Estimation of erosion induced nutrients loss under different land uses: A case study in Miandam Valley, Swat Pakistan

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Abstract: In order to design Sustainable Land Management (SLM) plans or interventions it is important to understand the land use change and subsequent impacts. The basic aim of this study was to assess the impact of land use land cover (LULC) change on soil physico-chemical properties and nutrients loss under different land use/land cover changes within Miandam watershed of Swat valley, Pakistan. The study area was divided into three major types on the basis LULC type (Dense forest, Moderate forest and Agriculture land). A total of 81 soil samples were collected from the study area (27 from each land use) through stratified random sampling and were transferred to the laboratory. The prepared soil samples were then tested for various physico-chemical properties such as pH, electrical conductivity, contents of organic matter, organic carbon, sand, silt, clay, nitrogen, phosphorus, potassium, iron, copper and zinc. Results showed that LULC significantly affected all soil parameters except electrical conductivity and potassium. For all the nutrients assessed, the enrichment ratio was greater than 1 which showed that the most fertile layer of the soil in the cropped areas was transported through soil erosion. In this study, time-series satellite images were used to determine the spatiotemporal changes in the LULC of Miandam valley of Swat, Pakistan, and the possible effect of LULC on soil properties was reported. The information generated on the soil properties as indicators of soil health could be used to inform the stakeholders about the effect of LULC change in the study area. Multi-temporal image acquired by Landsat sensors for the year 2018 was used for quantifying changes in the study area. The Landsat images for the year 2018 were classified into six land cover/land use classes. The increase in agricultural activities caused an increase in the land farming areas which led to an increase in the rate of deforestation in the valley. Thus, the present study results reveal that the use of the soil for agriculture instead of keeping them naturally or in other words changes in the land use land cover affects the soil physico-chemical properties and the overall nutrients availability.

Keywords: land use/land cover, soil properties, soil nutrients, Miandam, Swat valley
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1 Introduction

Sustainable land use becomes more important with increasing human demands. Identifying land use changes, finding the best alternatives for each area and assessment of ecological and economic benefits are the main factors in better land management[1]. In hilly areas, the major reason for soil erosion and nutrients loss is inappropriate land use[2]. Land use land cover change results in several undesirable consequences like a decline in soil carbon stock and soil fertility[3-6]. After deforestation, the decline in soil fertility and soil carbon stock has been recorded in the first 20-25 years[3,4,7]. Soil erosion is the most important process which influences the nutrients loss on steeply sloping land[8]. The irreversible nutrients loss may be accelerated by land use change[9].

Human induced land use practices that result in land cover change represent a major source of global environmental

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change[10,11]. Generally, land use practices vary across the globe having profound socio-economic and ecological consequences in different geographical settings for the immediate human need's fulfillment at the cost of environmental quality degradation[12-15]. Technical expertise regarding the ecosystem response to land use change is a pre-requisite for balancing the potential trade-offs between satisfying human needs and maintain other ecosystem functions[16,17]. These responses depend on the ecosystem settings and the type of LULC change.

One of the key resources in land use is soil that contributes to five major functions of a landscape i.e. water holding capacity, nutrient cycling, buffering, physical stability, biodiversity and habitats[18-20].

Globally, processes like salinization, erosion, compaction, nutrient imbalance and organic matter depletion are degrading soils[21,22]. In the tropic regions accelerated degradation of soil has affected nearly 500 million hm^2[23], while worldwide soil degradation has affected 33% of the land[24]. It is expected that accelerated erosion of soil resources will remain so in the 21st century; particularly in the developing countries of the world[22].

2 Study area

Miandam lies between 35°02′N latitudes and 72°33′E longitudes in the Hindu Kush mountain range with an elevation of 1200 to 3660 m above sea level. The climate of the valley is moist temperate. Summers are moderate and winters are extremely cold with heavy snow and frost. The valley of Miandam has borders with Monsoon and Mediterranean regions[25]. Western disturbances known as winter cyclonic depression that is starting over the Mediterranean Sea bring winter rainfall. Monthly Average temperatures in summers range from 14.81 ℃ to 31.39 ℃ in April and 15.63 ℃ to 31.48 ℃ in August. Monthly average temperatures in winters are in the range of 8.7 ℃ and 23.7 ℃ in October while in December the range is from 2.6 ℃ to 17.1 ℃. There are 11 villages in the valley and 15 hamlets, spanning over an area of 6949 hm^2 which is comprised of 638 hm^2 irrigated agricultural, 1081 hm^2 unirrigated agricultural, 4388 hm^2 forest area and the remaining 842 hm^2 other areas. The area has three sub valleys namely Swatoo, Gujaroo and Saprono. Three sub streams join together to make the main Miandam stream which drains the whole valley. This main stream joins river swat at the confluence point in Fatehpur. The population of the valley is mostly engaged in agriculture activities (nearly 40%) and thus the economy of the inhabitants is mostly agro-pastoral. Improper land use such as logging activities and unplanned urban sprawl is squeezing the forest area of the region. Besides illegal and unrecorded timber extraction, about 73623.8 m^3 timber was extracted from the forest in 2007. Over the last 30 years, a high deforestation rate of 2%/year has been recorded [26].

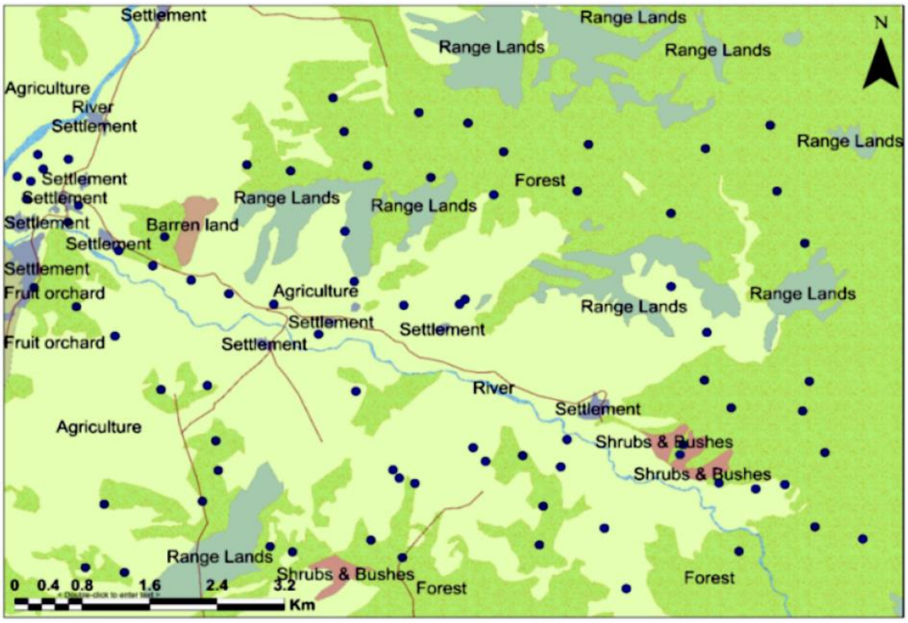

Figure 1 Land use map of the study area showing soil sampling locations of dense forested land use, moderate forested land use and agriculture land

3 Materials and methods

3.1 Site selection

The study area comprises a total of 81 experimental plots, 27 from each land uses i.e. densely forested, moderate forested and agriculture land (Figure 1).

3.2 Soil sampling

In August 2018, soil samples from three different land uses were sampled with the help of an auger. Stratified random sampling was done. Three soil samples from each site were bulked into one to make one composite soil sample. Soil samples were packed properly and labeled. Soil samples were passed through a 2 mm sieve after air drying and stones and twigs removal stage and were then stored in a cool dry place for laboratory analysis.

Figure 2 Study area showing different land uses

3.3 Land use/land cover

Multi-temporal images acquired by Landsat sensors for the year 2018 were used for quantifying changes in the study area. To minimize the impacts of the seasonal variation on the mapping, satellite images of the same season (June) were considered for this analysis. The data was preprocessed by running atmospheric correction and the digital numbers (DN values) were converted to reflectance. The reflectance images were then subjected to supervised classification routine to categorize various LULC classes. The spectral signatures of various classes were carefully selected to classify the image. After classification, the post classification analysis like vectorization, class extraction, merging and area calculation were performed. The classified map was overlaid and shifted in LULC classes, then quantified.

3.4 Laboratory analysis

The prepared soil samples for different physico-chemical properties were analyzed using standard procedures, viz., Soil pH using pH meter (Inolab WTW Series pH 720), soil texture by using hydrometer[27], electrical conductivity by EC meter[28], organic matter[29], AB-DTPA (ammonium bicarbonate diethylene triamine penta acetic acid) extractable Fe, Cu, Zn, P and K[30] and total Nitrogen by Kjeldahl digestion[31].

3.5 Statistical analysis

Various soil parameters like pH, electrical conductivity, organic matter, organic carbon, sand, silt, clay, nitrogen, phosphorus, potassium, iron, copper and zinc were analyzed statistically through ANOVA techniques as suggested by Steel and Torrie[32].

3.6 Nutrient loss through sediment

The amount of each nutrient lost through the sediment was determined using the following equation:

$$N = n\,s \qquad (1)$$

where, N is the total amount of each nutrient lost in the sediment collected, g; n is the total amount of direct soil sediment collected, g; s is the concentration of each nutrient in the sediment determined, g/g[33].

3.7 Enrichment ratio

Besides affecting the site of origin, soil erosion also affects the soil and ecosystems outside the eroded area. The soil properties are affected by the sediments and nutrients accumulation at the deposition site. The enrichment ratio (ER) is defined as enrichment of eroded materials in fine soil particles and plant nutrients in comparison with the remaining soil on the eroded site[34]. The ER is always greater than 1 if the sediment is richer in nutrients than the parent soil.

$$\text{ER} = \text{Nutrients concentration in sediment (g/kg)}/ \text{Nutrients concentration in the parent soil (g/kg)}^{[33]} \qquad (2)$$

4 Results and discussion

4.1 Land use/land cover

The Landsat images for the year 2018 were classified into six land cover/land use classes (Table 1 and Figure 3). The spatial extent of these classes (e.g., water, forest, urban, agriculture, barren soil, and pasture) shows the land cover and land use of Miandam valley Swat Pakistan.

4.2 Soil pH

Under various LULC types, the soil pH varies in this study. Under dense forest areas, the soil pH was lowest ranging from 5.11-6.01 with mean pH 5.45 followed by moderate forest which ranges from 5.23-6.94 with mean pH 6.21 while it was highest in cultivated agriculture land ranging from 6.03-8.21 with mean pH 7.03. Due to change in land use, soil pH varies significantly at p<0.001 (Table 2). Depending on changes in the land use, significant soil pH differences were indicated. An increase in soil pH is caused by cultivation in general. Management practices and agricultural activities such as mineral fertilizers and liming in order to convert natural forests to cultivated agriculture land may contribute to increasing soil pH. As a result, pH of cultivated agriculture areas is higher than dense forest areas[35,36].

Table 1 Covered areas (in both hectare and percentage) of various land cover classes in Miandam Valley for the year 2018

Land cover classes	2018	
	Area/hm^2	Area/%
Agriculture	1273	21.125
Urban	1869	31.01
Pasture	397	6.5
Forest	2045	33.925
Barren soil	397	6.555
Water	49.91	0.805
Total	6929	100

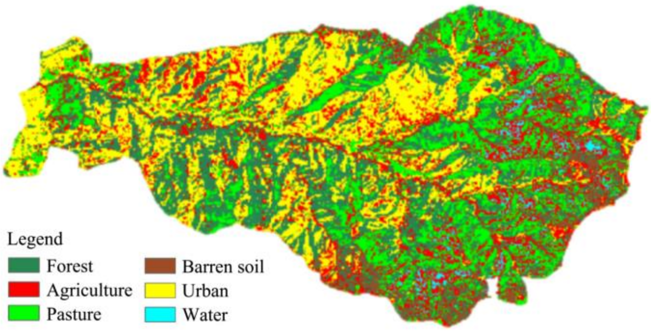

Figure 3 Land use/cover map of Miandam in 2018

4.3 Electrical conductivity

Analysis of soil samples shows variations in EC values for different land uses. Agriculture land use has slightly high EC values ranging from 100.40-283.00 dS/m with mean EC value of 182.54 dS/m followed by moderate forest with EC values ranging from 89.20-294.30 dS/m with mean EC value of 161.68 dS/m. The lowest EC values were recorded in dense forested area ranging from 70.20-305.10 dS/m with mean EC value of 144.31 dS/m. There was no significant change observed in the EC values of different land uses (Table 2). It can be due to low salt content of forest litter. The different concentrations of dissolved salts may result in variation of EC values[37]. Soil EC is affected by land use. EC can be increased by poor management practices of agricultural lands which can lead to poor drainage, low organic matter, compaction, poor infiltration and saturated soil.

4.4 Soil organic matter

The highest soil organic matter was calculated from the dense forest area ranging from 7.40%-9.90% with mean value of 8.40% followed by moderate forested area with SOM ranging from 5.90%-9.50% with mean value of 7.26% (Table 2). The lowest SOM was in the cultivated agriculture land ranging from 2.40%-4.90% with mean value of 3.56%. Significant SOM contents reduction (p<0.05) was occurred due to the conversion of dense forest into cultivated agriculture land as indicated by (Table 2). OM loss due to water erosion and higher SOM oxidation rates might cause significantly lower SOM contents of the cultivated agriculture land. Cultivation through minimum plant residues input and a higher soil disturbance is a reason behind significant reduction of SOM. Cultivation causes the rate of decomposition increased and

SOM redistribution. This shows an agreement with other authors' reported results[38,39]. Yimer et al.[40] also reported that SOM content of cultivated land was significantly (p<0.05) lower than forest and grazing lands of al-Abobo areas in western Ethiopia.

Table 2 Physico-chemical properties of soil under different land use

Dependent variable	Area (I)	Area (J)	Mean difference (I-J)	Sig.	99% Confidence interval	
					Lower bound	Upper bound
pH	Dense Forest	Moderate Forest	–0.72889*	<0.0001	–1.1005	–0.3573
		Agriculture Land	–1.54222*	<0.0001	–1.9138	–1.1707
EC	Dense Forest	Moderate Forest	–38.22963	0.032	–84.4078	7.9486
		Agriculture Land	–17.36296	0.324	–63.5412	28.8152
OM	Dense Forest	Moderate Forest	1.14815*	<0.0001	0.5900	1.7063
		Agriculture Land	4.84815*	<0.0001	4.2900	5.4063
OC	Dense Forest	Moderate Forest	0.66593*	<0.0001	0.3422	0.9897
		Agriculture Land	2.81193*	<0.0001	2.4882	3.1357
Sand	Dense Forest	Moderate Forest	–12.00000*	<0.0001	–20.5411	–3.4589
		Agriculture Land	–14.08148*	<0.0001	–22.6226	–5.5404
Silt	Dense Forest	Moderate Forest	4.47778	0.023	–0.6301	9.5857
		Agriculture Land	9.08889*	0.000	3.9810	14.1968
Clay	Dense Forest	Moderate Forest	7.97778*	<0.0001	2.6623	13.2932
		Agriculture Land	10.44815*	<0.0001	5.1327	15.7636
N	Dense Forest	Moderate Forest	5.82311	0.016	–0.4120	12.0582
		Agriculture Land	9.54893*	<0.0001	3.3138	15.7840
P	Dense Forest	Moderate Forest	1.82190*	<0.0001	1.3772	2.2666
		Agriculture Land	1.96673*	<0.0001	1.5220	2.4115
K	Dense Forest	Moderate Forest	8.70296	0.082	–4.3250	21.7309
		Agriculture Land	14.99481*	0.003	1.9668	28.0228
Fe	Dense Forest	Moderate Forest	7.08481*	<0.0001	5.1176	9.0520
		Agriculture Land	13.82852*	<0.0001	11.8613	15.7957
Cu	Dense Forest	Moderate Forest	1.62778*	<0.0001	1.1289	2.1266
		Agriculture Land	2.82444*	<0.0001	2.3256	3.3233
Zn	Dense Forest	Moderate Forest	1.35704*	<0.0001	0.8243	1.8898
		Agriculture Land	2.54593*	<0.0001	2.0132	3.0787

Note: * The mean difference is significant at the 0.01 level. LSD multiple comparison test results show that all the parameters tested for the dense forest, moderate forest and agriculture land were significantly different at p<0.0001 except electrical conductivity and potassium.

4.5 Organic carbon

The organic carbon content showed variation among studied land uses, following the trend of dense forest land use ranging from 4.29%-5.74% with mean value of 4.88% greater than moderate forest land use ranging from 3.42%-5.51% with mean value of 4.21%. The lowest SOC values were recorded from agriculture land use ranging from 1.39%-2.84% with mean values of 2.06% ($p\leq0.05$) as shown in Table 2. This higher rate of organic carbon in dense forest land use might be due to lower decomposition rate with higher biomass production as compared to agriculture land use with lower biomass production due to less vegetation cover. The results were matching with the findings of Yihenew et al.[41] who reported that physico-chemical properties of soil were greatly affected by the LULC types, management practices and slope classes in Zikre watershed, North Western Ethiopia. The mean values of organic matter (5.01%) were recorded under the natural forest and the lowest values of the same (2.57%) were registered in croplands. Yimer et al.[39] also compared croplands, forest lands and grazing lands and found that soil organic C and total N decreased in croplands as compared to forestlands. Gregorich et al.[42] also reported that the OC varied 10-fold times in forests than cultivated agriculture land.

4.6 Soil texture

The present study revealed the results that the land use change resulted in the change of soil properties across different sites. The highest sand contents were found in the agriculture land use ranging from 30.20%-85.50% with mean value of 63.789% followed by moderate forest land with sand contents ranging from 38.80%-79.80% with mean value of 61.71%. The sand contents were found lowest in the dense forest ranging from 35.90%-61.20% with mean value of 49.71%. Different LULC mean differences comparisons revealed that silt contents under dense forest were significantly higher at p<0.001 (Table 2) ranging from 9.00%-43.80% with mean value of 25.94% followed by moderate forest land use ranging from 9.70%-43.00% with mean value of 21.47%. The lowest silt contents were recorded from agriculture land ranging from 9.70%-27.40% with mean silt value of 16.86%. The clay contents were higher in dense forest land use ranging from 8.60%-42.10% with mean value of 21.16% followed by moderate forest land use ranging from 2.50%-23.30% with mean value of 13.18%. The lowest clay contents were recorded from agriculture land use ranging from 3.60%-24.20% with mean value of 10.71%.

An increase in the sand contents while the decrease in the clay contents was observed due to the conversion of dense forest to moderate forest and agriculture land. Clay fraction loss due to migration down the soil profile and erosion occurs in sparser vegetation cover or moderate forest cover areas. Erosion transports the finer particles as a result of breakdown of soil due to OC loss in cultivated agriculture soils. The findings of Ayoubi et al. and Celik[43,44] give supporting evidence to these results.

4.7 Available nutrients

In Table 2, almost all macro and micronutrients are found in higher range in dense forest land use than agriculture land use. Nitrogen is significantly higher in dense forest land use than moderate forest land use followed by agriculture land use with mean values of 35.67 mg/kg, 29.85 mg/kg and 26.12 mg/kg, respectively. It is attributed due to high OM and overall high turnout of nitrogen during decomposition in forests. As organic matter is the source of nitrogen, its loss in agriculture lands resulted in poor nitrogen retention ability therefore agriculture land soils showed low contents of total nitrogen as compared to dense and moderate forest land soils. The organic carbon loss greatly influences the SOM, hence the nitrogen contents and human activities are one of the reasons for the organic carbon loss in agriculture land due to which the nitrogen contents are low in agriculture land. Reduced aeration and higher soil compaction may cause nitrogen loss.

Results show higher concentration of Phosphorus in dense forest land use followed by moderate forest land use and agriculture land use with mean values of 2.90 mg/kg, 1.08 mg/kg and 0.93 mg/kg, respectively. The higher concentration of the soil organic matter in the dense and moderate forested areas enhances the greater phosphorus availability in dense and moderate forest soils. Yimer et al.[45] reported that the concentration of P in soils of the native forests is higher than the croplands. Soil erosion causes low status of the P parent material due to which the deficiency in available phosphorus in the agriculture soils is observed. This might also be due to P-fixation which is caused by low pH of the soil. These results resemble the findings of Yerima and Van Ranst[46] who reported that erosion by water, crop harvest and P-fixation are the main contributors to the low amount of available phosphorus. Phosphorous is higher in dense forest land use but does not show significant difference with agriculture land use, this could be due to the application of Di-ammonium phosphate (DAP) fertilizer on the cultivated land may have resulted in the increase of phosphorus in the agriculture soil too in line with the explanation made by Woldeamlak and Gebeyaw[47,48]. High content of OM in case of forests which also releases organic anions on decomposition and form chelates with Fe and Al and make the phosphorus available.

The concentration of potassium was higher in dense forest land use followed by moderate forest land use and agriculture land use with mean values of 91.65 mg/kg, 82.95 mg/kg and 76.66 mg/kg, respectively. The data showed a decreasing trend in the concentration of potassium with the increase in the cultivation practices. The two factors responsible for the distribution of soil K are (i) soil formation processes (i.e., soil types and parent materials) for potassium and (ii) land use change (i.e., agricultural practices) for available and exchangeable forms. Increased attention to K fertilization management is needed for the overall high fertility status of potassium in cultivated agriculture lands, as it creates nutrients composition imbalance in the long term. The high concentration of potassium under natural forest land can be attributed to a relative pumping of potassium from sub soil to top soil by vegetation cover[49]. The low concentration of potassium under agriculture land can be associated with soil degradation and losses due to leaching as agriculture lands are denuded of vegetation cover, however, due to intensive cultivation in case of agriculture irrigated which leads to removal of potassium and formation of organic complex’s with clay in forests and make K available[50].

Micronutrients are also found in higher range in dense and moderate forest land use than agriculture land use (Table 2). The amount of the available micronutrients found in dense and moderate forest land uses were higher than that present in agriculture land. The results indicated that the land use had a significant effect on the Fe, Cu and Zn concentration in the soil (Table 2). When the element concentrations for different land uses were compared, the soil under dense land use had the greatest mean concentration for all the micronutrients such as Fe (21.47 mg/kg), Cu (4.26 mg/kg) and Zn (3.74 mg/kg) followed by moderate forest land use with mean concentration of Fe (14.39 mg/kg), Cu (2.63 mg/kg) and Zn (2.38 mg/kg). For the dense and moderate forest soil, forest residues are usually left on the soil surface which might contribute to the high concentration of these elements. Agriculture land had the lowest mean concentration of Fe (7.64 mg/kg), Cu (1.44 mg/kg) and Zn (1.19 mg/kg). The higher concentration of micronutrients in the dense and moderate forest land uses can be due to high OM present in forest which contains all nutrients in an abundant content in available form than agriculture due to more intensive use of agriculture lands with less OM addition and lack of use of inorganic fertilizers for these micronutrients as most farmers are using fertilizers for NPK, not for other nutrients. Similar results are also reported by Ashoka[51] which stated that in the surface and sub-surface soils the contents of DTPA extractable iron, zinc and copper were higher in dense forest cover lands as compared to agricultural lands with intensive agricultural practices. Yitbarek et al.[40] also reported significantly (p<0.001) higher values of micronutrients under dense forest cover as compared to cultivated agriculture lands.

4.8 Enrichment ratios under agriculture land system

For all the nutrients assessed, the enrichment ratio was greater than 1 which shows that the most fertile layer of the soil in the cropped areas is transported through soil erosion. The rainfall amount with low nutrients solubility is the basic reason for low moisture content due to which the ER of soil nutrients was higher[52] which ultimately leads to increased concentration of nutrients in the runoff and sediments. The top soil layer which is detached is highly concentrated in soil nutrients[53]. Due to this nutrients depletion in the eroded soils, agricultural activities are strongly compromised. The lower ERs of nutrients are expressed as high nutrients dilution rates under high runoff and sediment rates[54]. Although from dense and moderate forested areas the amount of nutrients loss was lower than agriculture lands because of the fact that the nutrients were washed in the runoff which is highly concentrated in the sediments.

On the basis of the erosive factors, the soil particles can exhibit different degrees of erodibility during the process of erosion. For clay and silt particles, richness of fine particles in the eroded materials is an indication that ER is greater than 1. The most eroded particles were the one which was richer in plant nutrients. According to[55,56] higher amounts of soil nutrients are present in the soil sediments in available form than the soil from which it is eroded.

5 Conclusions

The land use practice appeared to have profound influence on soil physico-chemical properties and the status of nutrients. The comparative study of the effects of different LULC types on the physico-chemical properties and nutrient availability is concluded with the result that the soil properties get adversely affected by agriculture land use due to its intensive use and less input of sources. Improved soil physico-chemical properties and also sufficient nutrients were found in forest land use. The presence of higher organic matter reflects good physical properties of forest land use. High rainfall amounts result in soil nutrients loss from agriculture land. These findings highlight the importance of vegetation cover in order to sustain soil nutrients availability. The main factors behind LULC change and change in soil physico-chemical properties are climatic risks (rainfall) and human interventions (e.g., land use change, agricultural intensification). Among these factors, one of the biggest challenges is to mitigate human intervention in order to reduce soil erosion which ultimately will improve the soil quality. The soil quality also can be improved by maintaining the soil properties through addition of input sources like organic matter along with inorganic fertilizers particularly for the availability of micronutrients in the soil.

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