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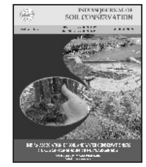

Estimation of soil erosion using revised universal soil loss equation in upper Umiew catchment, East Khasi hills, Meghalaya

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ABSTRACT

This study has attempted to estimate soil erosion for four years (2011-2014) in the upper Umiew catchment located in the Central Highland of Shillong plateau by using the Revised Universal Soil Loss Equation (RUSLE) modelled in a GIS environment. The rainfall erosivity factor was calculated seasonally. The slope length factor was obtained from a DEM of 20×20 m pixel size based on the contours of two toposheets of Survey of India at the scale of 1:50,000. The cover management factor that depends on the land use (LU) / land cover (LC) was obtained from Landsat-ETM of 30 m resolution of United States Geological Survey. The soil erodibility factor ranged between <.02 to >.06 t h $MJ^{-1}mm^{-1}$. The value of conservation practice factor was set at 1 as there were no conservation practices. Further, the results showed that during monsoon the average soil loss falling under the category of high to very severe soil loss (20 to >80 t ha^{-1}) accounted for a total area coverage of about 73.42%. The study also revealed the potential ability of rain-water to erode the undulating landscape that covers about 61.25% of the total area which is mainly associated with forest degradation, agricultural land use and quarrying activities.

1. INTRODUCTION

A process of soil erosion is a spatio-temporal phenomenon that modifies the earth's surface due to several geomorphic factors and is accelerated by human activity (Leopold *et al.,* 1964). Several studies showed that erosion by water is a natural phenomenon, especially in humid climatic regions. It is important to monitor the rate of soil erosion under diverse climatic conditions, topography, geological settings and LU/LC changes. According to Hessel *et al.* (2011), areas with considerable relief and sparse vegetation have some of the highest erosion rates, which is more erodible during wet season. Studies have also shown that an increase in vegetation prevents intense erosion. In areas of humid climates having a perpetual forest cover, shrubs and grasses, there is slow removal of soil which is part of the natural processes. Hill and Peart (1998) studied runoff and soil erosion based upon plot studies for southern China and found vegetation as a major control upon runoff and sediment production. The amount of vegetation cover determines the rate of soil erosion; as the vegetation cover increases, the soil loss decreases (Kouli *et al.,* 2009). Besides, topography also plays a role in determining the intensity of soil erosion. In vertical slopes, erosion is less intense from overland flow as the ground surface intercepts vey less of the falling rain (Strahler, 1975). In a natural state, soil loss is obvious, however with human interference, the processes get intensified which is a major environmental concern, especially in humid areas. The study conducted by Saha *et al.* (2018) in upper Kangsabati watershed shows that cultivated lands are susceptible to maximum soil erosion. Aswathy and Sindhu (2013) emphasised that urbanization reduces water holding capacity of soil, and runoff rate increases, which in turn leads to soil erosion. In literature, various models have been adopted for studying soil erosion, such as Modified Fournier Index (Ufoegbune *et al.,* 2011), Water Erosion Prediction Project and Unit Sediment graph (Chandramohan and Balchand, 2015) to name a few. However, one of the most-widely used models is the universal soil loss equation (USLE) by Wischmeier and Smith, 1965 (Saha *et al.,* 2018) which was later modified to RUSLE and that can also be modelled in a GIS environment. Prasannakumar *et al.* (2011) adopted RUSLE and GIS techniques to determine the soil erosion vulnerability of a forested mountainous sub-watershed in Kerala. Also, Jaiswal *et al.* (2014) assessed soil erosion under subtropical climatic conditions of Panchnoi river basin based on RUSLE and statistical techniques. A study by Biswas and Pani (2015) estimated soil loss in Barakar river basin using RUSLE due to its simplified nature. Machiwal *et al.* (2015) highlighted the estimates of soil erosion in an ungauged catchment situated in Aravalli hills of Rajasthan using remote sensing data by adopting USLE in GIS environment.

The current study is concentrated in the upper Umiew catchment that experiences summer monsoon. Because of its salubrious climatic condition, forest cover in the old days was dense from hill tops to valleys. However, gradually due to human pressure for livelihood and urbanisation, deforestation has been a major problem. At present, the area under dense forest cover is negligible and the only existing sacred grove is the *Law Lyngdoh Nongkrem*. Furthermore, the area is under traditional method of cultivation known as *Ka Rep Bun* and *Ka Soi Khyllip*. In *Rep Bun,* trees are cut down to provide space for cultivation and branches of trees, twigs and grasses are burned, and the resulting ashes are used *in-situ* for cultivating crops. *Ka Soi Khyllip* is practised only in areas that are devoid of trees. In this system of cultivation, the grasses along with the soil are dug and turned upside down and left for about a week before cultivation. Other major activities of the people were sand and stone quarrying.

Based on the above premises, this study recognised the need for understanding the magnitude of soil loss due to different physical factors (monsoonal rainfall and degraded forest), LU factor (agriculture, intense quarrying and urbanisation) and poor soil conservation practices. Due to variation in the amount of rainfall received in all seasons, it is important to estimate soil loss on a seasonal basis for four years (2011-2014), particularly in order to bring out clear depiction of soil loss during monsoon by adopting RUSLE.

2. MATERIALS AND METHODS

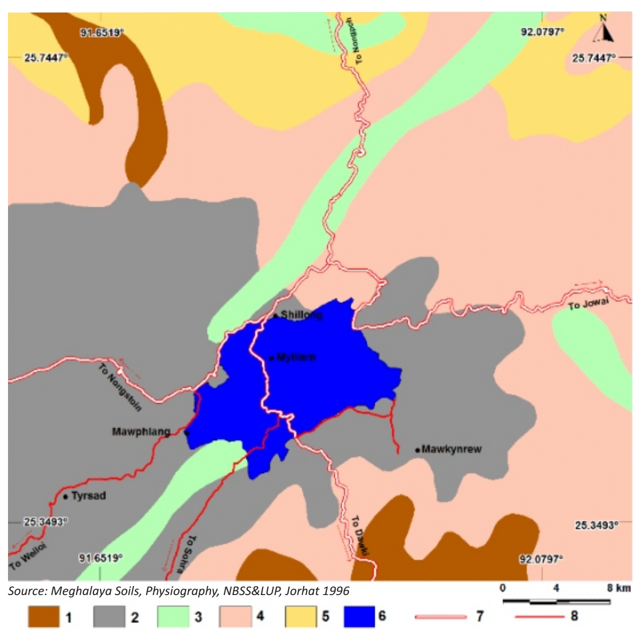
Study Area

The upper Umiew catchment is located in the Central Highland of Shillong plateau. Shillong peak, the highest point in the entire plateau at a height of 1963 m above mean sea level (AMSL), lies in the northernmost part of the catchment. In the present study, the area is limited to a total area of 120.4 km^2 up to Mawphlang dam that supplies water to Shillong city, the State capital. The geographical extension of the study area is 91°45'30.70" to 91°55'28.29" E longitudes and 25°24'55.93" to 25°32'46.50"N latitudes. Climatically, the catchment experiences heavy rainfall during summer, whereas winters are dry and biting cold. The average annual rainfall recorded in four years was about 3000 mm. The heavy rainfall during monsoon indicates the potential to generate soil loss, which is also determined by other physical factors and human intervention.

Geologically, the area comprises of Shillong series intruded by Mylliem granite. Different rock types in the area give way to landscapes comprising of gentle, moderate to very steep, and precipitous slopes. In the central part of the study area, the soil is underlain by deeply weathered granite area. On the undulating topography, soil slopes developed over different rock types offer scope of cultivation. During rainy season, these soil slopes generate significant soil loss due to anthropogenic activities (Warjri, 2015). Besides, the soil depth in the study area varies shallow, moderately shallow and moderately deep (Fig. 1). The soil type varies from drained fine loamy soils on gentle sloping hill tops to strong stoniness with very severe erosion hazards. On moderately sloping sides of hills, deep drained fined soils having loamy surface with moderate erosion hazards are found (Singh *et al.,* 1996).

Data Collection

In the study, the RUSLE was used, which is a modified version of USLE proposed by Wischmeier and Smith (1978). The model has compatibility for application in a GIS platform using Integrated Land and Water Information System (Tirkey *et al.,* 2013) for the present study. Further, in this study, the soil loss was calculated for three seasons, namely pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November) from 4-year period (2011-2014). Dry winter months from December to February were not taken into account in the present study.



1. Dissected Hilly Terrain ; 2. Upper Plateau ; 3. Valley ; 4. Intermediate ; 5. Lower Plateau ; 6. Catchment Boundary ; 7. Roads NH ; 8. Other roads

Fig. 1. Location map of the study area

The RUSLE equation is expressed as:

$$A = R \times K \times LS \times C \times P$$

Where, A = annual soil loss (t $ha^{-1}yr^{-1}$); R = rainfall-runoff erosivity factor (MJ mm $ha^{-1}h^{-1}yr^{-1}$); K = soil erodibility factor (t h $MJ^{-1}mm^{-1}$); LS = slope length and steepness factor; C = cover management factor; and P = erosion control conservation support practices factor. For calculation of each factor of RUSLE in order to generate seasonal soil loss of the studied area, the data collected were based on both primary and secondary sources, which were explained as follows.

Rainfall Erosivity Factor

For calculating the R-factor, the equation by Wischmeier and Smith (1978), Fournier (1960) and modified by Arnoldus (1980) was adopted.

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 \log_{10} \left(\frac{pi^2}{p}\right) - 0.08188\right)} \quad ...(1)$$

Where, p_i = monthly rainfall and P = annual rainfall. In this study, the R-factor was calculated on seasonal basis from the year 2011 till 2014 based on the rainfall recorded at Smit located north east of the catchment and which was considered as a reference for the whole study area.

Soil Erodibility Factor

Soil erodibility (K factor) was calculated based on soil samples collected and tested in the laboratory mainly for physical and chemical analyses, and also on the available data of Singh *et al.* (1996), such as soil types and depths of the area required for the study. The K factor was calculated based on the equation by Wischmeier and Smith, 1978; Ringo, 1999:

$$K = 2.8 \times 10^{-7} M^{1.14} \times (12 - OM) + 0.043(SC - 2) + 0.033 \times (4 - PC) \quad ...(2)$$

M = (% silt + % very fine sand) x 100 – % clay); OM = Organic Matter (% OC*1.72); SC=Structure code and PC = Permeability code. The structure and permeability code were referred to values of USDA (Shoeneberger *et al.,* 2012).

Slope Length Factor

The LS factor is governed by flow accumulation and slope steepness depending on data generated from the DEM of 20 × 20 m pixel size based on contours of two toposheets of Survey of India at the scale of 1:50000. The formula of LS factor (Dabral *et al.,* 2008) is expressed as:

$$L = (\text{Pixel size} / 22.13)^m \quad ...(3)$$

Where, L = slope length factor, pixel size = slope length, and m = dimensionless exponent that varies with slope steepness. The LS factor was calculated in ILWIS using the following expression (Lufafa *et al.,* 2003):

$$LS < 21 = \left(\frac{L}{72.6}\right) \times (65.4 \sin(S) + 4.56 \times \sin(S) + 0.065) \quad ...4$$

$$LS > 21 = \left(\frac{L}{22.1}\right) \times (6.43 \sin(S) + 4.56 \times \sin(S^{0.79}) \cos(S)) \quad ...5$$

Combining these three equations (3, 4 and 5) by an 'if' function, the following equation of Lufafa *et al.* (2003) is derived as: LS factor = if (slope < 21,SL < 21, SL > 21 where, L = slope length and S = slope 21 steepness factor.

Cover Management Factor (C) and Conservation Practice Factor (P)

The C factor is governed by different categories of LU / LC that was processed from Landsat-ETM of 30 m resolution (USGS, 2012) and the values attributed to each category were considered referring to studies of Dabral *et al.* (2008); Panda *et al.* (2005); Gonzalez (2008).

In the upper Umiew catchment, support practices such as contouring, strip cropping were absent and no other erosion resistance facility were adopted. Hence, the value of 1 was attributed to P-factor (Saha *et al.,* 2018).

In the present study, soil loss estimated for pre-monsoon (March-May), monsoon (June-Sept.) and post-monsoon (Oct.-Nov.) were classified into six groups of soil erosion classes namely slight (<1 t ha^{-1}), moderate (1-5 t ha^{-1}), high (5-20 t ha^{-1}), very high (20-40 t ha^{-1}), severe (40-80 t ha^{-1}) and very severe (>80 t ha^{-1}) soil loss.

3. RESULTS AND DISCUSSION

Rainfall Erosivity Factor (R)

The annual rainfall erosivity factor (R) during four-years period (2011 to 2014) was found in the range of 1187.97 to 2006.75 MJ mm $ha^{-1}h^{-1}y^{-1}$. During monsoon, the highest and lowest R factor was 1817.26 MJ mm $ha^{-1}h^{-1}$ and 946.69 mm $ha^{-1}h^{-1}$ in the years 2014 and 2013, when the amount of rainfall received was about 2739 mm and 1665.83 mm, respectively, whereas, the pre-and post-monsoon have low R-factor with the lowest values of 101.05 MJ mm $ha^{-1}h^{-1}$ and 32.48 MJ mm $ha^{-1}h^{-1}$ in the years 2012 and 2011 having maximum rainfall of about 257 mm and 98 mm, respectively. Apparently, the seasonal variations in amount of rainfall received influences the fluctuations in values of R-factor. Likewise, a particular season exhibits different values of R-factor in different years depending on the amount of rainfall. In four years, the maximum number of rainy days recorded during the monsoon was 94 days in the year 2013, though the amount of rainfall received was the lowest as mentioned earlier.

Soil Erodilbility Factor (K)

The values of K-factor in the catchment were classified into four categories ranging from below 0.02 t h $MJ^{-1}mm^{-1}$ to above 0.06 t h MJ^{-1} mm^{-1} (Fig. 2) and with a mean value of

0.041 t h MJ^{-1} mm^{-1}. The K value of .02 to .04 t h MJ^{-1} mm^{-1} predominates in the catchment.

Whereas, soil erodibility varies in the western, eastern, central and northern part of the catchment ranging between <.02 to >.06 t h $MJ^{-1}mm^{-1}$ (Fig. 2). The soil type that mainly dominates the catchment are *typic kandihumults* and *typic dystrocherpts*. Whereas, few pockets in the north eastern and south-western part are associated to *typic udorthents* and *umbric dystrocherpts* (Singh *et al.,* 1996).

Slope Length and Steepness Factor (LS)

Topographically, gentle (<5°) and moderate slopes (5°-10°) cover 73.5 km^2 (61.25%) of the study area, whereas very steep (30°-45°) and precipitous slopes (>45°) exist in only 5.23 km^2 (4.01%) area. The LS values varying from 0.03 to 19.16 were categorised into six classes (Fig. 3). The mean and standard deviation of the LS values were of 7.11 and 5.01, respectively. Notably, LS value class of 1 to 4 predominates in the study area covering 66.38 km^2 (39.25%) area. Whereas, the areas covered under LS classes of <1, 4-9 and 9-14 are more or less equally-distributed with a proportion of 19.12 km^2 (15.88%) to 23.55 km^2 (19.56%) of the total area. The LS class of 14 to more than 19 accounted for only 9.92 km^2 (8.24%) area.

Cover Management Factor (C)

The LU / LC map of the study area was classified into seven categories, namely open forest, grassland, fallow land, water bodies, agricultural land, quarries and built-up. It was found that about 39.55 km^2 (32.85%) of the area was agricultural land, whereas built-up areas and quarries accounted for 9.83 km^2 (8.16%) and 2.23 km^2 (1.85%), respectively. These areas are the most erosion-prone zones. Open forests and grasslands accounted for 31.15 km^2 (25.87%) and 18.79 km^2 (15.56%), respectively. Values of the C-factor ranged between 0.008 and 1 in the study area (Fig. 4).

Seasonally Estimated Soil Loss

Assessment of the six important parameters of RUSLE and their GIS analysis provided the spatial and seasonal variations of the estimated soil loss during 2011-2014 period (Fig's 5-13). During the pre-monsoon, the R-factor values ranged between 182.81 and 274.81 MJ mm $ha^{-1}h^{-1}yr^{-1}$. During this period, the catchment was more susceptible to slight, moderate and high soil loss of less than 20 t ha^{-1} (Fig. 10) with a total area coverage ranging from 96.98 km^2 (80.55%) to 113.99 km^2 (94.67%). Moreover, during the monsoon, range of the R-factor values increased in comparison to that in the pre-monsoon and varied from 1817.26 to 946.69 MJ mm $ha^{-1}h^{-1}yr^{-1}$, and in response, the erosive capacity also increased resulting in very severe soil loss (>80 t ha^{-1}) in the study area. However, the area coverage under very severe soil loss in the year 2013 was

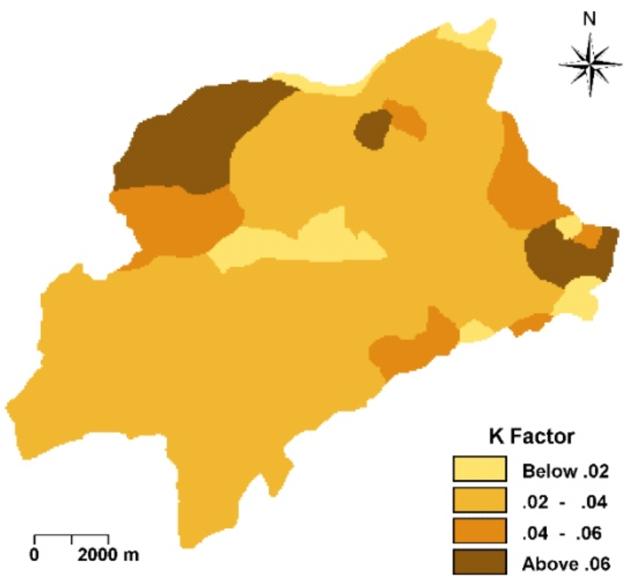


Fig. 2. Soil Erodibility Factor (K), Upper Umiew

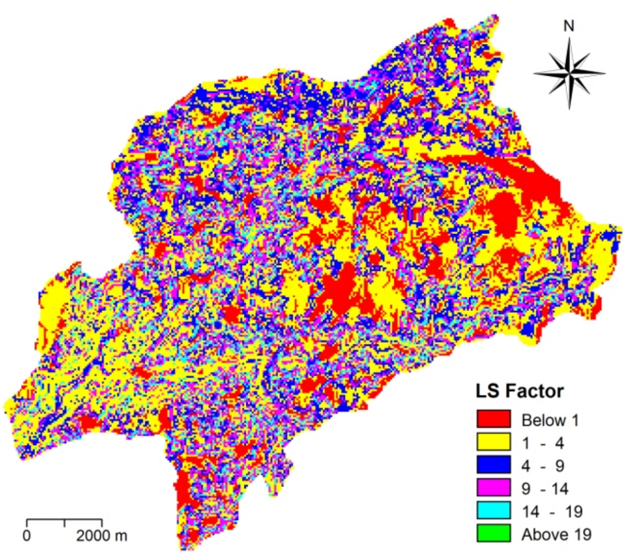


Fig. 3. Slope Length and Steepness Factor (LS), Upper

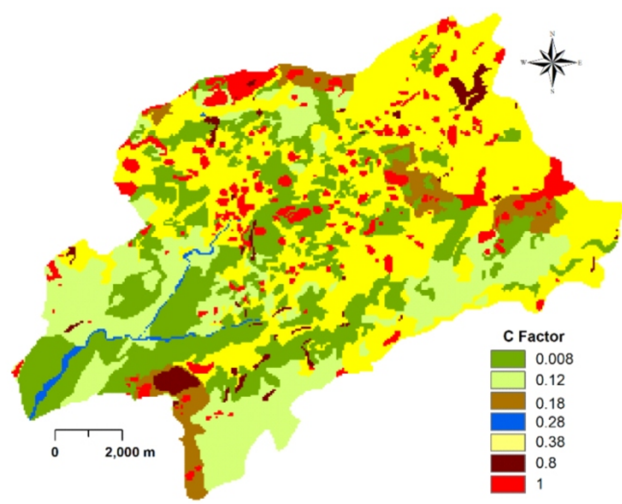


Fig. 4. Cover Management Factor (C), Upper Umiew

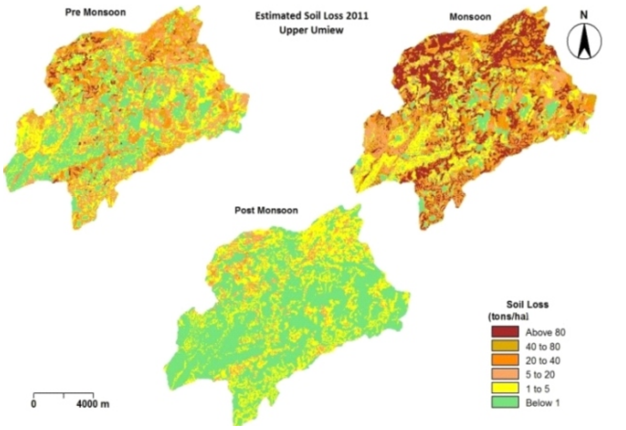


Fig. 5. Estimated Soil Loss in upper Umiew (2011)

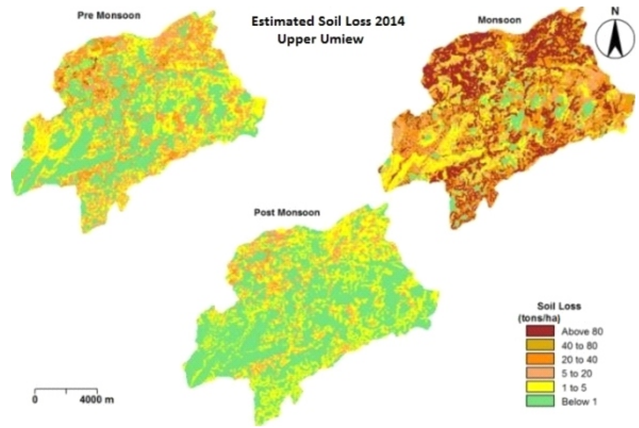


Fig. 8. Estimated Soil Loss in upper Umiew (2014)

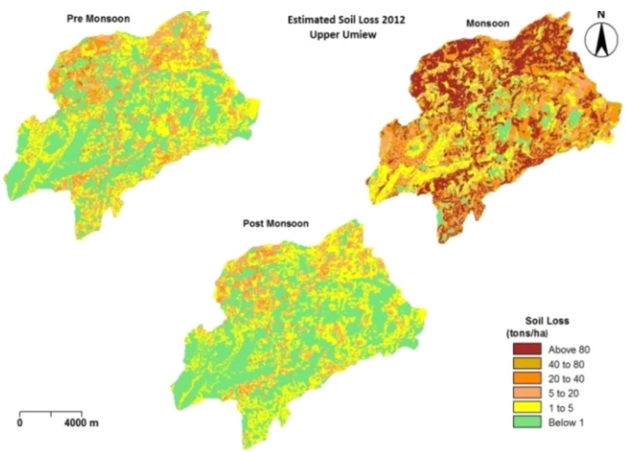


Fig. 6. Estimated Soil Loss in upper Umiew (2012)

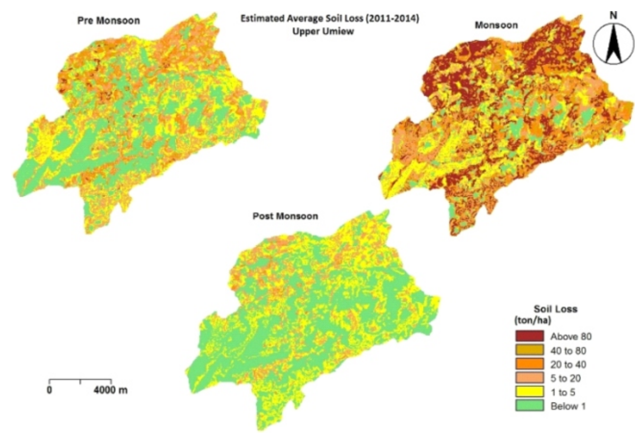


Fig. 9. Estimated Average Soil Loss in Upper Umiew (2011-2014)

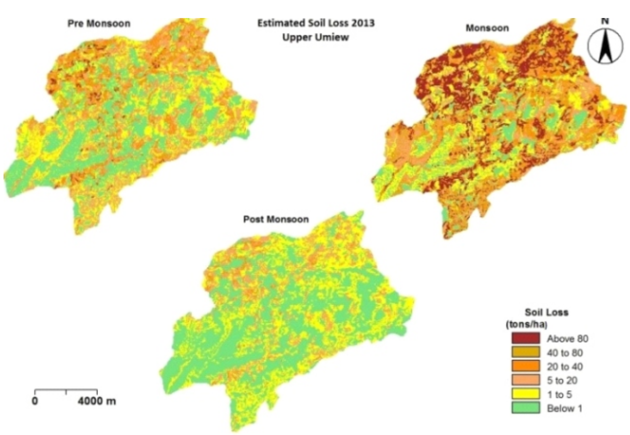


Fig. 7. Estimated Soil Loss in upper Umiew (2013)

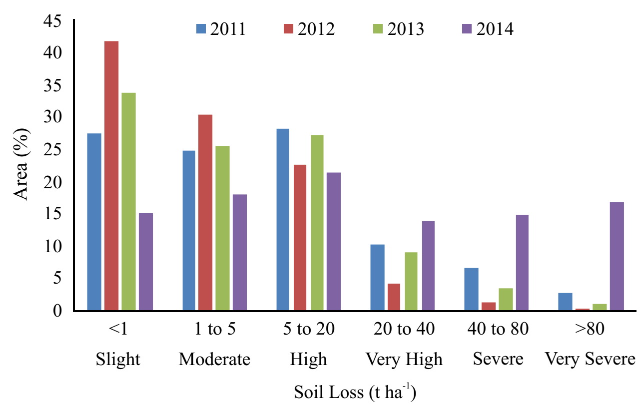


Fig. 10. Pre Monsoon Estimated Soil Loss in Upper Umiew (2011-2014)

less (Fig. 11) due to low R-factor value of 946.56 MJ mm $ha^{-1}h^{-1}$ as compared with the other years. When the post-monsoon season approaches, volume of rainfall decreases due to withdrawal of the southwest monsoon leading to low R-factor values that ranged between 32.48 and 59.55 MJ mm $ha^{-1}h^{-1}yr^{-1}$. Therefore, the rate of soil loss was not severe and evidently major part of the area experienced slight soil loss with the highest area coverage of 74.20 km^2 (61.63%) in the year 2011. Nonetheless, there were areas experiencing high soil loss in this period and evidently, the highest area coverage was 17.98 km^2 (14.93%) in the year 2012 and the amount of rainfall received was about 150.3 mm. During this period, occurrences of short duration and high intensity rainfall, locally known as *Lappraw,* is a common phenomenon that resulted into high soil loss.

4. CONCLUSIONS

The RUSLE model used to estimate soil erosion in the

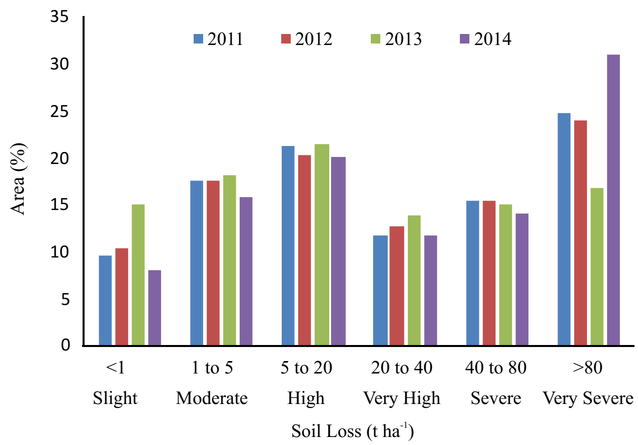


Fig. 11. Monsoon Estimated Soil Loss, Upper Umiew (2011-2014)

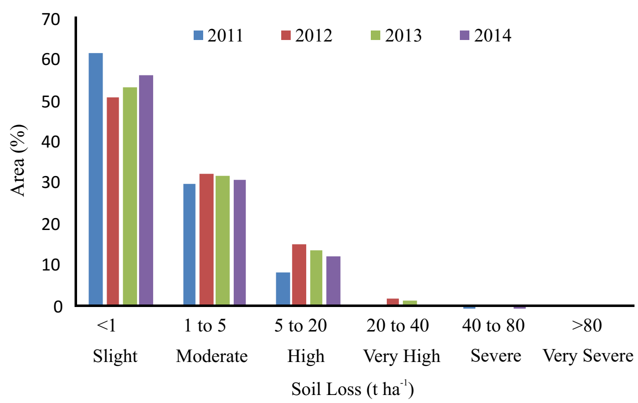


Fig. 12. Post Monsoon Estimated Soil Loss, Upper Umiew (2011-2014)

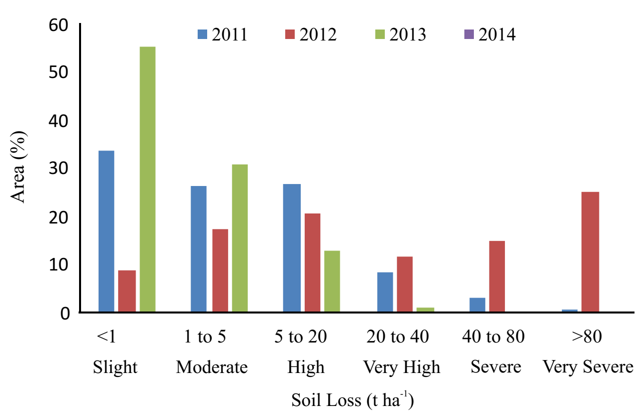


Fig. 13. Average Estimated Soil Loss, Upper Umiew (2011-2014)

Umiew catchment shows that there is are spatial and seasonal variations, and that the R-factor plays a significant role in determining soil loss. In the study area, soil erodibility value varies ranging between the lowest and highest values of .01 to .08 t h $MJ^{-1}mm^{-1}$, respectively, whereas, the K-factor value of 0.03 t h $MJ^{-1}mm^{-1}$ dominates in the northern and southern part. During the pre and post-monsoon, the average area coverage under slight (<1 t ha^{-1}) and moderate erosion (1-5 t ha^{-1}) in four years was 60.31% and 86.32%, respectively. During monsoon, the average estimated soil loss over a span of four years (2011-2014) indicated 73.42% (Fig's 9 and 13) of the area falls under high to very severe erosion (5 to >80 t ha^{-1}) that reflects the potential ability of water to erode the undulating landscape covering an area of about 61.25%, which is caused mainly due to cultivation, degraded forest, urbanisation and quarrying. Moreover, it was found that though the area coverage under quarries are not large, the depth of the quarries are quite high and the sediments that are highly fragile tend to be easily eroded during heavy monsoonal rainfall contributing to significant sediment loss. Further, in the south-western part of the catchment, soil loss was observed to have occurred during monsoon on very steep slopes and vertical cliffs face. This phenomena is explained by the existence of rolling and undulating topography which ends abruptly and gives way to steep slopes and vertical cliffs forming a deep gorge in which the Umiew flows, which provides an easy pathway for rain water flowing through the undulating topography to cascade down the very steep slopes and cliffs and giving the appearance of soil loss (Warjri, 2015). Considering the magnitude of erosion mainly during monsoon, it is important to take measures to control the rate of soil erosion, which would consequently affect the soil fertility leading to soil degradation. In addition, the eroded soils transported from different landuses on reaching the main river Umiew cause problems in water quality and siltation problems in the dam that supply drinking water to the main city. Besides, in the present study there is limitation in the data for detailed evaluation of soil loss as only one rain-guage station was used as a reference for the entire catchment.

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