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Effects of Land-Use Practices on Soil erosion and Sediment yield in the Kalaw Chaung Watershed Area

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1. Introduction

Soil erosion is the most important environmental problem in the developing world (Ananda and Herath, 2003). Tropical soils are under particular threat as these soils are less stable than those in temperate climates because of their properties and climatic conditions (Steiner, 1996). Sloping uplands in Asia are particularly threatened by the serious problems of soil degradation (Lapar and Pandey, 1999) since much subsistence farming is carried out on these lands without soil conservation measures. At a global scale, land degradation may not pose a threat to food security but it does pose critical problems in areas where soils are fragile, property rights are insecure, and farmers have limited access to information and markets (Marcoux, 1996).

In this current time, Inlay Lake has been in the increase sedimentation. The main causes of sedimentation are forest degradation and depletion in the watershed area and expansion of agricultural land and industrial zones driven by increasing population.

Different soil and water conservation (SWC) measures have been introduced and implemented over the last decades by governmental and nongovernmental institutions to increase food production in this region. Moreover, the implementation of SWC has been triggered to improve crop production, increase vegetation cover, reduce soil erosion, and improve the food security and livelihoods of rural communities.

Soil erosion predictions have been undertaken by many researchers at different times but their results show significantly varied. Therefore, up-to-date and reliable information on the current soil conservation measure for integrated watershed management is critical for designing effective land management systems and minimizing the negative impacts of sediment load in Inlay Lake.

2. Objectives

- To study the impact of land-use practices on soil loss and sediment yield
- To provide technical information for suggesting suitable measure to reduce soil loss in Inlay lake watershed

3. Literature Review

Soil erosion is defined as the natural phenomenon in which removal and transportation of soil material occur mainly through the action of erosive agents such as water, wind, gravity, and human disturbances (E. Aksoy and M. S. Dirim ,2009). It is the biggest threat to soil fertility and productivity, mostly due to human disturbances (M. Kefi and K. Yoshino ,2010).

Soil erosion causes negative impacts on the environment and the economy, removes organic matter and important nutrients, and prevents vegetation growth, which negatively affects overall biodiversity. The loss of soil fertility in arable lands and decline in the quality of the soil resources are the major consequences of soil erosion.

The soil erosion process alters the physical, chemical, and biological characteristics of soil, which creates a reduction in agricultural productivity and arable land size and causes facing the problem of food scarcity, especially in the context of growing world population. Soil loss from agricultural land leads to the decreased crop production, potential damaged drainage networks, and lower water quality surface. (Issaka and M. A. Ashraf, 2017). Soil erosion created severe problems for human sustainability on agricultural productivity, water quality, hydrological system, soil fertility, and environments (Dinesh Bhandari etal.,2021)

To design and implement successful management strategies, it is necessary to understand the mechanisms, extent, and severity of soil erosion, as well as the causes that drive it. Monitoring the spatiotemporal variability of soil erosion risk and sediment export is required for two fundamental practical reasons. The first one is, for proper resource allocation and effective watershed management activities. Soil and water conservation activities are labor intensive and demand huge investment. Therefore, available limited resources should be allocated to those landscapes which are vulnerable to soil erosion. The second reason is, for selection of effective soil and water conservation technologies. Different soil and water conservation technologies could be recommended for specific location depending on the agro ecology, topography and land use systems.

There are a number of valuable possible uses of runoff plots (FAO, 1993). Runoff plots can be used to demonstrate to farmers known facts such high erosion under bare plot compared to good vegetation covertest and demonstrate the effect of conservation measures, such as mulching, on runoff and soil erosion; and collect data to construct and /or validate a model for predicting runoff and soil loss. Field plots range in sizes: from small, USLE plots and the unit-source watersheds. According to Mutchler et al., (1994) small plots, usually about 1m^2area, are used in studying the basic aspects of soil erosion in detail as well as in developing or verifying basic operating equations that govern the physical processes of soil erosion.

4. Materials and Method

4.1 Study area

The study area, namely, kalaw chaung watershed, is located at the southern Shan State, Myanmar . The watershed has an area of 756. sq. km and the outlet of this watershed drains into the Inlay Lake. The study site has a tropical monsoon climate. Most of the precipitation occurs in June, July, August and September, with an annual precipitation of 189 mm. The annual average summer temperature of the study area is 18°C and the average annual winter temperature is 11°C.

In the study site, cultivation practices are mostly mono-cultivation and rotational upland farming along slope. Moreover, the watershed is a socio-economically and environmentally important watershed of Inlay Lake. Selected land-use practices and location map are shown in table 1 and figure 1.

Table 1. Description of land use type

No.	Item	GPS points
plot 1	Natural Forest Area	N 20˚41' 3", E 96˚ 41' 57'
plot 2	Soil conservation area	N 20˚40' 50", E 96˚42'7"
plot 3	5years cultivated area	N 20˚37' 28", E 96˚40' 34"
plot 4	10years cultivated area	N 20˚37' 31", E 96˚40' 35"
plot 5	15years cultivated area	N 20˚37' 22", E 96˚40' 36"
plot 6	20years cultivated area	N 20˚37' 8", E 96˚40' 38"
plot 7	30years cultivated area	N 20˚41' 1", E 96˚41' 50"
plot 8	Open bare land area	N 20˚40' 41" , E 96˚42' 37"

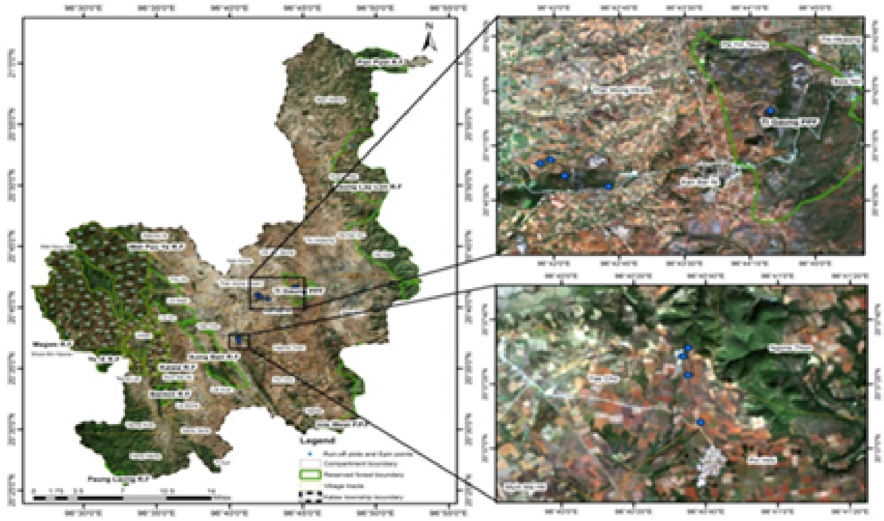

Figure 1. Location Map of Study area

Soil samples were selected randomly in an "X" shape on the original slope for analysis. Five soil sampling points were selected, and one sample of approximately 200 g, which was taken at each point from a depth of 0 to 10 cm, was sealed in a plastic bag and then transported to the FRI soil Laboratory for physical and chemical analysis. The particle-size distribution was determined by using the pipette method. The soil textural class is a clay loam texture (Table 2) and is susceptible to erosion. The soil pH was determined using a pH meter in a 1:2.5 soil: water suspension. Soil organic matter (OM) was determined by loss on ignition at 180 ◦C. Soil total nitrogen (TN) was measured by the semi-micro Kjeldahl method, and available phosphorus (Ava.P) was measured by the ultraviolet spectro - photometer method.

Table 2. Soil physical and chemical properties

Item	pH	Total N %	Ava. P ppm	OM %	Texture
plot 1	5.91	0.053	2.31	4.3	Loam
plot 2	6.3	0.05 0	2.19	3.8	Silt loam
plot 3	6	0.053	1.61	2.7	Clay-loam
plot 4	6.1	0.047	1.76	2.8	Clay-loam
plot 5	5.9	0.042	1.69	3.1	Clay-loam
plot 6	6.2	0.041	1.45	3.7	Clay-loam
plot 7	6.2	0.054	1.08	2.8	Clay-loam
plot 8	6.1	0.024	1.04	2.7	Clay-loam

4.2 Experimental set-up at the plot level

The runoff plots were set up under each land use type. Run-off frame design was established in each plot with a width of 1m x 1m .The plot was enclosed by 30 cm high galvanized iron sheeting buried to a 20 cm ground depth. The sheeting barrier prevented surface flow from entering or leaving the plot except through the collecting tank placed at the lower end of the plot. A collecting tank, approximately 100 L, was placed at the bottom end of each plot to measure the volume of runoff. And the tank was connected to a pipe line and covered with the iron sheet. To observe the soil erosion rate, erosion pin (30 cm x dia 0.5cm) with a mark at the top and bottom of the plot is driven into the soil until the mark level with the ground.

4.3 Field Measurement

Runoff and sediment in the tanks were collected and measured after every rainfall event, and soil erosion was also measured. The rainfall record from Heho Weather Station was also taken whenever the measurement of erosion. Sediment samples were taken out from the tanks with the plastic bottles at the time of raining. The plastic bottles used were labeled with date, time and number; and brought to the laboratory. Sediment samples were analyzed at the Forest Soil Laboratory to know sediment yield.

4.4 Data Analysis

Analysis of variance was prepared by using SPSS 16. The significant difference between treatments was differentiated by the statistical test known as Least Significant Difference (LSD), with a p-value less than 0.05.

5. Results

5.1 Soil loss assessment

The conversion of forest land to cultivated land resulted in severe land degradation mainly in the highlands of Inlay region. The human dominated landscape aggravated soil erosion by disturbing the natural ecosystem and expose the soil to severe soil erosion processes.

Figure 2 and table 3 showed the mean soil loss of the kalaw watershed area. The results indicated that annual soil loss of the study watershed varies from 6.0 to 103.0 t ha^{-1} yr^{-1} during the study period 2021. The highest mean value of soil loss 102.7 t ha^{-1} yr^{-1} was observed in bare land followed by cultivated land (from 62.0 to 81.0 t ha−1 yr−1) and soil conservation area (18.0 t ha−1 yr−1). Obviously the lowest value was recorded in natural forest land.

Table 3. Annual soil loss rate in different land use

Land use type	Soil Loss ton/ha
Natural Forest Area	6
Soil conservation area	18
5years cultivated area	62
10years cultivated area	54
15years cultivated area	66
20years cultivated area	74
30years cultivated area	81
Open bare land area	103

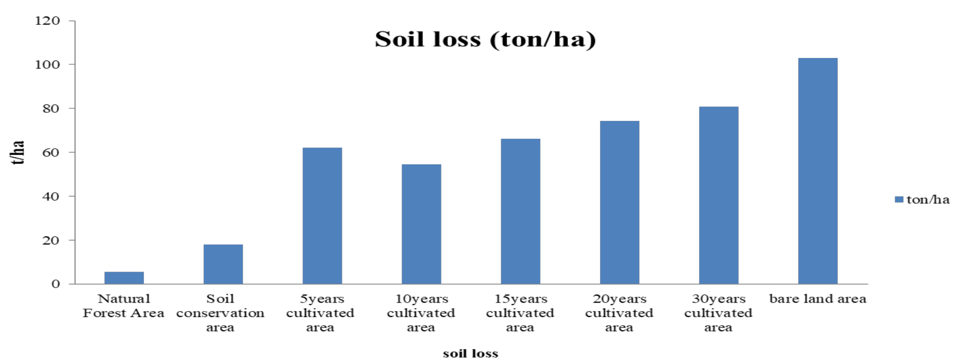

Figure 2. Annual soil loss rate in different land use

5.2 Soil erosion severity classes

Soil erosion severity classes were analyzed by reclassifying adopting class ranges of Haregeweyn et al. (2017). Soil loss rate ranged from 0 to 5 t ha^{-1} yr^{-1} rated as very slight; from 5 to 15 t ha^{-1} yr^{-1}rated as slight; moderate (15–30 t ha^{-1} yr^{-1}); severe (30–50 t ha^{-1} yr^{-1}) and very severe (> 50 t ha^{-1} yr^{-1}). The analyzed results were ranged from very slight to very sever severity class. Bare land and agricultural lands are classified under sever and very sever soil erosion severity class. Forest land and soil conservation area were classified slight to moderate soil erosion severity class.

5.3 Sediment yield assessment

Runoff plots in different landuse practices were determining using estimated average annual sediment yield of the Kalaw chaung watershed. It is helpful to prioritize locations for planning and choosing land management actions based on differences in the level of erosion risk among sub-catchment in Inlay watershed area.

The total quantity of sediment produced in the catchment ranges from minimal to approximately 59.0 t/ha according to sediment simulations. Forest land and soil conservation area had the lowest sediment output. The highest sediment production was found in cultivated areas with values ranging from 23.2 to 59.0 t ha^{-1} yr^{-1}, indicating more erosion exposure. Soil erosion has been recognized as the most severe in these land use types.

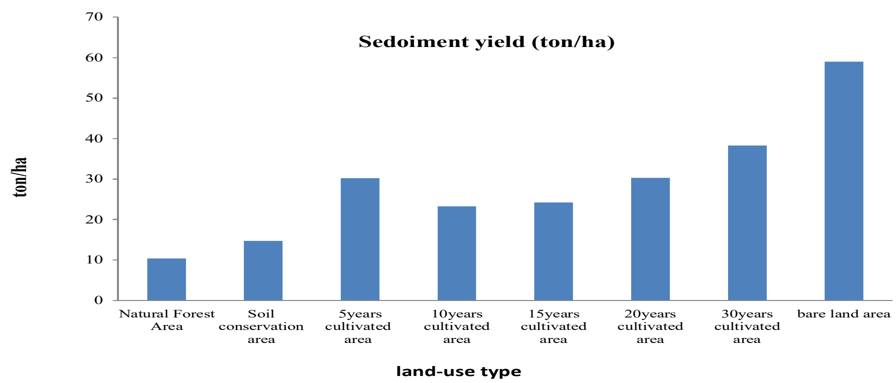

Figure 3. Annual sediment yield in different land use

6. Discussion

6.1 The impact of land use practices on soil erosion and sediment yield

Land use/cover dynamic is a major factor for the change in soil loss rate and sediment yield. This continuous severe soil loss and sediment yield obviously causes both onsite and of-site effect of soil erosion. Transport of soil nutrient elements with sediment which intern impacts agricultural productivity and food security is an onsite effect of soil erosion. In addition, sediment deposition and eutrophication on water bodies, particularly on lakes is an off-site. (Yeneneh et al.,2022)

The different land utilization and types of vegetation coverage in the kalaw chaung catchment might be the key factors responsible for the different soil erosion rates. Increased soil erosion rates were observed for the sites in an order of forest < control area < agricultural lands < bare land.

The lowest values of soil loss and sediment yield were observed in forest land and conservation area. .This is probably owing to the fact that forest can effectively reduce the intensity of the kinetic energy of raindrops and water flows as well as the wind speed above the soil surface (Li et al., 2005). The interlaced roots of vegetation with their exudates and microflora in the forest can also increase the cohesion and fixation of soil particles (Am´ezketa, 1999; Hudek et al., 2017; Musso et al., 2020; Pintaldi et al., 2018), inducing a suppression on soil erosion. Half soil erosion rates in the forests compared to that in the grassland should result from the different seasonal variability's in vegetation coverage between these two types of land. The forest site has relatively constant vegetation coverage throughout the whole year. The dominant species of tree in the forest in this region is the pine species , a perennial deciduous tree species with a large forest canopy and extensive litter, which effectively protects the surface soil from erosion by raindrops and wind, even in the winter.

The higher erosion rates at the agricultural lands than at the forest site were also reported by other studies in the kalaw chaung watershed (Nan Win Zaw , 2012, Cho Cho Win et al.,2017). The highest soil erosion rate (32.5–40.5 t/ ha/y) was observed at the cultivated lands. The low content of organic matter in the cultivated land arising from the low vegetation coverage hampers the aggregation of soil particles and water infiltration, exacerbating water-induced erosion (Massimo Conforti et al., 2013).

This is attributed to over exploitation of cultivated fields without applying any soil and water conservation strategies, which is evidenced from field survey work. Frequent cultivation for seed bed preparation disintegrates soil structure and reduces aggregate stability which hastens soil erosion, particularly in slope areas. In addition, cultivated fields and bare lands are exposed to direct rain drop impact contribute higher soil loss and sediment yield. Poor land use systems and over exploitation of resources are responsible factors for the expansion of bare lands.

In this regard, our result is comparable to the results of similar studies which were conducted in other catchments which found cropland has the highest contribution to a watershed's soil loss (Sharma et al. 2011; Yesuph and Dagnew 2019; Aneseyee 2020). Besides, although the study revealed a higher rate of soil loss per hectare on bare land, its contribution to the total soil loss was minimal because of its small area coverage in the watershed.

The estimated sediment export along the LULC classes was also in line with the results observed in the spatial distribution of the soil loss. The result revealed that the highest contribution to the total sediment export comes from cultivated lands. The result confirms to the findings of Haregeweyn et al. (2015) who found higher sediment export from cultivated lands. This is likely associated with the cultivation of steep slopes, intensive plowing and mono-cropping practices, and poor land management activities. Hence, the result gives a reason to suggest the need for promoting sustainable land management practices on steep slopes in the watershed

6.2 Effects of erosion control practice on the plot level

The implementation of soil conservation practices resulted in considerable improvement for sediment export reduction. The imposed watershed management alternatives (filter strips, soil/stone bunds, contouring, and terracing) had a significant impact on the watershed's sediment output reduction (Megersa Kebede Leta et.al,2023). In this study, the implementation of erosion control practice in this watershed, soil erosion rate as high to severe erosion prone was substantially reduced. In general, gully control with vegetative bench reduced sediment by 75% and 61% in comparison with bare land agricultural lands.

This demonstrates that SWC options can play a significant role in checking soil erosion and retaining sediment at the sub-watershed scale. A study by Nyssen et al. (2009) reported sediment yields reduction (78%) due to SWC intervention in northern Ethiopia. Another study also reported a 76% sediment yield reduction at Enabered (Tigray) (Haregeweyn et al., 2012) due to SWC intervention at the watershed scale. There was also a notable impact of SWC measures on sediment yield reduction (86%) at Gununo catchment in southern Ethiopia (Mitiku et al., 2006).

7. Conclusion and recommendation

The results indicated that annual soil loss of the current watershed varies from 6.0 to 103.0 t ha^{-1} yr^{-1} during the study period. The different land utilization and types of vegetation coverage in the kalaw catchment might be the key factors responsible for the different soil erosion rates. Soil erosion is more pronounced in agriculture and barren land. Annual soil losses rate from the forest land was found to be minimum. However, the implementation of erosion control practice in the watershed, soil erosion rate and sedimentation were substantially reduced. The findings of this study could be useful in resolving problems related to soil erosion, soil nutrient export, agricultural productivity and food security. The results could also provide new information for land managers, government officers, and development organizations to consider soil and water conservation technologies while they are designing development plans and implementing mitigation measures. Moreover, it helps to raise awareness among the local community about the importance of not further degrading the natural resources.

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