Soil Quality Assessment for Different Land Use in the Panchase Area of Western Nepal

Subin Kalu[*1], Madan Koirala[2], Udhab Raj Khadka[3], Anup K C[4]

[1,2]Central Department of Environmental Science, Tribhuvan University, Kirtipur, Kathmandu, Nepal

[3,4]Amrit Campus, Tribhuvan University, Thamel, Kathmandu, Nepal

[*1]kaluunique@gmail.com; [2]mkoirala@cdes.edu.np; [3]udhabk@yahoo.com; [4]kcanup04@gmail.com

***Abstract*-Soil quality management helps to maintain biological productivity; air and water quality; and human habitation and health. As improper land management can deteriorate soil function, the evaluation of soil quality for different land use is necessary. To evaluate soil quality for different land use types in the Panchase area, soil quality index was computed on the basis of the soil management assessment framework. Protected forest has the highest soil quality index (0.95) followed by community forest (0.91), pasture (0.88), khet (0.81), and bari (0.79). Available phosphorus and soil organic carbon play major roles in making significant differences in the SQI among the different land use types. Less anthropogenic impact and vegetation in forest land result in better soil quality, whereas attempts to increase productivity in cultivated land degrade the soil quality. The proper application of fertilizer and giving priority to organic farming is recommended to improve soil quality.**

Keywords*- *Land Use; Soil Management Assessment Framework (SMAF); Soil Quality; Soil Quality Index (SQI)

I. INTRODUCTION

Soil is a complex mixture of mineral nutrients, organic matter, water, air, and living organisms determined by various environmental factors such as climate, parent materials, relief, organisms, and time factors [1]. Physio-chemical characteristics of soils vary in space and time because of variations in topography, climate, weathering processes, vegetation cover, microbial activities, and other biotic and abiotic factors [1, 2]. Soil fertility depletion is important process in land degradation and a major constraint to improve food security in developing countries [3].

Soil quality is the ability of a soil to function within an ecosystem boundaries to sustain biological productivity, maintain air and water quality, and support human habitation and health [4]. Soil quality has two parts: the intrinsic part covering the inherent capacity of the soil for crop growth, and the dynamic part influenced by the soil user or manager [5]. Dynamic soil quality is the result of human use and management on soil function [6]. Soil quality includes physical, chemical, and biological properties of soil that depends on the soil nutrient pools and reserves, which are modulated by land use and a number of other management factors [7]. Degradation of soil quality has posed a threat to agricultural productivity, economic growth, and healthy environment on a global scale [8] caused by improper land use and soil management, erratic and erosive rainfall, steep terrain, deforestation, and overgrazing. In developing countries like Nepal, use of chemical fertilizers and pesticides for the sake of over-production has been the primary cause of soil degradation [9]. Additionally, socioeconomic and political issues such as land tenure, capital, and infrastructure hasten the degradation [10].

Soil functions not only in the production of food and fibers, but also in the maintenance of environmental quality which increases the importance of evaluation of soil quality [11]. As the mismanagement of soil can cause harmful changes in soil function, there is need for tools and methods to assess and monitor soil quality [12]. For the effective evaluation of soil quality, an understanding of the relationship between a soil indicator and a soil function is necessary. These relationships are necessary to determine if changes in a soil indicator represent improvement or degradation of a soil function and to determine if differences in the value of an indicator between treatments or over time are meaningful. There are a number of approaches for assessing soil indicators and soil functions. One effective tool to relate soil indicator measures to soil function is the soil management assessment framework (SMAF) [13], which is an additive, non-linear indexing tool for assessing soil function using scoring curves [14]. The scoring curves in the SMAF require soil indicator data along with crop and soil information.

Knowledge of soil quality is important for appropriate decision making regarding sustainable land use systems [15]. However, individual soil properties alone may not be sufficient for the assessment of soil quality [14]. An effective tool utilizes the concept of the soil quality index (SQI), which is based on a combination of soil properties that better reflect the status of soil quality compared to individual parameters [14, 16]. SQI can be an important tool for planners and decision makers to combat soil quality degradation through the introduction of appropriate intervention. However, few studies regarding the SQI in relation to different land use have been reported [17]. Therefore, this study was conducted to assess and evaluate soil quality of different land use and management types using the SQI.

DOI: 10.5963/IJEP0501006

II. MATERIALS AND METHODS

A. Study Area

The study was carried out in the Panchase area, which is the junction of the Kaski, Syangja, and Parbat districts of Nepal. It lies in the west of Pokhara in the western mid-hills of Nepal between the longitudes of 83°45′ and 83°57′E and latitudes of 28°12′ and 28°18′N. It ranges in altitude from 800m to 2517m from mean sea level. The mean annual air temperature varies from 20 to 25°C. This region is one of the highest rain-receiving areas of Nepal, with more than 5,000mm precipitation per year, resulting in humid climatic conditions [18].

The Panchase area consists of forest, grassland, and cultivated land, with forest land covering 50.5% of the total land. Forests are categorized into two groups, protected forest and community forest. Protected forest covers 68.69% of the total forest, and is protected by the government. The remaining forest land is community forest, managed by local communities [19]. Grasslands are mainly used as pastures for rearing livestock, and covers 10% of the total land; cultivated land covers 38.3%. Cultivated lands are divided into two types, Khet and Bari. Khet are irrigated lowland leveled terraces with paddy rice as the dominant crop. Bari is the rain-fed upland sloping terraces with maize, millet, and seasonal vegetables. Different land management practices in these land use types lead to differences in soil quality. Major crop/vegetation in different land use types of the Panchase area is mentioned in Table 1.

TABLE 1 LAND USE TYPE OF THE PANCHASE AREA

Land use types	**Major Crop/Vegetation**
Khet	Rice/Paddy
Bari	Vegetables, Maize, Barley etc.
Grassland	Grasses (mainly used as pasture)
CF	*Pinus roxburghii, Schima wallichii, Alnus nepalensis*
PF	*Quercus semecarpifolia, Daphniphyllum himalense, Rhododendron arboretum*

B. Soil Sampling and Analysis

A total of 60 soil samples consisting of 12 from each land use management type were collected from the plough layer surface (0 to15 cm) to quantify soil nutrient reserves and soil quality. The soil samples were analyzed for specific physical and chemical indicators. Soil pH was determined using 1:5 soil to water ratio and then analyzed by digital pH meter. Bulk density (BD) was determined by the core method [20]. Soil moisture content (θ_g) was determined from the core samples by calculating the difference between the wet core soil and the oven-dried soil. Water-filled pore space (WFPS) was calculated as ($\theta_g \times$BD)/(1-BD/2.65). Soil texture was determined bythe Bouyoucos hydrometer method [21]. Total nitrogen (TN) was determined by the Kjeldahl method [22], and the soil organic carbon (SOC) was analyzed with the Walkley-Black method [23], available phosphorus (P) by the modified Olsen’s method [24], and the available potassium (K) was analyzed by flame photometer after extraction using 1M ammonium acetate at pH 7.

C. Soil Quality Index Computation

For the assessment of soil quality, the soil quality index (SQI) was computed on the basis of the soil management assessment framework (SMAF). It includes three steps: indicator selection, indicator interpretation, and integration into an index [14].

1) Indicator Selection

The potential soil quality indicators were selected on the basis of the management goal of increasing productivity and protecting the environment by taking into consideration the ease and cost of sampling and laboratory analysis.

2) Indicator Interpretation

This step involved the transformation of the observed indicator value using a non-linear scoring curve into the unit less values from 0 to 1 using SMAF interpretation (version 2013-04) so that the scores could be combined to form a single value. The general relationship between a given indicator and the soil function dictates the shape of an indicator’s scoring curve. Some general shapes include more-is-better, less-is-better, and mid-point-optima [14].

3) Integration into an Index

This step was accomplished by summing the scores for each indicator and dividing by the total number of indicators.

$$SQI=\left(\frac{\sum_{i=1}^{n} S_i}{n}\right) \qquad (1)$$

(S represents the scored indicator value and n is the number of indicators.)

DOI: 10.5963/IJEP0501006

D. Data Analysis

To test the difference between soil quality parameters and soil quality index of the different land use types, one way analysis of variance (ANOVA) followed by Tukey HSD was performed using SPSS.

III. RESULTS AND DISCUSSION

A. Effects of Land Use Types on Soil Quality Parameters

The average value of the soil quality parameters varied among the different land use types (Table 2). One way ANOVA revealed that soil parameters like soil pH, soil moisture, bulk density, total nitrogen, available phosphorus, and soil organic carbon were significantly different among the different land use types ($P < 0.05$).

The texture of the soil common to all the land use types was sandy loam. Bulk density was found to be significantly higher in pastures, followed by agriculture soil (khet and bari) and then forest soils. Forests usually have loose soil due to the decomposition of fallen litters [25]. Regular tilling in cultivated land decreases bulk density, whereas soil compaction due to grazing animals could possibly lead to the higher bulk density in the pasture. The soil was found to be acidic in all the land use types (pH < 7). The Panchase area is one of the highest rain-receiving regions of Nepal. Due to the active rain, the basic cations are leached away, making the soil acidic [25]. Soil pH was significantly higher in the bari and pasture, followed by protected forest, khet, and community forest. The community forest was dominated by pine trees, and soils of pine forests are usually acidic due to the decomposition of fallen pine leaves. The higher level of soil pH in the bari could be due to the continuous application of compost, animal dung, and manure, which might have worked as liming. On the other hand, the acidic soil may be due to the acids released by the decomposition of organic residues from forest vegetation [1].

TABLE 2 MEAN (SD) OF SOIL QUALITY PARAMETERS OF DIFFERENT LAND USE TYPES

Landuse		pH	Moisture[%]	BD[g/cm^3]	TN[%]	P[mg/kg]	K[mg/kg]	SOC[%]	WFPS
Khet	Mean	5.71^{b}	32.28^{ab}	1.17^{ab}	0.16^{b}	62.48^{ab}	343.44^{a}	1.29^{c}	0.60^{a}
	SD	0.51	7.54	0.18	0.06	12.31	55.44	0.27	0.13
Bari	Mean	6.35^{a}	37.13^{ab}	1.08^{abc}	0.17^{b}	95.53^{a}	364.32^{a}	1.38^{bc}	0.64^{a}
	SD	0.65	9.99	0.16	0.07	50.00	93.32	0.37	0.18
Pasture	Mean	5.93^{ab}	27.98^{b}	1.21^{a}	0.18^{b}	29.25^{bc}	308.53^{a}	1.60^{abc}	0.56^{a}
	SD	0.35	8.11	0.12	0.08	25.45	78.06	0.38	0.19
CF	Mean	5.13^{c}	38.66^{ab}	1.00b^{c}	0.21^{ab}	30.50^{bc}	296.82^{a}	1.86^{ab}	0.61^{a}
	SD	0.15	11.73	0.17	0.09	31.04	56.82	0.60	0.13
PF	Mean	5.80^{b}	41.03^{a}	0.91^{c}	0.29^{a}	27.20^{c}	304.87^{a}	2.03^{a}	0.55^{a}
	SD	0.30	15.83	0.16	0.09	13.30	75.68	0.45	0.16

Means not followed by same letters are significantly different along the column.

Soil moisture was found to be significantly different in the pasture and protected forest. The pasture consisted of the lowest soil moisture content due to the evaporation of soil water. The high canopy coverage in the protected forest blocks the sunlight, retaining water and maintaining the highest soil moisture content. The soil organic carbon was significantly higher in the forest soils and pasture, followed by agriculture land. In natural forest conditions, all the organic matter produced by the vegetation is returned to the soil and the soil is not disturbed by tillage. In cultivated areas, much of the plant materials are removed for human or animal food and relatively fewer amounts find their way back to the land. Also, soil tillage aerates the soil and breaks up organic residues, making them more accessible to microbial decomposition [25]. The soil organic carbon rapidly declines with continuous cultivation [26]. Similarly, total nitrogen was found to be significantly higher in the forest, followed by pasture and agriculture land. The total nitrogen was higher, as expected, because large amounts of nitrogen are bound in organic matter. The conversion of natural forest into agriculture land reduces soil N in the long run [27]. The available phosphorus was found to be significantly higher in the agriculture land, followed by community forest, pasture, and protected forest. The use of fertilizers, with the expectation of over-production, in the agricultural land led to an increase in the concentration of available phosphorus. The low concentrations of available phosphorus in the pasture and forest soils might have been related to phosphorus fixation [28].

B. Soil Quality Index (SQI) of Different Land Use Types

Based on the researcher's knowledge and literature recommendations, the selected indicators from available data sets for calculating the SQI are soil pH, BD, available P, SOC, available K, and WFPS. A fewer number of carefully chosen indicators, when scored non-linearly and used in a simple index, can adequately provide the information needed for decision making [29]. For the selected indicators, the observed value was transformed into unitless scores that range from 0 to 1 using non-linear scoring curves developed by Andrews, et al., 2004 [14] and Wienhold, et al., 2009 [30]. The shape of the scoring curve of the

DOI: 10.5963/IJEP0501006

soil pH, available P, and WFPS was mid-point optima (Gaussian function), the SOC and available K was more-is-better (upper asymptotic sigmoid curve), and that of the BD was less-is-better (lower asymptote) (Fig.1). After indicator interpretations, the individual scores were integrated into the SQI using Eq. (1). A SQI value close to 1 refers to the best functioning soil, while a relatively lower value refers to degraded soil.

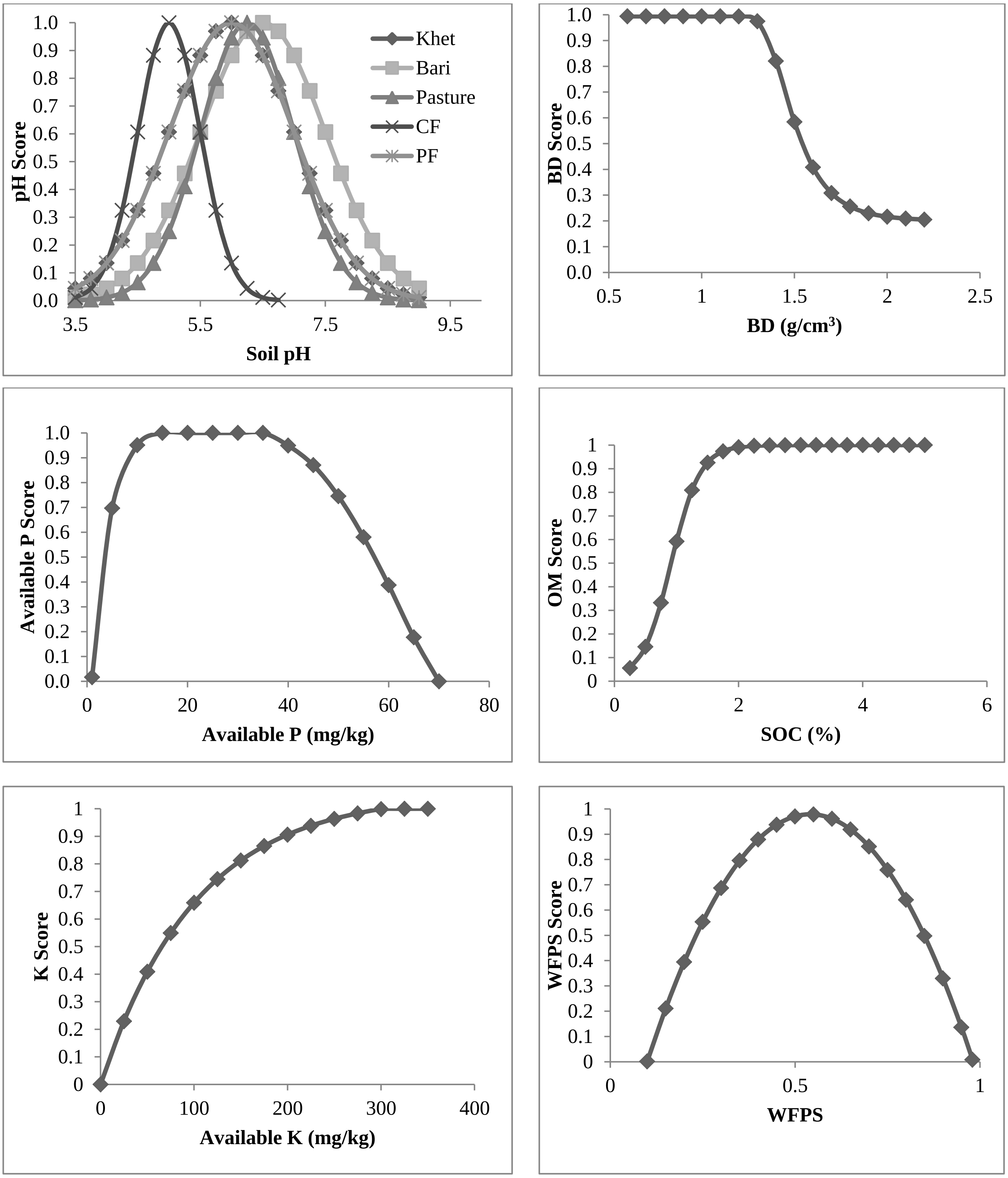

Fig. 1 Non-linear scoring curves for the selected indicators

The SQI was found to be significantly higher in the protected forest, followed by the community forest, pasture, khet, and bari (Table 3). The protected forest in the Panchase area is situated at a higher altitude and is less affected due to the anthropogenic effect. The decomposition of fallen litters from the trees provides organic matter and other nutrients for the soil,

DOI: 10.5963/IJEP0501006

maintaining the soil fertility. However, in the cultivated land, the activities like tilling and the application of chemical fertilizers and pesticides degrade the soil quality. Similar results were obtained from the Mai-Negus catchment of northern Ethiopia where the natural forest land systems have relatively good soil quality, whereas the uncultivated marginal land systems have seriously degraded soil [17]. Similarly, it was reported that the clearing and cultivation of forested lands resulted in the deterioration of soil properties compared to soils under well-stocked natural forest in the tropical forest ecosystems of Bangladesh [31].

TABLE 3 MEAN (SD) OF PARAMETER SCORE OF DIFFERENT LAND USE TYPES

Landuse		**pH Score**	**BD Score**	**P Score**	**SOC score**	**K Score**	**WFPS Score**	**SQI**
Khet	Mean	0.86 [a]	0.95 [a]	0.38 [b]	0.79 [b]	0.99 [a]	0.88 [a]	0.81 [bc]
	SD	0.13	0.08	0.28	0.11	0.02	0.09	0.05
Bari	Mean	0.85 [a]	0.98 [a]	0.29 [b]	0.82 [ab]	0.99 [a]	0.78 [a]	0.79 [c]
	SD	0.22	0.03	0.39	0.12	0.02	0.21	0.11
Pasture	Mean	0.86 [a]	0.96 [a]	0.75 [a]	0.91 [ab]	0.99 [a]	0.82 [a]	0.88 [ab]
	SD	0.20	0.08	0.37	0.08	0.01	0.18	0.08
CF	Mean	0.93 [a]	0.99 [a]	0.77 [a]	0.91 [ab]	0.98 [a]	0.87 [a]	0.91 [a]
	SD	0.07	0.00	0.38	0.15	0.04	0.13	0.06
PF	Mean	0.94 [a]	0.99 [a]	0.96 [a]	0.95 [a]	0.97 [a]	0.87 [a]	0.95 [a]
	SD	0.05	0.00	0.05	0.11	0.04	0.15	0.03

Means not followed by same letters are significantly different along the column

One way ANOVA showed that the P and SOC scores were significantly different in different land use types ($P < 0.05$), i.e. P and SOC were two major parameters that made a significant difference in the SQI of different land use types. P is a limiting nutrient in the soil, and SOC is simultaneously a source and sink for nutrients and plays a vital role in soil fertility maintenance [26]. Similar to the results of this study, it was reported that SOC had the highest weight in determining soil quality in the Pokhare Khola watershed of the mid-mountains in Nepal [7].

The shape of the scoring curve for phosphorus was mid-point optima. The left side of the P scoring curve (ascending to an upper-asymptote) was primarily on crop requirements. The right side (lower-asymptote) reflected environmental risk, i.e. P runoff to surface water and was based primarily on slope [14]. The protected forest had soil with an optimum amount of available phosphorus. So, the P score of the protected forest was high, whereas soil in the agricultural land had a high quantity of available phosphorus (Table 2) due to the addition of fertilizers. Cultivation in the steep slopes of the Panchase area could have led to the P runoff to the surface water, decreasing the P score. So, even a higher concentration of P in the cultivated land can lead to a lower P score. The shape of the scoring curve for the SOC was more-is-better. Since forests have higher SOC, followed by pasture and cultivated land, the SOC score followed the same trend.

IV. CONCLUSION

On the basis of the SQI, the soil quality of PF, CF, pasture, khet, and bari were ranked first to fifth rank respectively. The protected forest in its natural condition had the highest SQI, whereas tilling and the application of fertilizers on the cultivated land decreased the SQI. The major parameters that affected the SQI among the different land use types were the available phosphorus and soil organic matter content. Hence, the proper application of fertilizer and effective recycling of organic amendments, such as crop residues and manures, seems to be necessary in cultivated land.

ACKNOWLEDGMENT

We would like to thank the Central Department of Environment Science, Tribhuvan University for supporting the grant to conduct this study.

REFERENCES

[1] A. K C, G. Bhandari, S. P. Wagle, and Y. Banjade, “Status of Soil Fertility in a Community Forest of Nepal,” *International Journal of Environment*, vol. 1, pp. 56-67, 2013.

[2] E. N. V. Reddy, A. S. Devakumar, M. E. Charan Kumar, and M. K. Madhusudana, “Assessment of nutrient turnover and soil fertility of natural forests of central western Ghats,” *International Journal of Science and Nature*, vol. 3, pp. 162-166, 2012.

[3] P. Drechsel, M. Giordano, and L. Gyiele, “Valuing nutrients in soil and water: Concepts and techniques with examples from IWMI studies in the developing world,” *International Water Management Institute*, Colombo, Sri Lanka, 2004.

[4] D. Karlen, M. Mausbach, J. Doran, R. Cline, R. Harris, and G. Schuman, “Soil quality: a concept, definition, and framework for

DOI: 10.5963/IJEP0501006

evaluation (a guest editorial)," *Soil Science Society of America Journal*, vol. 61, pp. 4-10, 1997.

[5] M. R. Carter, "Soil Quality for Sustainable Land Management: Organic Matter and Aggregation Interactions that Maintain Soil Functions," *Agronomy Journal*, vol. 94, pp. 38-47, 2002.

[6] C. Seybold, M. Mausbach, D. Karlen, and H. Rogers, "Quantification of soil quality," *in Soil processes and the carbon cycle*, R. Lal, Ed. Boca Raton, FL: CRC Press, pp. 387-404, 1998.

[7] K. R. Tiwari, B. K. Sitaula, T. Borresen, and R. M. Bajracharya, "An assessment of soil quality in Pokhare Khola watershed of the Middle Mountains in Nepal," *Journal of Food Agriculture and Environment*, vol. 4, pp. 276-283, 2006.

[8] H. Eswaran, R. Lal, and P. Reich, "Land degradation: an overview," *in Responses to Land degradation*, E. M. Bridges, et al., Eds. Enfield, NH, USA: Science Publishers, pp. 20-35, 2001.

[9] R. Lal, T. Iivari, and J. M. Kimble, *Soil degradation in the United States: extent, severity, and trends*, CRC Press, 2004.

[10] M. A. Denboba, F*orest Conversion, Soil Degradation, Farmers' Perception Nexus: Implications for Sustainable Land Use in the Southwest of Ethiopia*, Cuvillier Verlag, 2005.

[11] J. Glanz, *Saving our soil: solutions for sustaining earth's vital resource*, Boulder, Colo, USA: Johnson Books, 1995.

[12] J. W. Doran and A. J. Jones, *Methods for assessing soil quality*, Soil Science Society of America Inc., 1996.

[13] B. J. Wienhold, S. S. Andrews, and D. L. Karlen, "Soil Quality: Indices and Appraisal," *in ICSWEQ - Proceedings*, New Delhi, pp. 67-72, 2005.

[14] S. S. Andrews, D. L. Karlen, and C. A. Cambardella, "The soil management assessment framework," *Soil Science Society of America Journal*, vol. 68, pp. 1945-1962, 2004.

[15] Z. Sakbaeva, V. Acosta-Mart ńez, J. Moore-Kucera, W. Hudnall, and K. Nuridin, "Interactions of soil order and land use management on soil properties in the Kukart watershed, Kyrgyzstan," *Applied and Environmental Soil Science*, vol. 2012, Article ID 130941, 11 pages, 2012.

[16] M. C. Amacher, K. P. O'Neill, and C. H. Perry, "Soil vital signs: A new Soil Quality Index (SQI) for assessing forest soil health," *USDA Forest Service Res. Pap.*, RMRS-RP-65WWW, 2007.

[17] G. B. Tesfahunegn, "Soil Quality Assessment Strategies for Evaluating Soil Degradation in Northern Ethiopia," *Applied and Environmental Soil Science*, vol. 2014, Article ID 646502, 14 pages, 2014.

[18] B. K. Sharma, K. Timalsina, R. Rai, S. K. Maharjan, A. Joshi, and B. Rakhal, *Biodiversity Resource Inventory. Ecosystem Assessment of Bhadaure Tamagi VDC*, Kaski. An Ecosystem-based Adaptation in Mountain Ecosystem in Nepal: IUCN Nepal, 2013.

[19] A. Aryal and S. K. Dhungel, "Species diversity and distribution of bats in the Panchase region of Nepal," *Tiger Paper*, vol. 36, pp. 14-18, 2009.

[20] G. R. Blake and K. H. Hartge, "Bulk density and particle densty," *in Methods of Soil Analysis. Part 1. Physical and Minerological Methods*, A. Klute, Ed. Madison, WI, USA: ASA-SSSA, pp. 363-381, 1986.

[21] G. W. Gee and J. W. Bauder, "Particle-size analysis," *in Methods of Soil Analysis. Part 1. Physical and Minerological Methods*, A. Klute, Ed. Madison, WI, USA: ASA-SSSA, pp. 383-411, 1986.

[22] J. M. Bremner and C. S. Mulvaney, "Nitrogen total," *in Method of Soil Analysis, Part 2. Chemical and Microbiological Properties*, A. L. Page, Ed. Madison, WI, USA: ASA-SSSA, pp. 595-624, 1982.

[23] A. E. Walkley and J. A. Black, "An Examination of the Degtjareff Method for Determining Soil Organic Matter, and Proposed Modification of the Chronic Acid Titration Method," *Soil Science*, vol. 37, pp. 29-38, 1934.

[24] S. R. Olsen and L. E. Sommers, "Phosphorus," *in Methods of soil analysis, Part 2: Chemical and Microbiological Properties*, A. L. Page, Ed. Madison, WI, USA: ASA-SSSA, pp. 403-430, 1982.

[25] N. C. Brady and R. R. Weil, *The Nature and Properties of Soils*, Pearson Prentice Hall, 2008.

[26] A. Bationo, J. Kihara, B. Vanlauwe, B. Waswa, and J. Kimetu, "Soil organic carbon dynamics, functions and management in West African agro-ecosystems," *Agricultural Systems*, vol. 94, pp. 13-25, 2007.

[27] H. Runquan, D. Junhua, H. Xingyi, and Pan Lei, "Jamming Effects on Soil Degradation Course in Three Gorges Reservoir Region," *presented at the 12th ISCO Conference*, Beijing, 2002.

[28] A. Moges, M. Dagnachew, and F. Yimer, "Land Use Effects on Soil Quality Indicators: A Case Study of Abo-Wonsho Southern Ethiopia," *Applied and Environmental Soil Science*, vol. 2013, Article ID 784989, 9 pages, 2013.

[29] S. S. Andrews, D. L. Karlen, and J. P. Mitchell, "A comparison of soil quality indexing methods for vegetable production systems in Northern California," *Agriculture, Ecosystems and Environment*, vol. 90, pp. 25-45, 2002.

[30] B. J. Wienhold, D. Karlen, S. Andrews, and D. Stott, "Protocol for indicator scoring in the soil management assessment framework (SMAF)," *Renewable agriculture and food systems*, vol. 24, pp. 260-266, 2009.

[31] K. R. Islam and R. R. Weil, "Land use effects on soil quality in a tropical forest ecosystem of Bangladesh," *Agriculture, Ecosystems & Environment*, vol. 79, pp. 9-16, 2000.

DOI: 10.5963/IJEP0501006