IMPACT OF CHANGING LAND USE LAND COVER ON ERODIBILITY OF THE OUTER HIMALAYAN SOILS

ABSTRACT

Land use change has an adverse effect on soil characteristics such as permeability, soil texture and aggregate stability, soil erodibility etc. which make soils susceptible to erosion and degradation. The outer Himalayan region is prone to large-scale soil erosion by water owing to the vast disparity in the slope gradient, undulating relief, largely mountainous joined with high intensity rainfall and lithological characteristics of these rocks. Soil erodibility, one of the key factors affecting the rate of erosion can be estimated by using various soil erodibility indices.In examining erodibility indices across various land use changes, it was evident that both the clay ratio (CR) and modified clay ratio (MCR) escalated as land use shifts from forest to more disturbed environments. As we transit from forest to agriculture, these ratios increased, and was even more marked in the transition from forest to wasteland. The erosional behaviour as per CR and MCR in agriculture land use transitions could be arranged in the order that forest < agriculture <builtup< wastelands. Among wasteland use transitions, the high CR and MCR in wasteland indicated potential challenges in soil management, while the lower CR and MCR in transitions to agriculture and forest suggested more favorable soil conditions for these specific uses. The CR and MCR ratios indicated that the lower the ratio, the more would be the clay accumulation and lesser the erosion. This information is crucial for understanding the implications of land use changes on soil erosion and health and for guiding effective land management practices in diverse ecological settings.

Keywords: Outer Himalayas,land use change, erosion, erodibility indices.

1. INTRODUCTION

Soil is the basis for human survival and development. It is related to multiple sustainable development goals (SDGs).Lal*et al.* (2021) explain that the SDGs aim to reach the goal of having 75% healthy soils by 2030. However, approximately 46% of soils are degraded due to excessive or inappropriate human use. Soil erosion is known as an important economic, environmental and social disaster (Wang *et al.*, 2013). It is the most common form of soil degradation, and soil erosion affects agricultural production, soil productivity, water resources, biodiversity, carbon sequestration (Amundson *et al.*, 2015) and food security (Lal, 2003). In most tropical and sub-tropical areas, soil erosion and soil physico-chemical changes is regarded as the single most serious threat to agricultural livelihoods by causing loss of nutrients, rooting depth, slope instability and reduced crop yields (Buttafuoco *et al.*, 2012; Ota *et al.*, 2020). Type and rate of soil erosion or loss in an area depend on different factors including climate, geomorphology, soil type and land use. Deforestation, overgrazing, and unsuitable agricultural practices are the main causes of soil erosion induced by human activities. Considering the different factors involved in soil loss, the land use is the most important one due to the potential destructive role of human effects.

Over the past decades, there has been land conversion from forests, savannahs and other native landscapes to croplands, pasture lands and settlements (Lambin and Meyfroidt, 2011). This rapid rate of land use conversion is a serious challenge affecting sustainable land use planning in many parts of the world. Land use change has an adverse effect on soil characteristics such as permeability, soil texture and aggregate stability, soil erodibility etc. (Lambin and Geist, 2008; Emadi *et al.*, 2009) which make soils susceptible to erosion and degradation (Sharma and Arora, 2015). Soil erosion triggered particularly by land use land cover (LULC) changes has been a topic of growing concern among researchers and policy makers alike (Sharma and Sharma, 2003; Adhikary *et al.*, 2014). The outer Himalayan region of India is one of the hot spots of erosion-induced soil degradation. Further, adverse impacts of soil erosion may be aggravated by climate change and the increase in frequency and intensity of extreme events. The region is prone to large-scale soil erosion by water owing to the vast disparity in the slope gradient. The rate of erosion is above100 t/ha/year at many places, which possibly accounts for the maximum rate of soil erosion by water throughout the nation due to the undulating relief, largely mountainous joined with high intensity rainfall that occurs seasonally. High erosion rate also results in losses of important nutrients resulting in land degradation (Sharma and Sharma, 2004). Despite widespread awareness of the severity of erosion and its adverse impacts, quantitative information about the effects of land use conversions on soil erodibility indices is scanty, especially for the vulnerable region of the outer Himalayas. Soil erodibility can be evaluated by using runoff plots (Sharma et al., 2023), which is quite expensive, time consuming and is not feasible at all places. It can also be estimated using nomograph developed by Wischmeier et al. (1971) but it may not be applicable in many situations (Rejman et al. 1999). Another way to estimate soil erodibility is by using various soil erodibility indices based on soil characteristics. Erodibility indices like dispersion ratio (Middleton 1930), clay ratio (Buoyoucos 1935), modified clay ratio (Bryan, 1968) and erosion ratio (Lugo-Lopez 1969) have been employed by different workers to assess the soil erodibility. However, very little information is available on the erodibility indices for the soils of outer Himalayas. This study aimed to study the impact of changing land use land cover on soil erodibility using clay and modified clay ratios.

2. MATERIAL AND METHODS

2.1 STUDY AREA

The study was conducted in the Outer Himalayan region of Jammu and Kashmir, India. This region spans from 32°17’N to 37°17’N latitude and 73°26’ to 80°30’E longitude, with elevations ranging from 350 to 1800 meters and an area of 42,241 km² (Fig. 1). The area featured diverse topography with dry hillocks and undulating terrain, and geological formations primarily composed of sandstone, shale, limestone, and conglomerates from Shivalik, Muree and Subathu group sediments. The climate is sub-tropical, with hot summers (18°C to 40°C), cold winters (4°C to 23°C), and a monsoon season (14°C to 32°C) that brings an average annual rainfall of 1140 mm, primarily from July to September. Soils in this region are light to dark colored, severely eroded, and range from coarse to medium textures with low nutrient (Sharma et al., 2009) and water holding capacity. The natural vegetation includes scrub-forests, chir forests, and deciduous trees, while agriculture predominantly features crops like maize, wheat, pulses, and oilseeds.

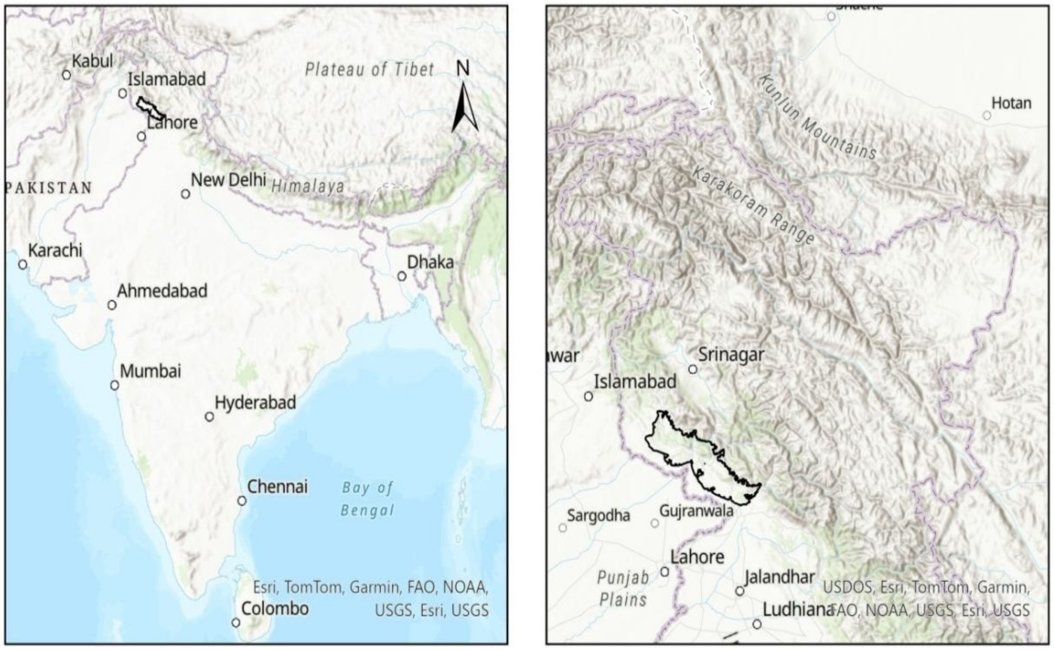

Fig. 1: Location and extent of outer Himalayas

2.2 Soil Sampling

After the comparison of temporal data of Land use land cover (LULC) maps of 2000 and 2023, ten land use transitions were observed. These were continuous forests, forest to agriculture, forest to wastelands, continuous agriculture, agriculture to wasteland, agriculture to builtup, agriculture to forests, continuous wastelands, wasteland to agriculture and wasteland to forest. Soil samples of 38 sites were collected from the land use change sites as well as from their adjacent sites where no land use change was observed for the purpose of studying the impact of land use changes on soil erodibility indices. The samples were analyzed for sand, silt, clay (Day, 1965) and organic matter content (Walkley and Black, 1934). The values obtained were then used to determine the clay ratio and modified clay ratio of the land use transitions.

2.3 Erodibilty indices

Clay ratio: This ratio was suggested by Bouyoucos (1935) and was calculated by dividing the total sand and silt percentage in the soil by the percentage of clay it contains.

$$\text{Clay ratio} = \frac{\%\ (\text{Sand+ silt}}{\%\ (\text{Clay})}$$

Modified clay ratio: Same as clay ratio with addition of organic matter in the denominator (Bryan, 1968).

$$\text{Modified Clay ratio} = \frac{\%\ (\text{Sand}+\text{Silt})}{\%\ (\text{Clay}+\text{Oranic Matter})}$$

3. RESULT AND DISCUSSION

Bouyoucos*et al.* (1935) proposed clay ratio (CR) to define contribution of clay in relation to silt and sand as an index of soil erodibility and later combined effect of clay and organic matter was suggested as modified clay ratio (MCR). Analyzing the erodibility indices revealed distinct trends across three land use changes: continuous forest, forest to agriculture, and forest to wasteland (Fig 2), continuous agriculture, agriculture to wasteland, agriculture to built-up, and agriculture to forest (Fig 3), continuous wasteland, wasteland to agriculture, and wasteland to forest (Fig 4).The properties examined were clay ratio and modified clay ratio.

3.1 FOREST LAND USE TRANSITIONS

Clay ratio in continuous forest landuse varied from 4.04 to 5.44 with a mean of 4.53, indicative of the natural clay content in forest soils. In transition of forest to agriculture, it increased to a range of 4.71 to 5.84 (mean of 5.17), potentially reflecting soil compaction or changes in texture due to agricultural use. Forest to wasteland raised further, ranging from 5.49 to 8.60 with mean of 7.13, suggesting major alterations in soil texture, possibly from loss of soil structure in wasteland conditions. Modified clay ratio in continuous forest ranged between 3.76 and 5.15 with mean of 4.26, consistent with the forest soil texture. Transition of forest to agriculture showed an increase to 4.48 to 5.43 with mean of 4.88, possibly reflecting changes in soil structure. In transition of forest to wasteland, it further increased to 5.37 to 8.14 with mean of 6.87, indicative of changes, likely due to degradation. These findings illustrated a clear trend across the different land use changes.

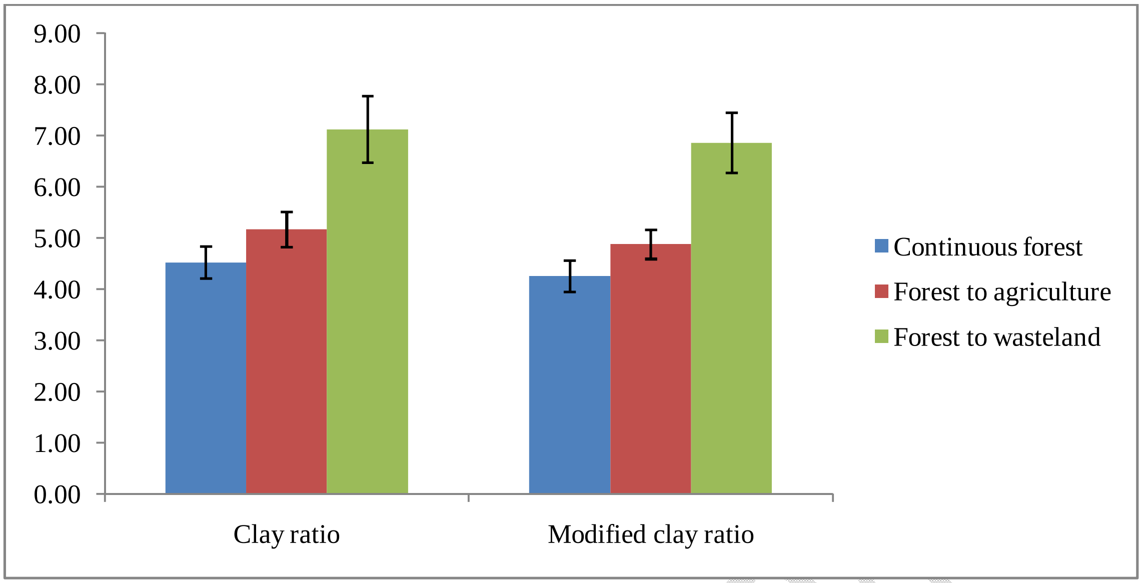

Fig. 2: Clay ratio and Modified clay ratio in continuous forest and landuse conversion from forest

In examining erodibility indices across various land use changes, it was evident that both the clay ratio and modified clay ratio escalated as land use shifts from forest to more disturbed environments. The continuous forest maintained lower ratios, reflective of the natural clay content and undisturbed soil conditions typical of forest soils. However, as we transit from forest to agriculture, these ratios increased, likely due to soil compaction resulting from agricultural activities. Similar were the findings of Karagul (1999) and Korkanc *et al.* (2008). This increase was even more marked in the transition from forest to wasteland, where the highest ratios were observed. Removal of vegetation cover exposed soil to direct raindrop impact and wind, accelerating erosion (Nearing *et al.*, 2005). Such significant changes in clay and modified ratios in the wasteland scenario are indicative of alterations in soil separates and structure, likely resulting from the loss of soil integrity and increased soil dispersion in wasteland conditions as clay soils generally resist erosion better than sandy soils due to finer texture and stronger cohesion. In a study conducted by Dutta *et al.* (2017) in the Nagaland region of India to determine soil erodibility characteristics under various land use patterns, higher dispersion ratio and erosion index than the threshold limits were reported and that clay showed significant negative correlation with dispersion ratio and erosion index. This trend underscored the substantial impact that different land use practices have on soil stability, which could have implications for water retention, and overall soil health potentially affecting overall ecosystem functioning. These insights into soil erodibility changes are critical for understanding the effects of land use transitions on soil properties and for guiding sustainable land management practices in these regions. The lower the ratios, the more would be the clay accumulation and lesser the erosion. The CRs were higher than MCRs which might be because of inclusion of organic matter in the denominator in the case of MCRs. Such pattern had also earlier been reported by Singh and Khera (2008).

3.2 AGRICULTURE LAND USE TRANSITIONS

In the agriculture land use, the clay and modified clay ratios (Fig. 3), suggested a reasonable content of clay in the soil. Clay ratio ranged from 4.14 to 5.89 with mean of 4.99 and modified clay ratio ranged between 3.96 to 5.59 with mean of 4.73. Contrastingly, the agriculture to wasteland scenario showed significantly higher clay ratios (5.49 to 10.14, mean: 8.37) and modified clay ratios (5.33 to 9.55, mean: 7.94). Transitioning from agriculture to built-up areas, the soil exhibited the highest clay ratios (6.71 to 10.47, mean: 7.79), indicating significant soil disturbance or compaction due to urban development. In contrast, the agriculture to forest transition presented the lowest clay ratios (2.64 to 3.78, mean: 3.07), and modified clay ratios (2.55 to 3.58, mean: 2.89), indicating finer soil texture and more stable soil structure typical of forest soils.

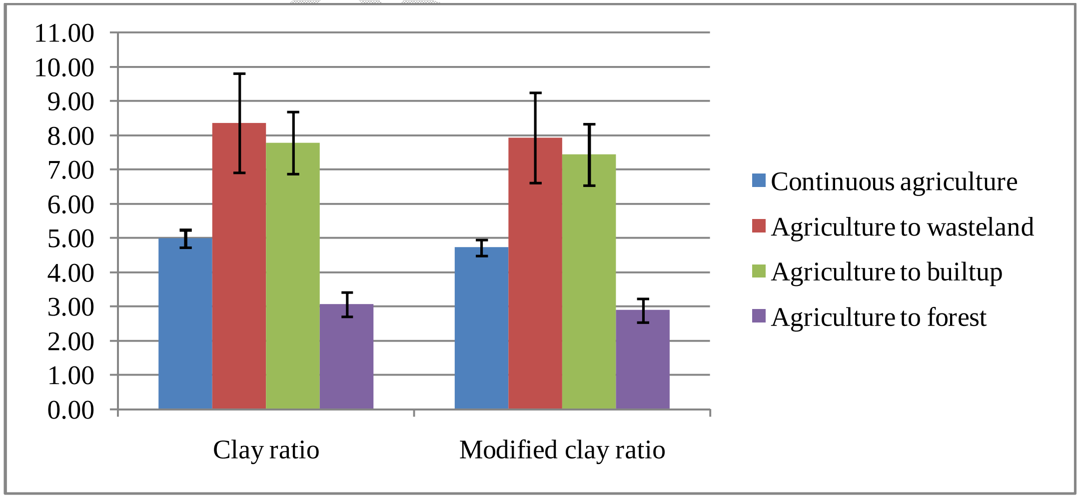

Fig. 3: Clay ratio and Modified clay ratio in continuous agriculture and landuse conversion from agriculture

In agriculture land use, the CR and MCR indicated a balanced soil composition, reflective of typical agricultural land. However, a shift from agriculture to wasteland is characterized by significantly higher CR and MCR. The erosional behaviour as per CR and MCR could be arranged in the order: forest < agriculture <builtup< wastelands. The CR and MCR ratios indicated that the lower the ratio, the more would be the clay accumulation and lesser the erosion. The degraded lands shows the highest CR and MCR which might be due to sparse vegetative cover as vegetation protects soil surface from impact of erosion, reduces runoff velocity, enhance soil stability by root binding and enhance water infiltration. Transitioning from agriculture to built-up areas marked higher CR and MCR indicative of substantial soil disturbance or compaction commonly associated with urban development. Conversely, the shift from agriculture to forested land revealed the lowest CR and MCR. This trend signifies a finer soil texture and more stable soil structure, characteristic of forest soils. The lower ratios in forest soils suggest better soil integrity and reduced disturbance, likely due to the preservation of natural vegetation and lesser human intervention, whereas in agriculture, frequent tillage disrupts soil aggregates, reducing cohesion and increasing susceptibility to runoff (Montgomery, 2007). These variations in CR and MCR highlight how transitions to wasteland or urban areas can lead to increased soil compaction and altered soil properties, while a return to forest conditions fosters more stable soil structures. Understanding these changes is vital for effective soil management and conservation strategies, especially in the context of diverse land use practices and their environmental implications.

3.3 WASTELAND TRANSITIONS

Clay Ratio in wasteland scenario (Fig 4) ranged from 7.33 to 10.41, with an average of 8.72. Wasteland to agriculture transition showed a decrease in clay ratio compared to continuous wasteland, with the ratio ranging from 4.31 to 6.39 and averaging 5.39. This reduction implies improved soil conditions for agricultural activities. The transition of wasteland to forest scenario exhibited the lowest clay ratio, ranging from 2.68 to 4.13 with an average of 3.23, which suggested a significant reduction in erosivity of soil, and aligned with the optimal conditions for forest growth. The reduced clay ratios in forest soils might facilitate better root growth and soil structure, suitable for forest vegetation. Modified clay ratio in continuous wasteland also showed higher values, ranging from 6.59 to 9.40, averaging 8.12. This aligned with the higher clay content observed in the standard clay ratio. The scenario of wasteland to agriculture transition reflected a lower modified clay ratio than continuous wasteland, ranging from 4.00 to 6.05 with an average of 5.02. This suggested increased clay content, which could be more conducive to agricultural practices. The transition of wasteland to forest had the lowest modified clay ratio, ranging from 2.45 to 3.82 with an average of 3.02. This indicated a higher clay content in the soil, which could suggest better water retention. The high clay and modified clay ratios in wasteland indicate potential challenges in soil management, while the lower clay and modified clay ratios in transitions to agriculture and forest suggested more favorable soil conditions for these specific uses. This information is crucial for understanding the implications of land use changes on soil erosion and health and for guiding effective land management practices in diverse ecological settings.

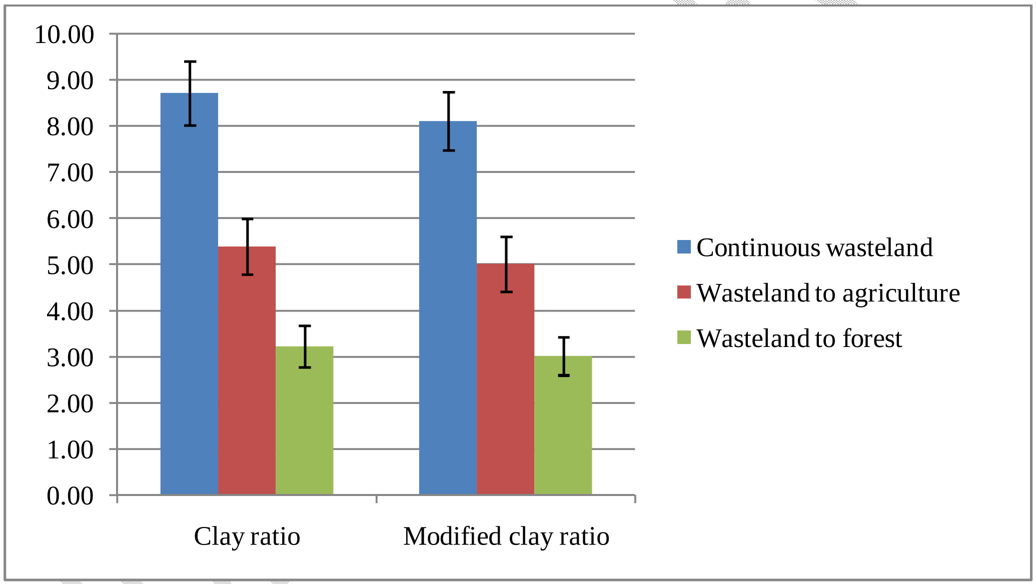

Fig. 4: Clay ratio and Modified clay ratio in continuous wasteland and landuse conversion from wasteland

4. CONCLUSION

After the analysis of soil samples collected from the identified sites undergone land use transitions, the examination of soil properties in the outer Himalayas unveiled a nuanced understanding of the impacts of land use transitions on soil erodibility. The clay ratio and modified clay ratios were were found to be minimum in forests followed by agriculture and wastelands. Forested areas exhibited higher clay content, indicative of their better soil structure and organic matter enrichment. However, transitions to agriculture or wasteland bring about significant alterations in such indices, with increased sand content and reduced clay content, potentially impacting crucial soil functions such as water retention, nutrient availability and erosion losses.

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