analyzed in the watershed. Nearly 76% of the study area had SQI values in the range of 60-75, whereas 22.16% of the area had SQI<60 and 2.59% had SQI>75. The overall results indicated that a higher degree of soil quality existed at the higher elevation regions of the watershed. Majority of the soils in the watershed accounted for only 60% of the maximum possible value of SQI, which necessitates the adoption of better management practices for improving the soil quality.

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Introduction

Soil quality indicates the capacity of the soil to perform the various ecosystem services and by far it is the central element which determines the long term sustainability of any agricultural production system. It refers to the capacity of soil to function within natural or managed ecosystem boundaries and to sustain plant productivity while maintaining or enhancing water quality, supporting human health as well as habitation and reducing soil degradation (Doran et al., 1994; Karlen et al., 1997; Karlen et al., 2003). Comprehensive assessment of agricultural soil quality (Pieri et al., 1995; Stamatiadis et al., 1999) aids in making decisions in respect to improve crop production and environmental sustainability.

Soil quality being a complex functional concept, can't be measured directly in the field or laboratory (Stockings, 2003), but can only be ascertained from various soil properties or characteristics (Diack and

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Scott, 2001). Soil quality indicators are defined as soil processes and properties (combination of physical, chemical and biological) that are sensitive to changes in soil functions (Doran and Jones, 1996; Herrick et al., 2002,; Aparicio and Costa, 2007). An ideal soil quality indicator should possess specific characteristics like correlating well with ecosystem processes/soil functions. It should be sensitive to various management practices and climatic conditions as well as external change (natural or anthropogenic) in addition to easy interpretability and integration into larger, ecosystem-scale models (Doran and Parkin, 1996). Different sets of soil quality indicators have been proposed and used for evaluation of soil quality based on the total data set (TDS) indicator method (Larson and Pierce, 1994; Doran and Parkin, 1994; Karlen et al., 1998).

Among the various soil quality evaluation methods developed so far (Klingebiel and Montgomery, 1961; Ditzler and Tugel, 2002; Doran et al., 1994; Doran and Jones, 1996; Diodato and Ceccarelli, 2004; Larson and Pierce, 1994), soil quality indices are perhaps the most widely and commonly used methods for sustainability and soil management studies (Andrews, et al., 2002). Soil quality indices are particularly significant to soil management practices because of their ability to use site-specific indicators of soil status that can integrate anthropogenic effects over time and over numerous types of effects (Wang and Gong, 1998; Arshad and Martin, 2002).

Soil organic matter (SOM), more precisely soil organic carbon (SOC) content, is widely considered as a key indicator of soil quality. This can be attributed to the fact that presence of SOM/SOC has been found to be beneficial for nutrient retention/recycling, soil productivity, water holding capacity, carbon sequestration (Prescott et al., 2000; Munson and Carey, 2004; Seely et al., 2010; Six and Paustian, 2014). Studying soil organic carbon on a regional or watershed scale invites special attention these days as it is considered a key parameter, playing central roles in various environmental issues such as climate regulation, food and water security (Jague et al., 2016). Quantifying and estimating spatial distribution of SOC is vital for evaluating various soil functions and aids in understanding different soil carbon sequestration processes (Venteris et al., 2004). Similarly SOC stratification ratio has also been used as an indicator for dynamic soil quality (Franzluebbers, 2002; Wang et al, 2010).

Soil quality index estimation, an indirect approach for evaluating soil quality is based on various soil quality indicators and their relative importance for various soil functions (Qi et al., 2009). Scoring of various indicators using diverse scoring functions (Gaussian, sigmoid etc) and assigning weights for each of the attributes, forms the integral part of soil quality index development (Mandal et al., 2010). This approach is widely accepted because of its ability to evaluate the vital relationships between various soil indicators and soil productivity, through the use of various mathematical models (Burrough, 1989; Fu, 1991; Tang, 1997; Dobermann and Oberthur, 1997; McBratney and Odeh, 1997; Sun et al., 2003), apart from its capacity to identify the complexity of soil productivity under various natural conditions as well as different farming practices. For assigning weights to various attributes in determination of soil quality as well as land evaluation procedures, the analytical hierarchy process (AHP) is one of the widely adopted multi criteria decision analysis method (Saaty, 1977).

Thus, determination of soil quality becomes an important prerequisite for better planning and utilization of the land resources. Particularly if we consider the Himalayan ecosystem, it is typically characterized by its low input subsistence agriculture, dwindling productivity and climatic vulnerabilities which demands maximum focus on optimum land use practices for maintenance and improvement of soil quality. For planning and implementation of sustainable land management strategies, detailed spatial information of soil quality is an essential requirement (Zhang et al., 2012). However, there is a lack of quantitative information on spatial variability of soil quality of watershed in the hilly and mountainous terrain of Himalayan region, where easy accessibility is restricted due to ruggedness of the terrain.

Currently, various geostatistical methods such as Inverse Distance Weighted (IDW), kriging, co-kriging etc are widely being used to prepare continuous spatial distribution using point observations of various variables (Viscarra Rossel and McBratney, 1998; Lin and Chen, 2004). The different spatial interpolation techniques estimate parameter values such as SOC, at un-sampled locations using data from point observations and provide us with an ideal tool for meeting our requirement for spatial distribution data (Viscarra Rossel and McBratney, 1998; Lin and Chen, 2004). However, while comparing the various spatial interpolation techniques researchers reported that IDW produced less error in SOM content prediction measured by root mean square error (RMSE) values, in comparison to other interpolation techniques such as kriging (Liu et al., 2015). Spatial distribution maps of soil quality parameters generated by IDW can best represent the true situation prevailing in the watershed and helps us to make judicious interpretations and adoption of better management strategies (Liu et al., 2015).

Thus, keeping in view the importance of soil quality in land use planning and management, the present study was carried out to analyze the soil quality and its spatial variability using remote sensing techniques in a watershed of the North West Himalayan region. Considering the better performance of IDW over kriging, this technique was employed for generation of the spatial distribution map for SOC, SOC stratification and CN ratio of the watershed, which are the prime parameters on which soil quality is dependent. The SQI was also computed based on AHP and their distribution was analyzed to get an overview of the impact of different land use systems on soil quality.

Material and Methods

Study area

The study area is a hilly watershed located between latitudes 32° 4' 35.04" N to 32° 1' 3.8964" N and longitude 76° 39' 49.60" E to 76° 44' 15.84" E and covers a total geographical area of 1000 ha (10 km^2). The watershed is a part of the foothills of Shivalik range in the middle Himalayas (Figure 1). The elevation of the watershed ranges from 1,111 m to 1,651 m above mean sea level. The climate is warm and temperate with an average temperature of 19.1°C and average rainfall of 1250 mm. The coldest month of the year is January with an average temperature of 6.7°C and the hottest month of the year is June with a temperature around 39.6°C. The maximum precipitation occurs during the monsoon period extending from July to September. The slope in the watershed ranges from gently sloping to moderately sloping and around 55 percent of the area holds south west facing slopes. Geology of the watershed indicates presence of pre-cambrain period rocks and is a result of complex tectonism and geological evolution. The lithology of the area consists of shale, dolomite, siltstone, phyllite sandstone, limestone, glauconitic sandstone, carb, calcareous slate etc. Mostly Paddy (*Oryza sativa*) is grown in *kharif* (summer) season and wheat (*Triticum aestivum*) in *rabi* (winter) season and majority of the farmers practice low input subsistence organic agriculture.

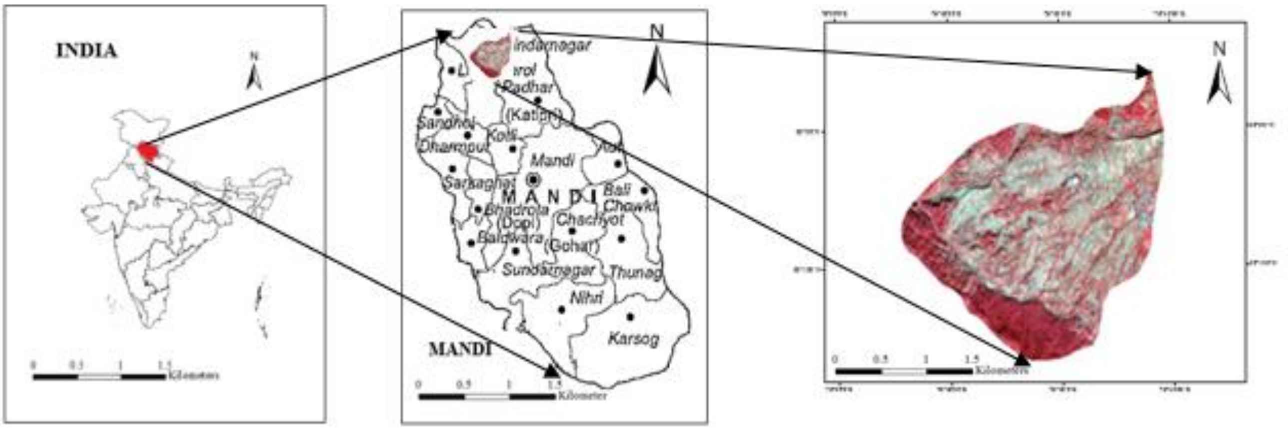


Figure 1. Location of the study area

Soil sampling and laboratory methods

A comprehensive sampling is a crucial step to ensure precise and accurate soil sampling. Grid sampling approach was adopted for soil sample collection, with a grid size of 250 m x 250 m on ground. Survey of India (SOI) topo sheet No. 52 D/12 was used to identify watershed and grids were drawn over Google earth image at 1:10000 scale, for ensuring systematic and well distributed sampling in the field. Using this grid sampling approach, total 150 soil samples (surface i.e., 0-15 cm and subsurface i.e., 15-30 cm) were collected from 75 sampling points, in the fallow period of November 2015. Care was taken to collect soil from exposed portion of field free from any weed growth or litter deposition as well as on or near field bunds. Geographic coordinates as well as elevation of each sampling point were recorded with the help of a portable GPS. The collected samples were air dried in the laboratory and sieved through 2 mm sieve. Air dried 2 mm sieved samples were homogenized and sieved again through 0.2 mm sieve for organic carbon analysis using TOC analyzer, in triplicate (Velmurugan et al., 2009). Similarly 2 mm sieved samples in three replications were homogenized and analyzed for total nitrogen using CHNS analyzer. The other soil parameters such as pH, electrical conductivity (EC), available phosphorus, available potassium as well as soil texture were estimated using standard analytical procedures.

Soil organic carbon (SOC) was estimated using TOC analyzer. Total nitrogen (TN) present in the soil samples were estimated using CHNS analyzer. Processed soil samples were used for estimation of pH and EC (1:2), using pH meter and conductivity meters respectively (Jackson, 1973). Soil texture (sand, silt and clay %) was estimated by dispersing soil samples in distilled water using sodium hexametaphosphate followed by Bouyoucos hydrometer method (Bouyoucos, 1962). Available phosphorus was estimated spectrophotometrically, by extraction of soil samples using Bray No.1 reagent followed by colour development using Murphey-Riley solution (Murphy and Riley, 1962). Available potassium in soil samples were estimated using a flame photometer, after extraction with ammonium acetate solution (Jackson, 1973). The C:N ratio was calculated using the soil organic carbon and total nitrogen contents of soil samples. The SOC values were divided by total nitrogen values to yield C:N ratio values of each soil sampling site.

SOC stratification ratio and soil carbon density

According to Franzluebbers (2002), stratification ratio is defined as the ratio of the value of a soil property at the soil surface to its value at a lower depth. It is generally used as an indicator of dynamic soil quality. In the present study, SOC stratification ratio was determined as the ratio of SOC content (g kg^{-1}) at 0-15 cm depth to that of 15-30 cm depth.

SOC density of each soil layer was estimated using the equation which was used by Schwager and Mikhailova (2002) as well as Wang et al. (2010). We used the upper 30 cm depth for estimation of SOC density, as suggested by earlier researchers like Bernoux et al., (2002), Bhatti et al. (2002) and Wang et al. (2010).

$$D_{oc} = SOC \times \gamma \times H \times \left(1 - \frac{\delta 2nm}{100}\right) \times 10^{-1} \quad (1)$$

Where D_{oc} and SOC are the density (t ha^{-1}) and content (g kg^{-1}) of soil organic carbon, respectively; γ is the bulk density (g cc^{-1}); H is the thickness of soil layer (cm); and $\delta 2nm$ is the fraction (%) of soil particles with >2mm particle size. Since the soil in the study area was loamy type with particle size mostly below 2 mm, this was not calculated. In this study two different bulk density values were used, as earlier studies in the area (Kumar and Verma, 2005) indicated higher bulk densities in the lower depths, due to impact of various agricultural activities. So we used bulk density values of 1.3g cc^{-1} and 1.4 g cc^{-1} for the surface (0-15 cm) and subsurface (15-30 cm) layers respectively.

Soil Quality Index

For assessing the variation in soil quality, important soil properties like SOC, N, available P, available K, clay % and pH were used for the development of soil quality index.

The SQI was computed by assigning scores and weights to the various selected soil properties. The weights were allocated using AHP and the scores were allocated based on their function towards soil quality. It was computed for the surface soil layer collected from 75 sampling points.

Assigning Weights Using AHP

AHP is a powerful Multi-Criteria Decision Making (MCDM) tool based on mathematics, which enables to organize and analyze complex decisions and ensures consistency in judgment (Saaty, 1977; Mishra et al., 2015). Here the situation under consideration, namely assessment of soil quality index was studied and the criterions were established using AHP. The next and most important step performed is developing ratings for each criterion. It was achieved through pair wise comparison matrix and standardized matrix. The pair wise matrix enables to assign ratings for indicators under consideration and the standardized matrix enables normalization of these values. Then consistency ratio was calculated to check the appropriateness of ratings allocated.

The pair wise comparison in AHP enables allocation of comparative rating between each criterion involved in the study. This was achieved by following Saaty Scale for Pairwise comparison given in Table 1 (Saaty, 2008; Chandio, et al., 2011). Then the values or ratings were normalized through standardization matrix. It was achieved as each value is normalized to the scale of 1 by dividing it with the sum of total values within respective columns. Consistency Index (CI) analysis ensures that the ratings allocated to the indicators are consistent to the situation under consideration. The consistency index (CI) is calculated as

$$CI = \frac{\lambda MAX - N}{N - 1}$$

Where N=total number of criterion, λMAX = priority vector*column sum

Consistency Ratio (CR) is a measure of precision and acceptability of AHP. The value of CR should be less than 0.1 for the weights to be accepted. It is the ratio of CI by RI (Random Index).

$$CR = \frac{CI}{RI}$$

Where, RI is calculated for the number of criteria involved and is predefined by Saaty.

Table 1. The weight and relationship as per Saaty (2008)

Weight for Importance	Relationship
1	Equal Importance
2	Weak or Slight
3	Moderate Importance
4	Moderate Plus
5	Strong importance
6	Strong Plus
7	Very Strong
8	Very Very Strong
9	Extreme Importance

The RI values defined for number of criteria is given in Table 2.

Table 2. RI values against Number of Criteria

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Assigning scores for various indicators

Scoring was done distinctly for different parameters on a scale of 0 to 1 based on their function towards soil quality assessment. For parameters which improve/enhance soil quality with increase in their potential concentration in soil i.e. "more the better" condition, the values were divided by the highest observed value. Similarly for parameters which reduce the soil quality with increase in their concentration i.e. "less the better" condition, lowest observed value was divided by the parameter value (denominator). But for indicator values which follows normal distribution curve like pH, scoring is done as 'higher is better' upto a threshold level (value of 7), then scored as 'lower is better' above the threshold depending on the range into which the indicator value is falling (Andrews et al., 2002; Roy and Kumar, 2014).

Computation of Soil Quality Index (SQI)

Soil Quality Index (SQI) was calculated using the concept proposed by Wu and Wang (2007). It is estimated as summation of the product of weight and score assigned to each parameter or indicator under the consideration.

$$SQI = \sum_{i=1}^{n} (Wi * Si)$$

Where, W is the respective weight and S is the respective score assigned for each soil quality indicator, under consideration.

The values of scores and weights assigned to the respective indicators were multiplied and summed up to yield the SQI value at each sampling locations. The SQI thus generated for all the 75 sampling points were then interpolated to generate spatial distribution map of SQI of the watershed using IDW interpolation technique (Inverse Distance Weighting).

Spatial variation of soil quality parameters and Soil Quality Index

IDW, a widely used interpolation technique (Wang et al., 2010, Gong et al., 2010, Liu et al., 2015) was used for generating spatial distribution maps of SOC content (g kg^{-1}), SOC stratification ratio, C:N ratio as well as soil quality index in the watershed. This technique determines cell values at un-sampled locations using a linearly weighted combination of a set of sample points. It assumes that the variable being mapped decreases in influence with distance from its sampled location (Gong et al., 2010).

Software used and Statistical data analysis

Statistical analysis of soil data was carried out using Microsoft Excel and plots were obtained using R software ver 3.3.1. ArcGIS 10.3 software was used for handling of spatial data. IDW interpolation for spatial mapping of various soil quality parameters was done using ArcGIS 10.3 software. Various descriptive statistical parameters of the data were estimated to capture an idea about its trend. The major parameters estimated were mean, standard deviation (SD), variance, maximum and minimum values. To know the variation among individual observation of each layer coefficient of variation (CV) was calculated as ratio of standard deviation to the mean value. Differences in distribution of SOC at different soil depth layers were assessed by performing one-way ANOVA.

Results and Discussion

Distribution of SOC in the watershed

The various statistical parameters of SOC at two depths (0-15 cm and 15-30 cm) in the watershed are given in Table 3. The average SOC content of the watershed is 11.95 g kg^{-1} up to 30 cm depth. The coefficient of variation (Cv) was observed to be moderately high with values of 35.8 percent and 33.5 percent at 0-15 cm and 15-30 cm depths, respectively. The Cv values in the range 10 to 90 percent denotes moderate variability, thus the SOC have moderate variability in the study area. It indicates heterogeneous spatial distribution of SOC, which may be due to variation in land use, soil depth, terrain characteristics, topography and other factors (Fang et al., 2012).

Table 3. Statistical parameters of various soil quality indicators at different depths.

Soil quality indicators	Depth	Mean	S.D	Variance	Cv (%)
pH	0-15	4.85**	0.26	0.07	5.31
	15-30	5.17**	0.34	0.12	6.64
SOC	0-15	13.42**	4.80	23.08	35.8
	15-30	10.49**	3.51	12.34	33.5
Clay	0-15	3.47**	2.45	5.98	70.59
	15-30	4.67**	3.04	9.25	65.18
Nitrogen	0-15	0.16**	0.04	0.002	24.48
	15-30	0.12**	0.03	0.001	27.48
Available P	0-15	12.89#	3.90	15.21	30.25
	15-30	12.83#	3.70	13.69	28.83
Available K	0-15	127.93#	66.02	4358.76	51.61
	15-30	120.65#	56.65	3209.57	46.96

*** Means are significant at *P <0.01* # Means are not significantly different

The SOC content varied significantly at depths of 0-15 cm and 15-30 cm depths (P<0.001), with average values of 13.42 g kg^{-1} and 10.49 g kg^{-1} respectively. The standard deviation as well as variance was also found to be higher in the surface layer compared to sub surface layer. The distribution ranges of SOC content at these depths are shown in the boxplot (Figure 2). It clearly indicates that SOC content decreased with increasing soil depth. Outlier values at both depths were also identified using the inter quartile range (IQR) relationship. These results are in agreement with the findings of various researchers who reported higher SOC contents at the surface soil in hilly watershed (Wang et al., 2010; Wen et al., 2015), mountainous landscape (Liu et al, 2015), terraced rice fields (Li et al., 2015), erosion affected landscape (Jague et al., 2016), as well as an altitudinal gradient in the mountainous region (Parras-Alcántara et al., 2015). Similar variation of soil organic carbon with depth, has also been reported by Bera et al. (2016), under corn production systems with addition of various organic amendments.

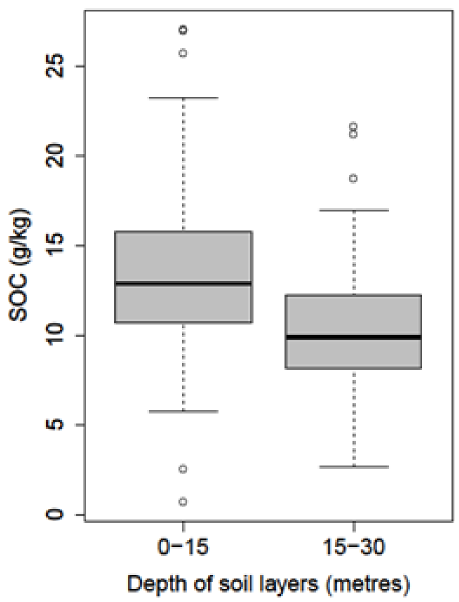


Figure 2. Boxplot showing SOC distribution at different depth layers

Spatial distribution of SOC

Spatial distribution maps of SOC at different depths were generated using IDW interpolation technique (Figure 3). The maps indicated spatial variation in the SOC distribution at both surface and subsurface layers. The maps indicate a gradient in SOC distribution, with lower SOC contents at the west side of watershed which increases gradually towards east. The pattern was evident in both the depths (0-15 cm and 15-30 cm). In the surface layer, nearly 15.48 percent, 56.52 percent and 27.99 percent area were found to have SOC content less than 10 g kg^{-1}, between 10 to 15 g kg^{-1} and more than 15 g kg^{-1}, respectively (Table 4). In the subsurface layer, the area under less than 10 g kg^{-1}, between 10 to 15 g kg^{-1} and more than 15 g kg^{-1} accounted for 50.77 percent, 47.27 percent and 1.96 percent of the total watershed area. This indicates the increased effect of disturbances and interventions in the form of tillage as well as residue addition at the surface layer (Diacono and Montemurro, 2010). The predicted spatial distribution maps were generated using IDW technique and it revealed large spatial variation of SOC content in the study area. Liu et al. (2015) reported lesser error in prediction of SOC by IDW, indicated by lower RMSE values, in comparison with Universal Kriging (UK) technique, in a hilly mountainous terrain.

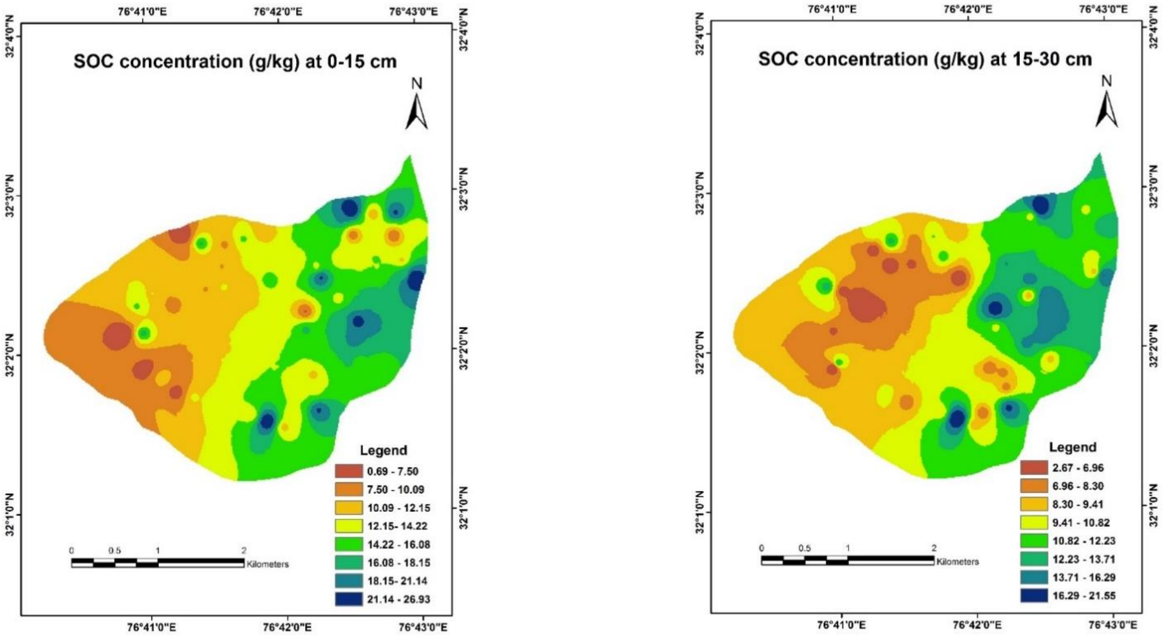


Figure 3. Spatial distribution of SOC concentration (a) 0-15 cm and (b) 15-30 cm

Table 4. Area distribution of SOC at different depths in the study area

SOC (g/kg)	Surface (0-15cm)	Subsurface (15-30 cm)
	Area (ha) (%)	Area ha (%)
< 10	154.78 (15.48%)	507.46 (50.77%)
10-15	564.91 (56.52%)	472.48 (47.27%)
>15	279.78 (27.99%)	19.54 (1.96%)

SOC stratification ratio

Stratification ratio is widely used as an alternative tool for soil quality assessment in order to overcome the inherent differences in the capabilities of varied environments for carbon sequestration. It is widely used as an indicator of dynamic soil quality induced by various management practices. It is used as a relative measure than absolute, where the extent of stratification is considered as indicator of soil quality, as surface SOC is vital in controlling erosion, infiltration as well as conservation and release of various soil nutrients (Franzluebbers, 2002). The SOC stratification ratio varied from 0.09 to 3.36 in the study area (Figure 4a). The spatial distribution of stratification ratio was generated by spatial interpolation using IDW method in the entire watershed.

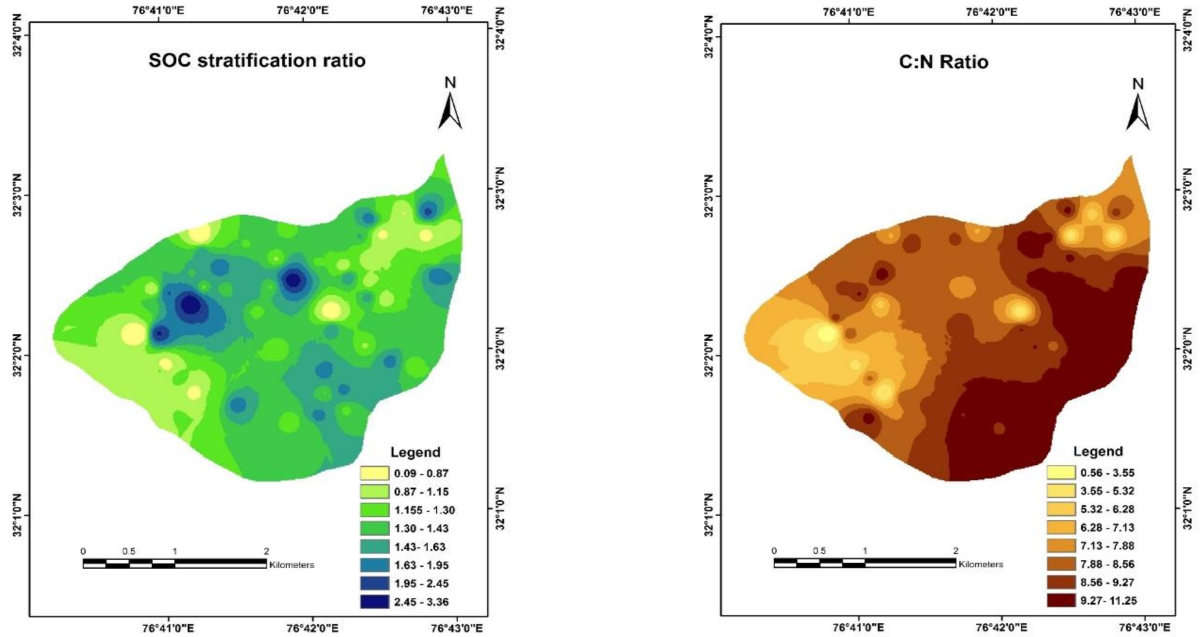
SOC stratification ratio value >2 indicates improvement of soil quality under no tillage (Franzluebbers, 2002). As the present study doesn't deal with no tillage situation, it will be inappropriate to use this threshold value for soil quality assessment. Wang et al. (2010) used a threshold value of SOC stratification ratio > 1.2 as an indicator of improving soil quality, using cropland and orchards as reference. In the watershed under study, nearly 77% area having SOC stratification values > 1.2, thus indicating good soil quality (Figure 4a). The high values of >2 are located at very few localized areas (nearly 1.73% of total area), which might be due to continous addition of farmyard manure (FYM) or organic matter by the farmers practicising subsistence agriculture (Table 5). Those areas with SOC stratification values < 1.2 may need special attention and management strategies for improving soil quality. These areas may be managed with improved addition of manures and crop residues in conjunction with proper incorporation and controlled soil disturbance for sustainable agricultural production.

Table 5. Areal distribution of SOC stratification ratio

SOC stratification ratio	Area (ha) (%)
< 1.2	228.93 (22.91 %)
1.2-2.0	753.19 (75.36 %)
>2.0	17.33 (1.73 %)

C:N Ratio

C:N ratio values varied from 0.56 to 11.25 in the watershed (Figure 4b). The C: N ratio varied as a smooth gradient in the east-west direction, with higher values observed at eastern region. C: N ratio values <12:1, indicated high degree of soil quality and increased rate of organic matter mineralization (Heal et al., 1997). This may be due to the low input organic agriculture including organic manure as well as green manure additions and non-mechanized ploughing (Ryals et al., 2014), adopted widely in the study area. It also indicates the presence of vibrant microbial population capable of adequately decomposing added organic matter and thus releasing the essential nutrients contained in it for plant growth (Diacono and Montemurro, 2010).



(a) (b)

Figure 4. Spatial distribution of (a) SOC stratification ratio (b) CN ratio

Soil Quality Index calculation

Soil quality index was computed using various soil parameters i.e., indicators which have a prominent influence on crop growth and yield. The soil parameters used to compute SQI were SOC, pH, N, clay percentage, available P and available K. The mean values along with the distribution of these soil quality parameters used for SQI development, at different depth layers in the watershed are shown in Figure 5. The weights were assigned to various soil quality indicators based on AHP analysis and are given in Table 6**.** The soil quality indicators for each sampling location were transformed using linear scoring functions, so that each indicator was assigned a score, ranged between 0 and 1. The linear scoring function adopted was based on the concepts of "more is better" and "less is better" or a combination of both. Soil parameters such as SOC, N, K and percent clay, where the higher values were considered better, the highest value of all the indicators received a score of 1, which is the maximum. The scores of all these indicators were then obtained by dividing the corresponding observed indicator values with the highest value. In case of the available P indicator, 'more is better' concept is valid upto a threshold value of 50 kg ha^{-1} (Wander et al., 2002) and thereafter 'less is better' concept was followed. In the study, the available P values were less than the threshold of 50 kg ha^{-1}, thus only the 'more is better' concept was used for scoring. Similar approach including the combination of both concepts was used for scoring the pH values, with the threshold fixed at a pH value of 7.0 (Andrews et al., 2002).

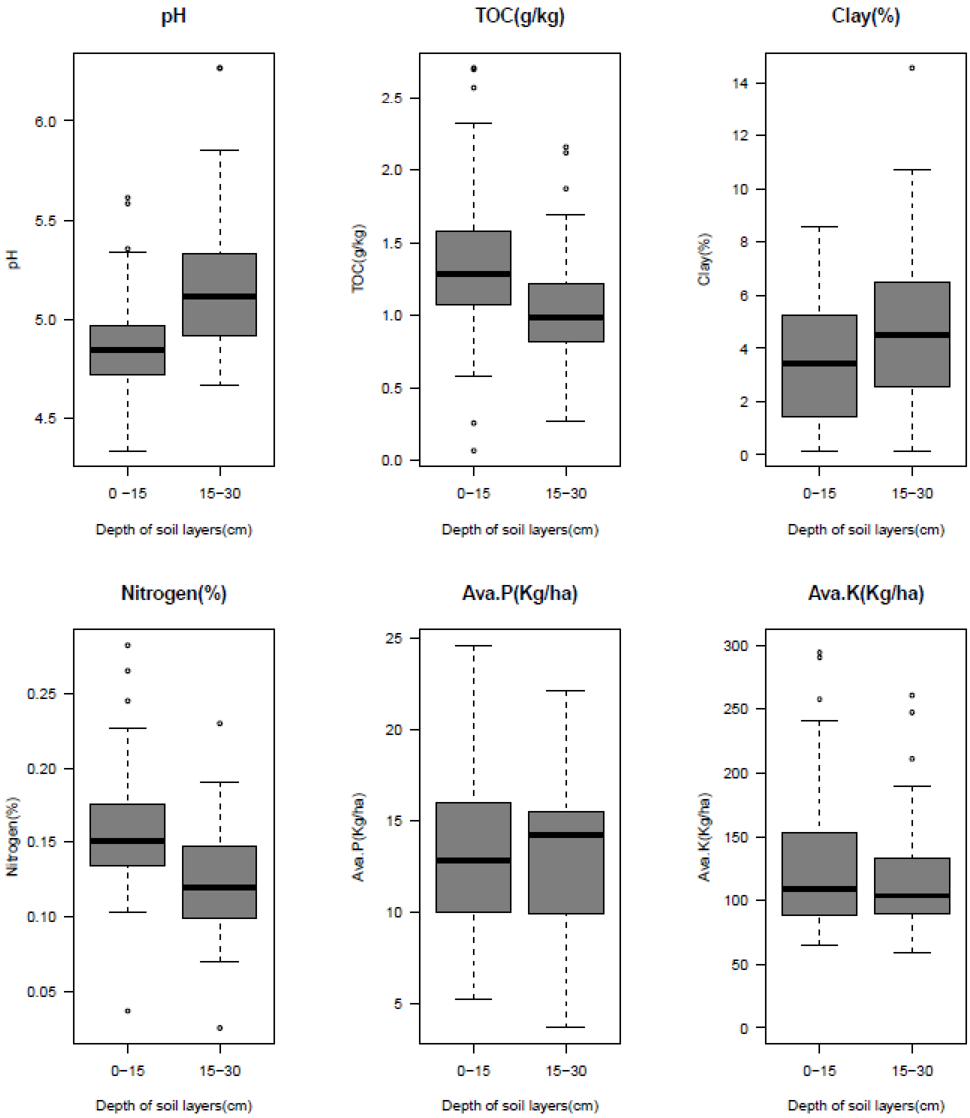


Figure 5. Boxplots showing distribution of various soil quality indicators at different depth layers

Table 6. Weights assigned for various soil properties using AHP

Sl No	Soil Property	Weight (%)
1	SOC	37.5
2	pH	23.1
3	N	16.5
4	Clay (%)	9.3
5	Available P	6.9
6	Available K	6.6

The scores for all the six indicators were multiplied by their corresponding weights (assigned using AHP) and summed up to derive the SQI value for all the 75 sampling points in the watershed. The average SQI value was observed to be 64.5, with the values ranging from a minimum of 47.4 to a maximum value of 87.8, within the watershed. The spatial distribution of SQI within the watershed was also generated by IDW interpolation (Figure 6), which depicted higher SQI values at the higher elevation region of the watershed in comparison to the lower values at lower region. It also indicated a gradient in SQI distribution, with comparatively lower values at the west side of watershed which increased gradually towards east. This may be attributed to the closer proximity to settlement area of farmers, which increased the addition of organic manures and other inputs. In comparison to fields at the higher elevation areas and eastern side of watershed, which are closer to farmer houses, the fields at lower elevation and western side are comparatively far away, which adversely affects the regular addition of organic manures. Nearly 76% of the study area had SQI values in the range of 60-75, whereas 22.16% of the area had SQI<60 and 2.59% had SQI>75 (Table 7). This shows that large area of the watershed had SQI values of 60 percent of the maximum possible value of SQI, which necessitates the adoption of better management practices for improving the soil quality.

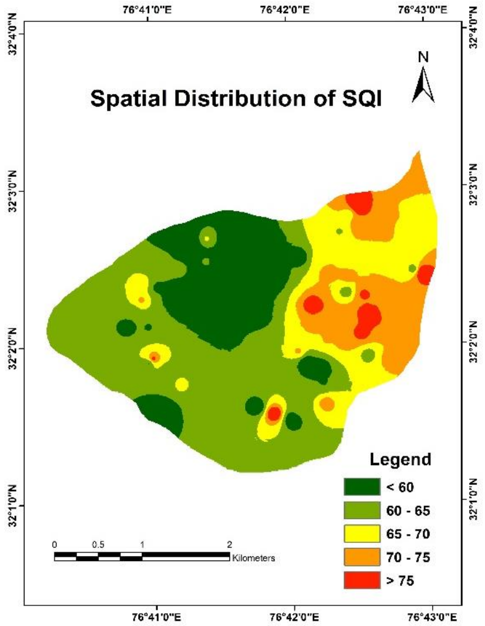


Figure 6. Spatial Distribution of Soil Quality Index (SQI)

Table 7. Areal distribution of SQI values in the watershed

Sl No	SQI range	Area (ha)	Area (%)
1	<60	221.65	22.16
2	60-65	420.90	42.90
3	65-70	181.12	18.11
4	70-75	149.91	14.99
5	>75	25.90	2.59

Conclusion

Understanding and characterizing soil quality is a key issue in sustainable soil and land management. It's inviting greater attention these days due to its key roles in global carbon cycle, mitigation of land degradation, enhancement of crop production and food security. Soil quality parameters as well as soil quality index (SQI) are used to assess sustainable use of land resources. The soils in study area had an SQI value ranging from 60-75 indicating good soil quality throughout the watershed. It indicates that the present land use and cropping pattern followed by the farmers are helpful in maintaining the organic C concentrations in the watershed area. Also, the remoteness of the location and difficult accessibility to improved fertilizers and high yielding varieties restricts the farmers to use the modern agriculture inputs needed for intensive agriculture. They are mainly dependent on the animal manures and composts to supply nutrients to the crop plants which helps to maintain high organic C and hence the high SQI.

However this study gives only a glimpse of the variation in SQI due to land management practices for the Himalayan region. More intensive studies on this aspect will help in generating vital information required for sustainable land use planning and assessing soil quality under various management practices and appropriate nutrient management in fragile ecosystems of hilly area. Also, since North West Himalayan states have great potential for different high value horticulture crops which can be adopted under organic practices these studies would help the policy makers to frame the policies for promoting organic agriculture in the areas because of the intangible benefits of high soil quality and organic C and better income generation of the farmers in these areas.

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