RESEARCH ARTICLE

Effects of Land Use Change on Soil Physical Properties and Erodibility in Ghatigaon Block of Gwalior District in Madhya Pradesh, India

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ABSTRACT

The soil detachment by water is described as soil erodibility by Universal Soil Loss Equation (USLE), which can be affected by land-use change. The present attempt was taken to quantify the changes of USLE Soil erodibility (K-factor) and its soil driving factors in three land uses, including agriculture land, forestland and wasteland in Ghatigaon block of Gwalior district of Northern Madhya Pradesh. Soil composite samples were obtained from two layers in three land uses, and the related soil physicochemical properties were measured. The agriculture land use showed the highest sand content, pH, EC, CEC, sodium carbonate, sodium bicarbonate, exchangeable sodium and exchangeable calcium. In contrast, highest silt, clay, mean weight diameter, organic carbon and exchangeable magnesium were found in forest land use. The highest particle density, bulk density, permeability and soil erodibility were observed in the wasteland use. The USLE K-factor has a negative and significant correlation with clay, organic matter, mean width diameter, and soil permeability. There is a positive and significant correlation between USLE K-factor, particle density, and soil carbonate. However, no significant correlations were observed between USLE K-factor and silt, sand, bulk density, pH, electrical conductivity, cation exchange capacity, soil bicarbonate, exchangeable sodium, calcium and magnesium and sodium absorption rate and exchangeable sodium percentage. In the wasteland, the K-factor (0.071 Mg h/MJ/mm) was significantly higher, and the particle size distribution greatly impacted the K-factor.

Keywords: *Soil Erosion, Land Use, Erodibility, Soil properties, Universal soil loss equation.*

INTRODUCTION

Soil erosion is an important essential, environmental and social disaster [1. Soil erosion is described as detachment and removal of surface particles from the soil due to wind or rainfall. Soil loss is a worldwide concern, threatening soil and water resources [2]. As the most critical of an ecosystem, soil can secure food production, enhance the w resources, and promote biodiversity and carbon sequestration [3] if it is well managed [4-5]. The main parameter in soil erosion is the inherent soil characteristics, called the soil erodibility factor. The type and rate of soil erosion/loss in an area depend on different geomorphology, soil type and land use. Considering the different factors involved viciousness, and use is the most important one to the potential destructive role of human effects. Land use change and agricultural development cause large changes to soil characteristics, making soil susceptible to erosion and degradation [6]. Land-use change harms soil characteristics such as permeability, soil texture and aggregate stability [7]. Changes in these characteristics are significant because they lead to changes in the rate of soil erodibility. Some researchers also showed that transformation of land use from forest to crop lands may result in clay and silt increase and sand decrease [8]. This could

be attributed to the selective detachment of soil particles and decomposition of organic carbons related to the instability of soil aggregates. In this regard, investigation of the organic carbon impact on soil parameters denoted that organic carbon application had a positive effect on water holding capacity and soil porosity, leading to reduction of soil erodibility [9]. Soil erosion in agricultural land use has a pronounced impact on the river's source and amount of sediment. [2] Demonstrated that the conversion of pasture to farmlands accelerated soil erosion on a watershed scale. The Universal Soil Loss Equation (USLE) model is a well-known method extensively used to predict and determine the factors affecting soil loss [10]. The USLE model is a simple empirical model which has been developed based on multiplying five erosion factors, including soil erodibility (K-factor), soil erosivity (R), topography (LS), land cover (C) and practice (P). As already mentioned, soil erodibility is the most impressive factor for assessing the soil susceptibility to erosion, and it is necessary for estimating soil loss in USLE [11]. Although the USLE has been widely used to predict K-factor in many studies [12], it may not apply to all soils with different soil-forming processes.

The K-factor is more strongly related to soil physical characteristics. The accurate evaluation of the K-factor the for development of soil management strategy, is crucial. Organic carbon (OC) content is crucial for determining of soil erodibility that can be severely affected by land use change [7]. Impacts of land use change on soil OC, permeability and aggregate stability [7] can lead to the changes in the inherent soil erodibility. [13] showed that soil erosion was influenced greatly by anthropogenic activities in vineyards and barley, respectively. No sufficient study has been conducted to investigate the effects of land use change on USLE K-factor changes in Ghatigaon block of Gwalior district of Madhya Pradesh. Thus, the main objective of this study is to quantify changes of USLE K-factor and its soil driving factors by investigating the land use change in Ghatigaon block of Gwalior district in Madhya Pradesh state of India.

MATERIALS AND METHODS

Study area

The study area is located as Ghatigaon block of Gwalior district in northern part of Madhya Pradesh state of India. The soil moisture regimes and temperature are xeric and thermic, respectively. The long-term means of annual precipitation and temperature were 700 mm/y and 27.1˚C, respectively. According to soil maps of the study area, all sites of three land uses were located in the same soil type (classified as alluvial soil) and the other landscape characteristics including aspect, elevation (322 mean sea level) and slope position were roughly identical. The assumption is that the changes in soil erodibility are caused only by land use change, and other soil-forming factors are the same.

The sampling and analysis of soils

The composite soil samples from different land uses (Agriculture, forest and waste land) were randomly collected from two layers (0-20 and 20-40 cm). Thirty soil samples for the each land uses and each soil depth were collected. Total 180 (90 undisturbed and 90 disturbed) soil samples were collected. The undisturbed samples were used for bulk density and mean weight diameter (MWD) determination. The particle size distribution [14] was estimated by hydrometer method, Soil organic carbon (OC) measured by Walkley-Black method [15] and multiplied by van Bemmelen factor 1.724 to measure OM of the soil. Moreover, wet sieving method was applied to identify the stability of soil aggregates quantified as MWD [16].

The double rings method was applied to simulate soil permeability. Various infiltration equations for soil water infiltration were introduced using the experimental and observational data. The Kostiakov equation used for determination of permeability [17].

K-factor can be calculated via the USLE which is frequently used to calculate soil loss based on other factors gained from the simulated or natural rainfall data (experimental) [11]. The most well-known approach is the USLE presented by [11] as follow:

$$K = 2.8 \times M^{1.14} \times 10^{-7} \times (12-a) + 4.3 \times 10^{-3} \times (b-2) + 3.3 \times 10^{-3} \times (c-3)$$

Where, K denotes erodibility of soil (Mg h/MJ/mm), M is product of (100 – clay %) × (very fine sand (0.05–0.1 mm) + %silt), and OM refers to organic matter (%). Very fine sand was measured

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through wet sieving method with 270 mesh sieves [16]. The P coefficient was obtained through the measurement of infiltration rate by double rings method, and the S coefficient was determined using the shape and the size of soil aggregates [12]. In this study, the codes were assigned based on the measured MWD and field observation as described by [11]. In each land use, permeability was measured using double rings method at four replicates in the dry season to lower the effect on moisture on infiltration [18].

Six classes are identified based on soil permeability classification [11] in cm/h, as follows:

1. High to very high (>12.5)
2. Moderate to high (6.25 – 12.5)
3. Moderate (2 – 6.25)
4. Moderate to low (0.5- 2)
5. Low (0.125- 0.5)
6. Very low (<0.125)

Soil structure is divided into four classes [11] as follows:

Very fine crumb and granular structure (<1mm)
Fine crumb and granular structure (1-2 mm)
Moderate crumb and granular structure (2-5 mm) and coarse structure (5-10 mm).
Massive structure (prismatic, columnar, and blocky).

Statistical analysis

Factorial design was followed in completely randomized design (CRD) using SPSS software. All the analyses were done in four replications for each land use. The means were compared with the help of least significant difference (LSD) test at the $P<0.05$ significance level.

RESULTS AND DISCUSSION

Soil characteristics

All parameters (clay, sand, silt+vfs, MWD, porosity, OM and k-factor) of present study showed significantly different relationship with various land uses and soil depths. The physicochemical soils characteristics are illustrated in Table 1. Results indicated that soils in rainfed farming land use had significantly lower OM, porosity and aggregate stability than in other two land uses. The highest amounts of sand, clay and silt+vfs (very fine sand) were recorded in rainfed farming, orchard and rangeland land uses, respectively. The highest amount of clay content was recorded in both depths of rainfed farming land use compared with rangelands and orchards which was probably attributed to the irrigation with muddy water (Table 1). The soils in the orchards had a considerably higher amount of ($p<0.05$) sand than the soils in the rangeland and rainfed farming lands for both depths (Table 1). The higher amount of sand observed in orchard land use can be attributed to the flooding irrigation of orchards by farmers. It can also be attributed to the selective leaching of the fine particles, which leads to the increase of sand portions in soil profile. In addition, incorporating the sand and manure during the plantation may lead to the increase of sand in orchards. On average, the amount of sand in a 0-20-cm-layer of orchards soils was 56.02% and 41.06% more than that in the rangelands and rainfed farming lands, respectively. The amount of silt+vfs in the rangeland soils was significantly greater than in the orchards and rainfed farming soils. Percentage of silt in pasturelands was significantly increased as compared to agricultural land due to land use changes [19]

The lowest porosity in a 20-40-cm-layer of rainfed farming soil was 15.22% and 21.23% less than that in the rangelands and orchards, respectively. This is due to the cultivation and tillage operations which increase the soil compaction. Tillage in rainfed farming land use decreases the porosity in compensation of great and major pore linkages [20]. Decrease of porosity and collapse of pore duration at the soil surface can prevent permeability and therefore provide a favourable condition for formation of severe surface erosion and runoff. The highest rate of OM recorded in a 0-20-cm-layer (4.32%) of orchards and was more than rangelands and rainfed farming lands, this could be attributed to the commonplace use of livestock manure in this land use type. The intensive tillage in rainfed farming land use may result in the increase of aeration inducing the acceleration of organic carbon oxidations [21]. Most of the MWDs in the rangelands and especially orchards were between 2 and 4 mm, which is considered to be "very stable" as classified by [22].In rainfed farming land use, the aggregate stability or MWD of wet aggregate size distribution is statistically lower than other two land uses (Table 2). Loss

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of OM with cultivation in rainfed farming land use is connected to the decrease of MWD, which leads to the degradation of macro-aggregates and makes soil more susceptible to erosion. According to Wischmeier's nemograph [11] cannot be applied to a silt content exceeding 70%. Since, in the studied watershed, the silt content ranges from 45.5% to 49.20%, the USLE nemograph is applicable. The higher MWD indicates that the soil is more stable in orchard. Soil aggregate stability, as a main trait of soil, controls soil erodibility. Therefore, soil structure classes of rangelands, orchards and rainfed farming lands were assigned as 2, 3 and 4, respectively. Soil OM decomposition and soil compaction due to cultivation are the main reasons for soil structural damage in the rainfed farming land use.

Soil permeability (Table 2), represents the cumulative infiltration equations and the instant and average infiltration rates of three land uses estimated by the Kostiakov equation. The infiltration rate in orchard land use was more than that in the other two land uses. The accumulation infiltration rates in the orchards are higher than those in the rangelands and rainfed farming land uses, showing that condition of the orchards soil is suitable for reducing the soil runoff and subsequently restricting the soil loss.

The soil permeability in the rainfed farming land use is significantly decreased compared to rangelands and orchards land uses due to the long-term intensive agricultural operation and the sharp decline of organic matter, porosity and high bulk density. According to [11], the soil permeability in the three studied land uses was in the class of moderate to low (0.5-2 cm/h). Therefore, the soil permeability class of 4 was assigned to rainfed farming lands, orchards and rangelands land uses with the soil permeability mean values of 0.94, 1.49 and 1.07 cm/h.

Soil erodibility factor

The difference between mean values of calculated USLE K-factor for the three land uses and the two layers has been presented in Table 2. The highest USLE K-factors were obtained in the wasteland (0.071 Mg h/MJ/mm) followed by Agriculture (0.069 Mg h/MJ/mm) land while minimum ULES K-factor was recorded in forest land (0.066 Mg h/MJ/mm) in depth of 0-20 cm.

Table 2. Calculated soil erodibity factor (K) under various land use/land

Land use	Soil erodibility K-factor (Mg h/MJ/mm)
Agriculture	0.069±0.004
Forest	0.066±0.003
Wasteland	0.071±0.005

The main cause for the highest rate of erodibility within the wasteland (0.071 Mg h/MJ/mm) is the highest amount of silt+vfs in the 0-20-cm-layer. The silt+vfs lacks adhesion properties and if moisturized, becomes easily broken and transported, having an increased impact on soil

Table 1: Comparison of means for some soil properties in various land uses and depths (0-20 and 20-40 cm)

Parameters	Agriculture		Forest		Wasteland	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
Sand (%)	58.8±1.65	59.0±2.14	56.4±2.21	58.4±2.60	58.6±2.23	58.1±1.59
Silt+VFS[1] (%)	17.8±2.08	17.9±2.12	19.0±2.34	18.2±1.74	17.9±2.37	17.8±1.58
Clay (%)	23.4±3.11	23.1±2.12	24.6±2.48	23.4±3.44	23.5±3.64	24.1±2.08
PD (Mg m^{-3})	2.70±0.07	2.79±0.07	2.49±0.07	2.58±0.07	2.74±0.08	2.84±0.07
BD (Mg m^{-3})	1.35±0.02	1.39±0.02	1.24±0.01	1.27±0.01	1.37±0.02	1.41±0.02
MWD[2] (mm)	1.26±0.06	1.22±0.07	3.68±0.05	3.33±0.06	1.02±0.06	0.95±0.12
Porosity (%)	49.89±0.47	50.41±0.97	50.40±1.67	50.87±1.68	49.47±1.22	50.85±0.67
OC[3] (%)	0.44±0.07	0.30±0.08	1.21±0.07	0.90±0.05	0.34±0.08	0.30±0.07

[1]VFS: Very Fine Sand; [2]MWD: Mean weight diameter; [3]OC: Organic matter. Values presented in different letter (s) in each depth signify the meaningful statistical difference in LSD test at probability level of 0.05.

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Table 3: Correlation between soil physico-chemical properties and USLE K-factor

	Sand	*Silt*	*Clay*	*PD*	*BD*	*MWD*	*SP*	*pH*	*EC*	*OC*
Silt+vfs	-1	1								
Clay	-1	1	1							
PD	0.975	-0.975	-0.975	1						
BD	0.976	-0.976	-0.976	1.000	1					
MWD	-0.988	0.988	0.988	-0.998	-0.998	1				
SP	0.728	-0.728	-0.728	0.863	0.860	-0.826	1			
pH	0.946	-0.946	-0.946	0.850	0.854	-0.884	0.467	1		
EC	0.997	-0.997	-0.997	0.954	0.955	-0.972	0.670	0.969	1	
OC	-0.984**	0.984	0.984*	-0.999	-0.999	1.000	-0.839	-0.873	-0.966	1
K Factor	0.885	-0.885	-0.885**	0.967*	0.965	-0.947**	-0.963*	0.687	0.845	-0.954**

PD = Particle Density, BD = Bulk Density, MWD = Mean Weight Diameter, SP = Soil Permeability, OC = Organic carbon,

**: significant at p<0.01; *: significant at p<0.05

erodibility [23]. The lowest erodibility rate in the orchards belonged to high rate of aggregate stability, organic matter and permeability. The decomposition of soil OM is increased by the physical disturbance caused by soil tillage, breaking down the macro-aggregates and exposing the C protected in their interiors to microbial decomposition [7]. Meanwhile, intensive cultivation of agricultural lands in the rainfed farming land use with limited or no recycling of crop residues lowers the OM content, resulting in increment of K–factor [23]. The present study reviled that soil particle size distribution had considerable effects on soil erodibility, when soil texture class may vary.

Relationships between USLE K-factor and soil characteristics

The soil erodibility in the study area is affected by the relationship between the calculated USLE K-factor and soil physical characteristics (Table 3) and results revealed that soil erodibility in the study area is affected by clay content, particle density, mean width diameter, soil permeability and organic matter content in the soil. The K-factor has a negative and significant correlation with clay content, organic matter content, mean width diameter and soil permeability. There is a positive and significant correlation between USLE K-factor and particle density. However, no significant correlations were observed between USLE K-factor and silt, sand and bulk density.

CONCLUSION

Comparison of soil erodibility (USLE K-factor) was conducted in three land uses in Ghatigaon block of Gwalior district in northern Madhya Pradesh. From the study it can be concluded that the highest soil erodibility belonged to the wasteland use in the surface layer (0.071 Mg h/MJ/mm). The soil MWD, permeability and OM was highest in forest land use within land uses showing the more sustainability for runoff and sediment loadings. The study revealed that organic matter, particle size distribution, permeability, and aggregate stability greatly impacted soil erodibility. The findings suggest that soil erodibility has been heavily influenced by land use change. The results obtained in this study can be used/tested in other areas with the same soil type and landscape conditions.

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