Dorji et al. 2020 Bhutanese Journal of Agriculture 3(1) 1-17

Soil Loss Prediction Using Revised Universal Soil Loss Equation (RUSLE) for Amochhu Watershed in South-western Bhutan

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ABSTRACT

Soil erosion by water is a serious problem all over the world affecting sustainability of agricultural production. In Bhutan, the limited productive land suffers risk from various forms of soil erosion. Although the soil erosion is common in all parts of Bhutan, it is not well quantified and documented. To generate information on soil loss, this study was conducted in Amochhu watershed using Revised Universal Soil Loss Equation (RUSLE). Geographic Information System (GIS) was exclusively used to generate factor maps of RUSLE. The factor maps include rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), Cover management (C), and conservation practice (P). A spatial distribution of soil erosion over Amochhu watershed was obtained by integrating all the factor maps in Arc GIS environment. The soil erosion was found to vary between 5 Mt/ha/yr for well covered areas (forest) to more than 150 Mt/ha/yr in steep-slope areas with sparse vegetation. The average soil erosion is 130 Mt/ha/yr. The predicted amount of soil loss and its spatial distribution provides a strong basis for integrated management and sustainable land use for the watershed. It also gives clear picture as to where we need to focus our sustainable land management interventions. However, similar soil loss prediction study needs to be rolled out to other watersheds so that we have soil loss information at the national level.

Keywords: *Soil loss prediction, RUSLE, GIS, Amochhu Watershed, Bhutan*

1. **Introduction**

Bhutan is a small landlocked country with total land area of 38,394 km^2 in the Eastern Himalayas. It is located geographically between 26°47'N to 28°26'N latitudes and 88°52' to 92°03'E longitudes with most of the mountain ranges running from north to south. Due to its rugged terrain, the country has only about 8% arable land (of which 2.93% is actually cultivated) and 70.46% (excluding 10.81% shrubs) under forest cover (NSSC, 2010). The predominantly steep slopes make land degradation a more serious threat in Bhutan than in most other places (Norbu et al., 2003). As per the study conducted by NSSC across the country, annually, about 3 to 21 t ha−1 of fertile topsoil is lost due to soil erosion (NSSC, 2010), which is a serious problem as mountain soils are generally defined as poorly developed, shallow, acidic and relatively infertile (Romeo et al., 2015). Loss of top soil significantly reduces the inherent soil fertility resulting in poor land productivity and crop yield. The land degradation, especially through soil erosion is thus becoming

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an important issue in Bhutan, because of its adverse impact on agronomic productivity, the environment, and consequently on food security and livelihoods.

In Bhutan, land degradation by landslides, soil erosion, internal biophysical and chemical deterioration is the main constraint for sustainable land use. It is caused by various interplay of factors such as anthropogenic factors (i.e. increased population, unsustainable land management practices, overgrazing, deforestation); bio- physical factors like unfavourable geology; and environmental factors viz. monsoon climate and the emerging effects of climate change observed through uncharacteristic patterns of weather conditions (Rinzin, 2008). There are other factors that do not trigger immediate attention like socio-economic changes and earthquakes in contributing to land degradation (Gyeltshen, 2010). The inclusion of the natural factors such as earthquake is crucial, especially in regions located in the seismically active zones, for instance in the Himalayan belt (Bali, Bhattacharya, & Singh, 2009), as one of the indirect factors causing physical land degradation, which is also confirmed through a series of physical land degradation assessments carried out in Bhutan (NSSC, 2013).

Notwithstanding the above facts, there is still no clear understanding about the extent of land degradation in Bhutan. This is mainly because of extreme diversity in agro-ecological zones, the relative inaccessibility of the country, the lack of reliable data (especially the latest satellite images) and the limited human capacity. Therefore, to help predict and build information on soil loss, this study was conducted in Amochhu watershed using the Revised Universal Soil Loss Equation (RUSLE).

2. **Materials and Method**

2.1.Site description

The Amochhu watershed is located between 26°47’N and 28°26’N latitudes and 88°52’ and 92°03’E longitudes (Figure 1). It covers an area of 88,929.53 hectares. Land use is mainly dominated by agriculture and the common crops grown are rice, cardamom, ginger, citrus, areca nut, maize, and vegetables. The communities also depend on livestock rearing for income generation mainly through sale of butter and cheese.

The sites fall within tropical to subtropical type of climatic zone with altitudes ranging from about 160 m to 2200 metres above sea level (masl). The sites vary in topography from nearly flat to very steep mountainous slopes. Precipitation is generally higher in the Central and Western Himalaya, due to the location close to the head of the Bay of Bengal. Although, screened from the full brunt of the monsoon by the Meghalaya hills in India, southern Bhutan still receives heavy and intense orographic rainfall, with annual means in the range 2.5-5 m (MoA, 1994). The rainfall data for the central and northern parts of the country show a decrease in precipitation recording with annual means precipitation of less than 1000 mm.

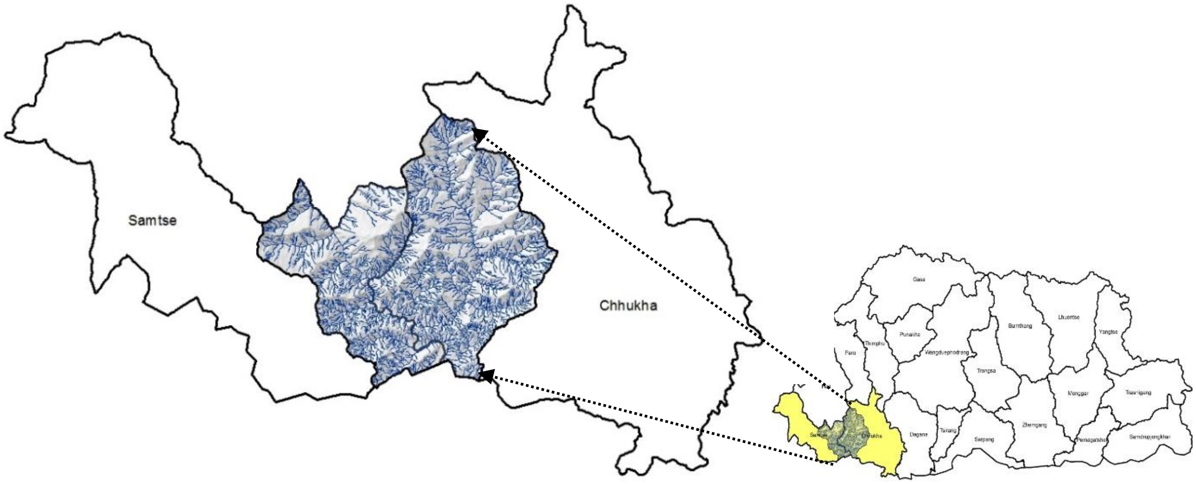

Figure 1. Map showing the location of Amochhu watershed

2.2 Information on rainfall, soil, land cover and DEM

For the Amochhu watershed, the annual soil loss rate was computed based on the RUSLE model in Geographic Information System (GIS) using Arc GIS 10.2.2 and its associated GIS packages. Annual soil loss is defined as the amount of soil lost in a specified time period over an area of land which has experienced net soil loss. It is expressed in units of mass per unit area, e.g. Mt $ha^{-1}y^{-1}$ (Nearing, Lane, & Lopes, 1994)

Rainfall data from 1996 to 2011 was obtained from the National Centre for Hydrology and Meteorology (NCHM), Ministry of Economic Affairs (MoEA), Bhutan to compute the rainfall erosivity using the equation (2) developed by Renard and Freimund (1994).

Soil information, especially soil texture was determined by feel method during the 24 days fieldwork. 259 point data were collected for the purpose of interpolation using inverse distance weighted method (IDW).

Land use cover map obtained through digital image processing technique from ALOS images (AVNIR-2) of 2006-2009 winter seasons with 10 meters resolution was used to compute the **C** factor. Digital Elevation Model (DEM) with 90 m resolution obtained by SRTM, LANDSAT was used to generate the slope length and slope steepness.

2.3 RUSLE Model

The Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) was developed initially as a tool to assist soil conservationist in farm planning. It was widely used model in predicting soil erosion loss on specific slopes in specific fields. The USLE was extensively applied all over the world at many scales mainly due to the simplicity of the model formulation and easy availability of the data set (Wang et al., 2009; Pan, Zhang, & Zhao, 2005, Shi et al., 2004; Bartsch, Van

Miegroet, Boettinger, & Dobrowolski, 2002; Jain, Kumar, & Varghese, 2001; Jain & Kothyari, 2000). The Revised Universal Soil Loss Equation (RUSLE) was developed with the basic structure of the USLE with several improvements in determining factors (Renard & Freimund, 1994). The update was based on an extensive review of the USLE and its data base, analysis of data not previously included in the USLE, and theory describing fundamental hydrologic and erosion process.

The RUSLE quantifies the soil erosion as the product of five factors:

$$\mathbf{A = R \times K \times LS \times C \times P}$$

Where, **A** is the soil loss in Mt per hectare, **R** is the rainfall - erosivity index, **K** is the soil erodibility index, **L** represents slope length, **S** is the slope steepness factor, **C** is the cover management, and **P** is the supporting practices factors.

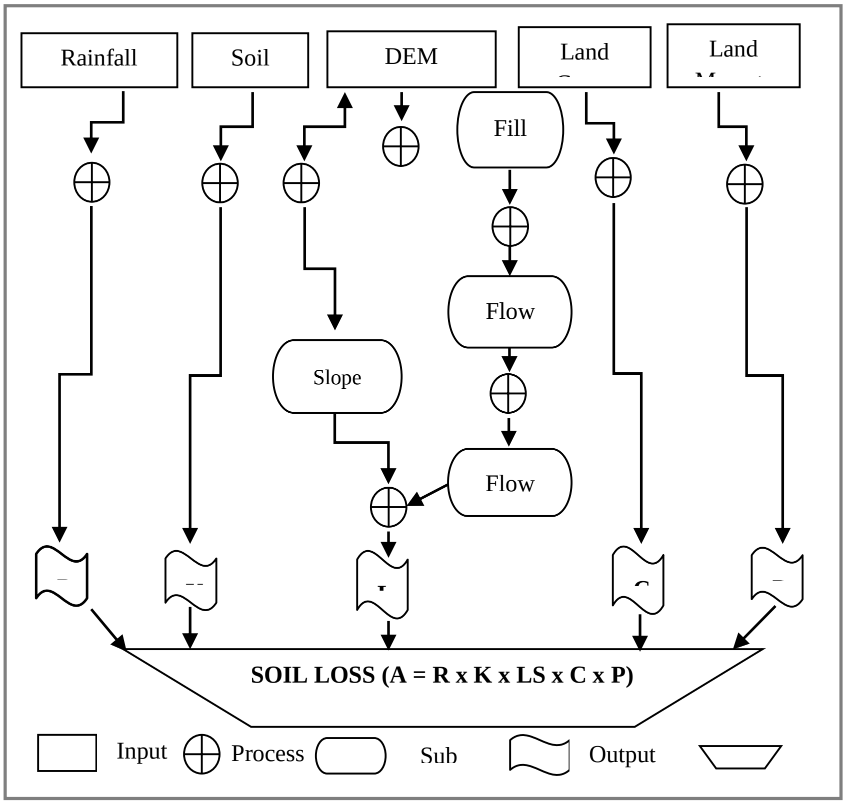

Figure 2. Flow chart of the methodology

2.3.1 Rainfall Erosivity Factor (R)

R factor is the quantitative expression of the erosivity of local average annual precipitation and runoff causing soil erosion. It is a measure of the erosive force of a specific rainfall. The greater the intensity and duration of the rain storm, the higher the erosion potential.

Since there is no record of rainfall intensity available with the NCHM for Amochhu watershed, the records of monthly rainfall data was used to determine the R factor. Rainfall data of 16 years average for four weather stations distributed over the watershed were used to calculate R values based on the equations of RUSLE and USLE developed by Renard and Freimund (1994). Equations are:

$$R = 0.0483 \text{ x } P^{1.61} \quad \text{for } P < 850 \text{ mm} \qquad (1)$$

$$R = 587.8 - 1.219 \text{ x } P + 0.004105 \text{ x } P^{2} \quad \text{for } P > 850 \text{ mm} \qquad (2)$$

Where ***R*** is the R-factor in RUSLE equation, ***P*** is the average annual precipitation.

Taking into consideration the average annual precipitation $P < 850$, the equation (1) was used to compute the R factor values.

Table 1. Rainfall Erosivity (R) values

Stations	Mean rainfall (mm)	R factor
Phuntsholing	334.81	560.90
Sipsu	465.28	952.73
Chukha	127.12	117.96
Haa	73.79	49.13

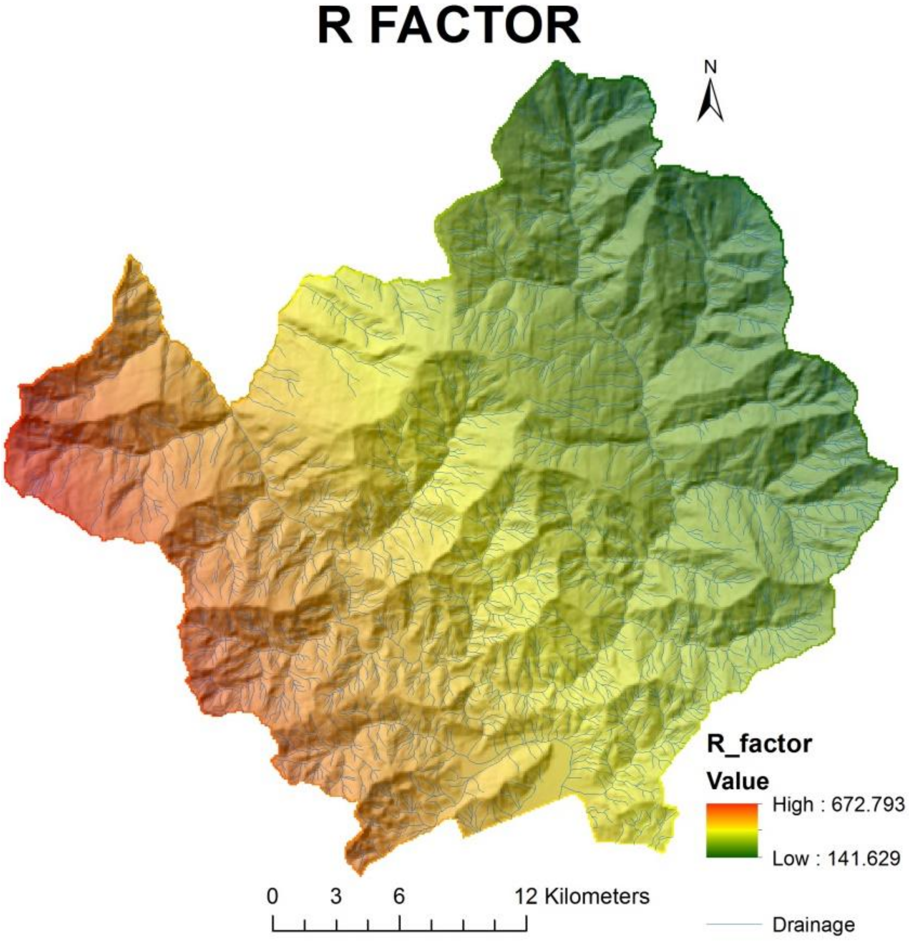

Figure 2. Map showing R factor

2.3.2 Soil Erodibility Factor (K)

The soil erodibility factor (K) is the average soil loss in Mt/hectare (Mt/ha) for a particular soil in the cultivated/or continuous fallow lands with selected slope length of 22.13 m and slope steepness of 9%. Texture is the principal factor affecting K, besides soil structure, organic matter and permeability. However, in the absence of soil map of Bhutan, only soil texture was considered.

The first step in soil erodibility (K) evaluations for USLE was the publication of K values for the runoff and erosion stations. Olsen and Wischmeier (1963) computed soil erodibility based on the new rainfall factor. Wischmeier and Mannering (1969) used a rainfall simulator in a study to measures soil loss on 55 Corn Belt soils. They computed soil erodibilities from the data adjusted to the unit plot. Then, they related soil erodibility to a number of variables using multiple regression techniques. A major finding was that very fine sand behaved much more like silt than like sand.

These data were further analyzed and used with the benchmark soil's erodibilities to develop a soil erodibility nomograph (Wischmeier, Johnson, & Cross, 1971) that has been proven as a good tool for estimating soil erodibility for most soils.

Basic data for estimating soil erodibility were collected from the field and a total of 259 soil texture points were captured using Global Positioning System (GPS) device. The data were then interpolated to generate soil texture of the unknown sites from the known points. Based on several literature reviews, the ordinary inverse distance weighted (IDW) method of interpolation was found to be appropriate to generate K factor map. The K factor values as proposed by Maiti (2013) based on the estimates using the published soil erodibility nomograph (Wischmeier & Smith 1978, Renard et al., 1996) was used for calculating K factor values as shown in Table 2.

Table 2. Soil Erodibility K values

Soil type	Erodibility	K value range
Fine-textured; high in clay	low	0.05 - 0.15
Course textured; sandy	low	0.05 - 0.20
Medium textured; loams	moderate	0.25 - 0.45
High silt content	high	0.45 - 0.65

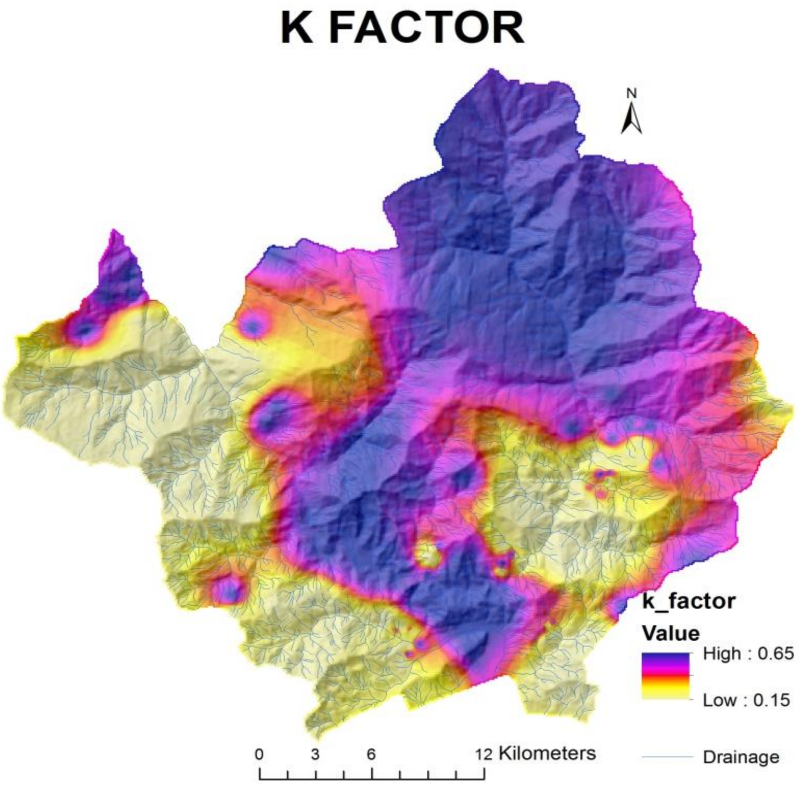

Figure 3. Map showing K factor

2.3.3 Slope Length and Slope Steepness Factor (LS)

The LS factor represents the effect of slope length (L) and slope steepness (S) on the erosion of a slope. The combination of the above factors gives the actual topographic factor. Thus, LS is the predicted ratio of soil loss per unit area from a field slope of 9% (5.16°) on 22.1 m slope length. The Digital Elevation Model (DEM) with a resolution of 90 m was used to calculate L and S factors. The slopes were reclassified into 5 classes based on LS value distribution proposed by Hui et al., (2010).

The actual slope length is the horizontal distance (excludes slopes) of the plot being modeled and is converted to the slope length factor by the following equation (3)

$$L = \left(\frac{\lambda}{22.1}\right)^{m} \qquad (3)$$

Where λ is the actual slope length and m is the slope length exponent that is the ratio of rill to interill erosion.

The S factor (slope steepness factor) is the ratio of soil loss relatives to a 9 % slope, which is the standard slope that experiment plots use. The slope steepness factor is calculated as a function of slope as shown below:

$$S = 10.8\,Sin\,\Theta + 0.03, slope\ gradient\ \leq 9\,\% \qquad (4)$$

$$S = 16.8\,Sin\,\Theta + 0.50, slope\ gradient > 9\,\%$$

Where S is the slope factor, and ϴ is the slope angle. Depending on the measures slope gradient, a different equation for S must be used. Choosing S allows the RUSLE to be more finely tuned for different terrains. This is important because the topographic factor and the RUSLE as a whole is very sensitive to the slope factor S.

In this study, LS is calculated by the USPED (Unit Stream Power Erosion and Deposition) method, which is using the raster calculation between flow accumulation and slope of watershed that can be done using Arc GIS.

In comparison to the RUSLE, the USPED is physically based model that incorporates a spatial component. In the RUSLE, L is dependent on linear distance λ_i, which is the horizontal length from the start of sediment transport to point *i* on the slope. Thus, they are inherently a single dimensional function. The USPED instead uses the area of upland contributing flow at distance *i*. In USPED, the area is substituted in place of the former slope length. The L calculation for point *i* on a slope is shown in Equation (5)

$$L = (m+1)\left(\frac{\lambda_A}{22.1}\right)^m \qquad (5)$$

Where, L is the slope length factor at some point on the landscape, λ_A is the area of upland flow, *m* is an adjustable value depending on the soil's susceptibility to erosion, and 22.1 is the unit plot length.

The calculation of S value is shown in Equation (6)

$$S = \left(\frac{Sin\,(0.01745\ X\ \Theta_{deg})}{0.09}\right)^n \qquad (6)$$

Where, ϴ is the slope in degree, 0.09 is the slope gradient constant, and *n* is an adjustable value depending on the soil's susceptibility to erosion. In this study, value m = 0.4 and n = 1.4, which is typically for farmland and rangeland with low susceptibility to rill erosion as mentioned by Pelton, Frazier & Picklingis (2014) based on Mitasova, Hofierka, Zlocha & Iversion (1996) was used. The slope (%) was derived from DEM and value of m was adapted from Wischmeier and Smith (1978) as shown in the Table 3. The result of the analysis is shown in Figure 5.

Using USPED method, the LS factor is calculated in the GIS Environment. The spatial analyst toolkit of the GIS software was used to generate raster layer of the slope gradient and hydrology toolkit to calculate flow direction and then flow accumulation. The output layer was used in the GIS raster calculator to generate LS factor map based on the following formula:

LS = Power (“Flow Acc”* resolution/22.1, 0.4) * Power (Sin (“Slope”*0.01745) / 0.09, 1.4) *1.4 and finally divided by 100 to convert to real LS factor following the formula: LS factor = LS/100

Table 3. M values

m-value	Slope (%)
0.5	> 5
0.4	3 – 5
0.3	1 – 3
0.2	< 1

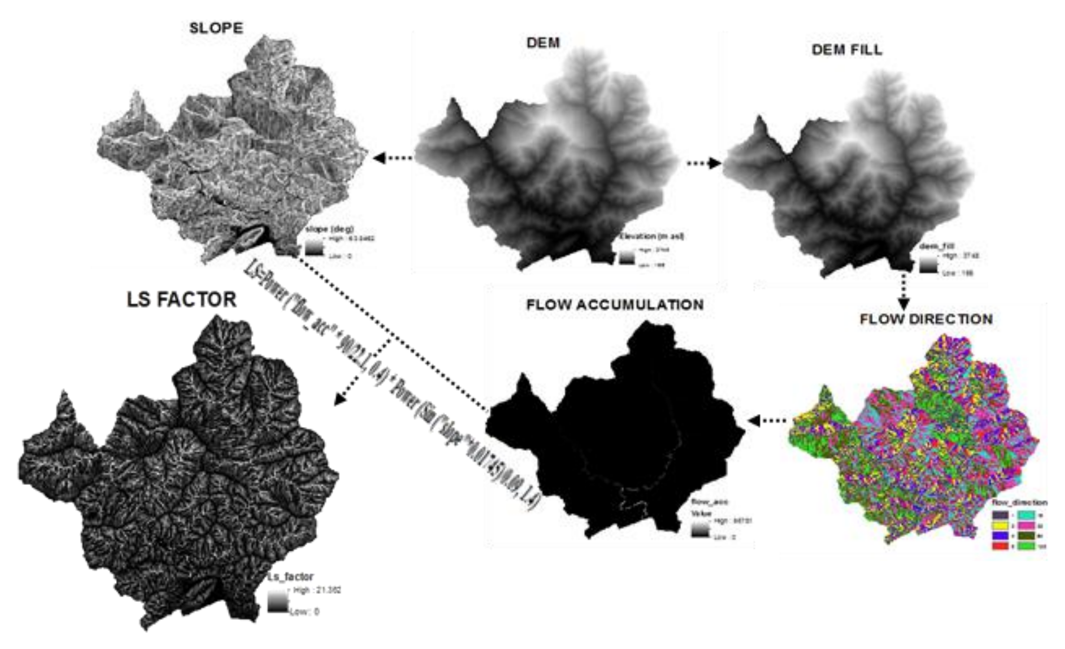

Figure 4. Map showing LS factor

2.3.4 Crop Management Factor (C)

During the land cover assessment in 2010, digital image processing technique was used. ALOS images (AVNIR-2) from the 2006-2009 winter seasons with 10 meter resolution, The Land Use Planning (LUP,1995) land cover maps, topography maps from the National Land Commission Secretariat (NLCS), LandSat (2004–2005) and image captured from Google Earth were used for the purpose of assessment.

Digital image processing was done in ERDAS platform. The images were first projected to DRUKREF–03 (Bhutan standard coordinated system, NLCS) to match the images with the existing topographic features such as contour and drainage lines.

The unsupervised classification was used to classify the images with the minimum of 30 classes with 10 iterations. Zonal Statistics function was used to summarize the values of a raster within the zones of another datasets. K means algorithm in R-Statistics was applied for grouping of homogenous segments. The initial assignment of land cover types was done by referring LUP (1995) land cover maps and the Google Earth prior to field verification. The minimum mapping unit was set at 500 m2.

Intensive field verification was done in almost all the gewogs for improving and validating the draft land cover maps. In order to ensure a reasonable level of precision, system accuracy assessments were carried out by comparing randomly selected referenced pixels. Random points were generated by the system with the minimum of 50 random points per class if the number of class is less than or equal to 12 and minimum of 75 to 100 random points per class if the total number of class is more than 12 at every geog level. The overall acceptance level of map accuracy was set at 85%. The Look up Tool in Arc GIS was used to reclassify the land use/cover map according to its C values (Table 4), which were assigned based on Hui et al. (1996). These values were used to reclassify the land cover map to obtain the C-factor map of the watershed.

Table 4. Crop Management C values

Category	C- factor
Agriculture	0.63
Built up area	0.003
Barren soil	1.00
Forest	0.003
Shrub	0.014
Grass	0.05
Water bodies	0.00

Table 5. Land use area

Sl.no	Name	Area (ha)	Area (%)
1	Agriculture	7993.27	8.99
2	Built up area	252.53	0.28
3	Barren soil	586.16	0.66
4	Forest	73231.11	82.35
5	Shrubs	4204.73	4.73
6	Grass	772.78	0.87
7	Water bodies	1888.95	2.12
Total		88929.53	100

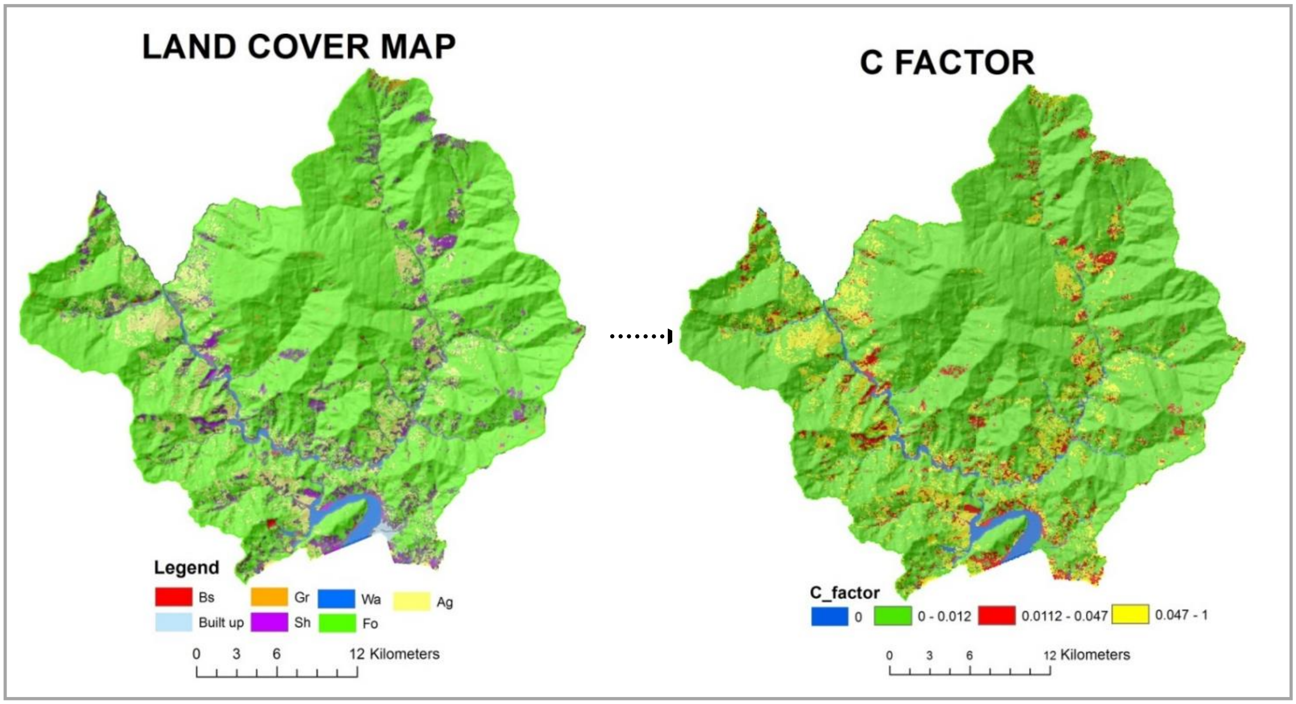

Figure 6. Map showing C factor

The land cover and management factor represents the effect of vegetation, management and erosion control practices on soil loss, the value of which ranges from 0 in water bodies to 1 in barren land.

2.3.5 Conservation Practice Factor (P)

The support practice factor P represents the effects of those practices such as contouring, strip cropping and terracing that help prevent soil from eroding by reducing the rate of water runoff. It is the ratio of soil loss with a specific support practice on croplands to the corresponding loss with slope-parallel tillage (Wischmeier & Smith 1978). The P factor map was derived from the land use/cover map and each value of P was assigned to each land use/cover type and slope as shown in Table 6. The Look up Tool in Arc GIS was used to reclassify the land use/cover and slope length maps according to its P value with contouring support practice.

Table 6. Support practice P (Shin, 1999)

Slope %	Contouring	Strip cropping	Terracing
0.0 – 7.0	0.55	0.27	0.10
7.0 – 11.3	0.66	0.30	0.12
11.3 – 17.6	0.80	0.40	0.16
17.6 – 26.8	0.90	0.45	0.18
> 26.8	1.00	0.50	0.20

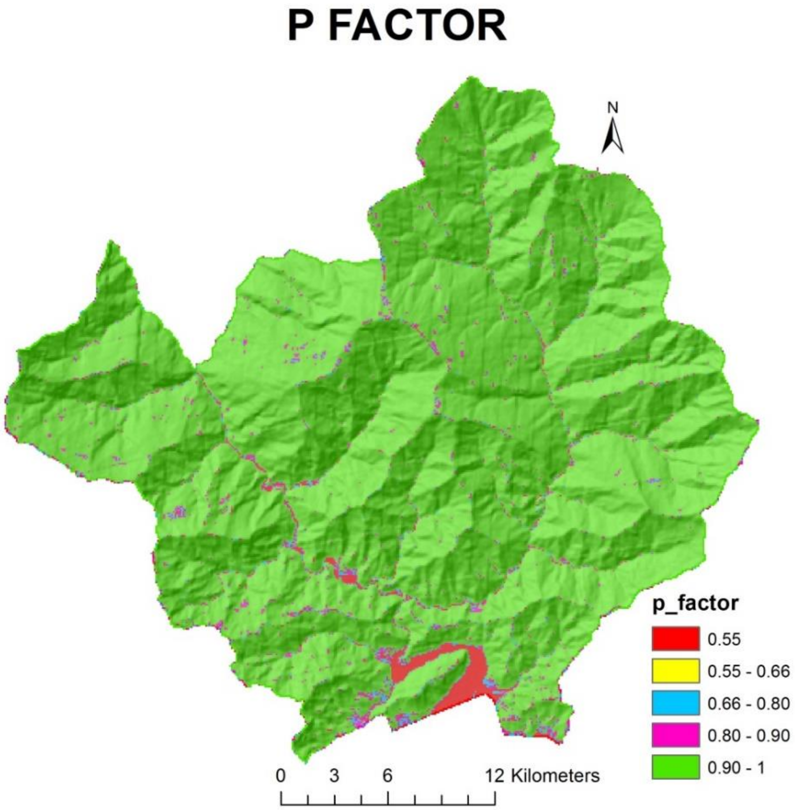

Figure 7. Map showing P factor

3. **Results and Discussion**

The data layers (factor maps) extracted for R, K, LS, C and P were integrated in the raster calculator option of the Arc GIS spatial analyst to quantify and generate the soil loss map of Amochhu watershed. The rainfall erosivity factors (R) of the four weather stations were found to be in the range of 142 and 673 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}}$. The highest R value recording of 673 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}}$ occurs in the lower part of the Amochhu watershed and the lowest value of 142 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}}$ in the upper reaches of the watershed.

The K factor value for soil type obtained through literature review and based on Table 4 proposed by Maiti (2013) was used for K factor calculation. The erodibility of soils varies from 0.05 to 0.65 $\mathrm{ton.ha.hr^{-1} \cdot MJ^{-1} \cdot mm^{-1}}$.The soil with the minimal erosion occurs in the lower reach of the watershed and the most erodible soils are distributed over the middle and the upper sections of the watershed.

The LS factor was calculated by using SRTM DEM with a resolution of 90 m. It is obvious from LS map that low LS value is distributed along the valleys in the lower part of the watershed. High S value occurs on the upper steeper slopes, suggesting the areas prone to erosion.

The map of C factor (Figure 6) was generated by reclassification of each land cover type using C values given in Table 4. From the table, a total of 82.35% is covered by forest, while agriculture covers 8.99%, barren soil 0.66%, grass 0.87%, shrub 4.73% and water bodies 2.12%. The C map of the watershed is mainly composed of values ranging between 0.01 and 0.70, respectively, for forest and barren soil. The higher C factor values indicate higher soil erosion potential as C factor is a ratio of soil loss in a cover management sequence to soil loss from the bare soil unit plot (Nyakatawa, Reddy, & Lemunyon, 2001).

The P factor map (Figure 7) was prepared from the spatial analysis program in GIS based on Table 6, which shows the relationship between P factor and slope levels for various land use types. The contouring support practice was considered in the present study based on the presence of hedge rows and terraces during the field work. The values of P factor of Amochhu watershed ranges from 0.55 to 1.0 with mean value of 0.78.

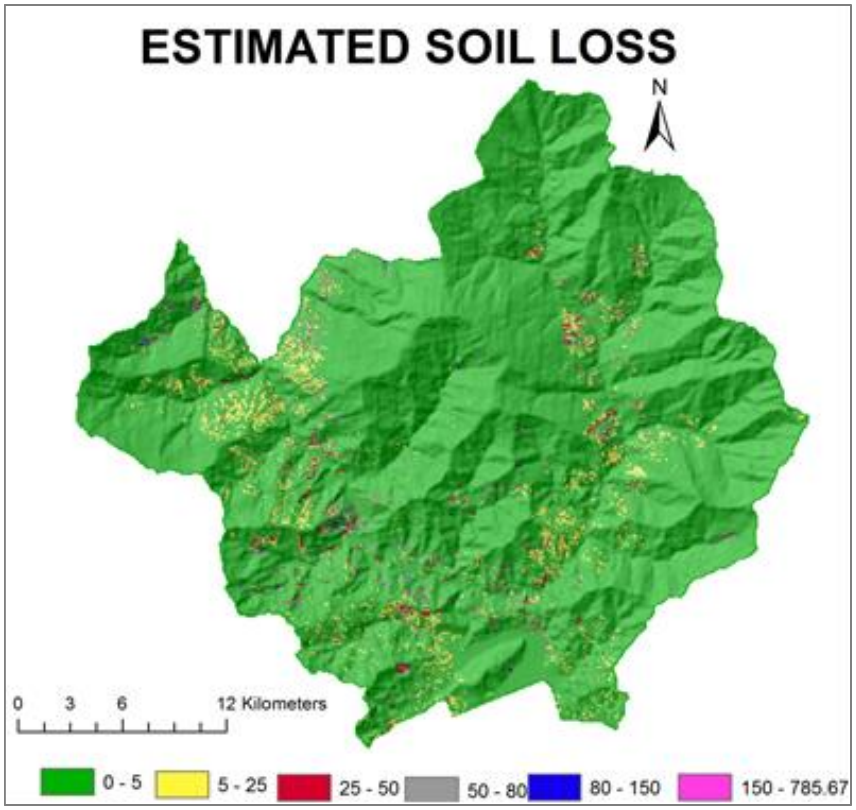

Figure 8. Estimated Soil loss map

Based on the analysis, the amount of soil loss in the Ammochhu watershed is about 5 Mt/ha/year under forest, accounting for 93.41% area of the watershed. The predicted soil loss from agriculture land ranges from 5-25 Mt/ha/year. The average soil loss from the watershed is about 130 Mt/ha/year. The maximum soil erosion of above 150 Mt/ha/year occurred on very steep section and accounts for 0.05% area of the watershed. The vegetated areas and the gently sloping sections of the watershed show least susceptible to soil erosion.

Table 7. Soil loss rate

Area (%)	Soil loss (Mt/ha/yr)
93.41	5
4.22	25
1.57	50
0.50	80
0.25	150
0.05	> 150

4. **Conclusion**

Soil erosion caused by water is becoming a serious problem for Bhutan given its limited arable land, which is located on steep slopes. The main objective of this study was to generate soil loss information using the Revised Universal Soil Loss Equation (RUSLE) and Geographic Information System (GIS) for Amochhu watershed. The rainfall erosivity factor (R) ranged from 142 MJ mm ha/hr/year at the upper reaches of the watershed to 673 MJ mm ha/hr/year in the lower part of the watershed meaning that the erosion potential due to rainfall intensity is higher at the lower end of the watershed than the upper part. While the erodibility of soils (K) varied from 0.05 to 0.65 ton ha/hr/MJ/mm indicating that the minimum soil erosion occurs in the lower end of the watershed as compared to the upper reach. Similarly, the slope length and slope steepness (LS) factor was found low along the lower part of the watershed suggesting that the lower areas of the watershed are less prone to erosion as compared to the upper steep slopes.

The predicted amount of soil loss ranged from 5 Mt ha/year under forest cover to 150 Mt ha/year on very steep slopes and with less vegetation cover. Clearly the watershed areas with good vegetation cover and gentle slope are less susceptible to soil loss than the other areas with less or no ground cover and with steeper slopes. The predicted amount of soil loss and its spatial distribution, therefore, provides a strong basis for integrated management and sustainable land use for the watershed. It also gives clear picture as to where we need to focus our sustainable land management interventions. However, similar soil loss prediction needs to be rolled out to other watersheds so that we can have soil loss information at the national level.

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