# Application of Geo-informatics for Soil Erosion Mapping

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## KEYWORDS

*Geo-informatics, Universal Soil Loss Equation (USLE), Soil erosion, Modeling,*

## ABSTRACT

*Soil erosion is a most severe environmental problem in hilly area. The study is carried out on Upper Bagmati River basin, North of Kathmandu valley having an area of 61 Sq.km. (approx). Universal Soil Loss Equation (USLE) model, with Geographic Information System (GIS) has been used to quantify the soil loss. Erosion modelling requires huge amount of information and data, usually coming from different sources and available in different formats and scales and for management of these data, GIS was used, which helped considerably in organizing the spatial data representing the effects of each factor affecting soil erosion. Five essential parameters of USLE Rainfall erosivity factor (R), Soil erodibility Factor (K), Slope length and steepness (LS) factor, Cropping management factor (C) and Support practice factor (P) have been used to estimate soil loss amount in the study area. All of these layers have been prepared in Arc GIS using various data sources and data preparation methods. DEM was prepared from the contour data with the interval of 20m which was used to generate LS factor. The monthly rainfall data (2010) of 17 rain gauge stations within the catchment area have been used to predict the R factor. K, C and P factors in basin area are adopted from the literature. The spatial distribution map of soil loss of the basin has been generated and classified into six categories depending on the calculated soil erosion amount. The annual predicted soil loss ranges between 0 and 292.878 t/ha/y. Low soil loss (mean 9.7 t/ha/y) have been recorded under forested areas. The high rate (mean 40.4 t/ha/y) of soil erosion was found in the cultivation area.*

## 1. BACKGROUND

Land degradation is a global issue, which is manifested in various processes (Shrestha, *et al.* 2004). Soil erosion by water is a complex process that involves the interrelationship of many factors some of which influence the capacity of rainfall and runoff to detach and transport soil material, while others influence the ability of soil to resist the forces of the erosive agents. Water erosion is by far the most serious land degradation type with a global estimate of about 11 million km$^2$ (Oldeman, 1994).

Soil erosion is a major part of land degradation that affects the physical and chemical properties of soils and resulting in on-site nutrient loss and off-site sedimentation of water resources (Brhane and Mekonen, 2009). It is natural phenomenon which occurs due to forces from rain water, surface runoff, wind, gravity, etc., exerting on surface soil and result in detachment and transport of soil from that area (Liengcharernsit *et al.*2007).

Soil erosion occurs when water that cannot infiltrate into the soil becomes surface runoff and transports soil down slope. A soil becomes unable to absorb water when the rainfall intensity exceeds the surface infiltration capacity, when the rain falls onto a saturated surface because of antecedent wet conditions, or when the underlying water table is at the surface. Once runoff is initiated, forms of erosion are likely to occur, that show variety in space and time: sheet hill slope erosion, parallel linear erosion, and gully erosion.

Soil erosion rate varies depending on many factors including rainfall intensity and duration, area slope, covered vegetation, soil type, wind velocity, surface runoff rate, etc. Soil erosion has resulted in loss in surface soil which normally has high nutrients. It also causes environmental problems in downstream area and receiving water body.

Over forty years of research by the U.S. Department of Agriculture has helped to identify the major factors of soil erosion and to establish their functional interrelationships (*http://www.usask.ca, retrieved on 4th Feb, 2008*). From over 40 years of research comprising more than 250,000 runoff events at 48 research stations in 26 states, the Universal Soil Loss Equation (USLE) has been developed (Wischmeier and Meyer, 1973). The USLE is the result of more than 20 years of study and development by scientists of the USDA (USDA, 1980). This equation is used extensively for sediment prediction and erosion control planning for agricultural soils and disturbed sites and has been widely accepted and utilized in most countries. USLE is a simple technique for predicting the most likely average annual soil loss in specific situations. Each factor in the equation can be predicted from easily available meteorological and soils data.

Given the limited capacity of the manual method, there is a growing need to systematically map soil erosion, using GIS and related technologies for speed and accuracy (Mongkolsawat *et al.,* 1994). The integrated approach of Remote Sensing (RS) and GIS gives quick as well as more advanced response. This technique has also been used for landslide susceptibility mapping using slope, aspect, relief, flow accumulation, soil depth, soil type, land use and distance to road in GIS environment (Dahal*, et. al,* 2008). Similarly, combination of GIS and RS has been used by Lee and Pradhan (2007) to map land slide hazard.

Four main factors are generally considered: soil, topography, land use and climate (Wischmeier and Smith 1978). However, the equation cannot predict soil loss which is solely due to snowmelt, thaw and wind (Wischmeier and Smith 1965). The USLE predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. However, it has been observed that the USLE/Revised USLE over-predicts low annual average erosion and under-predicts high average erosion (Risse *et al.,* 1993)

## 2. METHODOLOGY

GIS can be equated to both computer database and database system for producing maps and significant increase of the technology is seen globally. The technology provides operational tools for making policy, planning for management and decision making (Karim, 1995). USLE was used in GIS environment to analyze annual soil loss for upper bagmati watershed.

### 2.1. Study Area

The Bagmati River and its major tributaries *Nagmati Khola, Syalmati Khola* and *Thulo Khola* originate from the Northern fringe of

Kathmandu valley the hydrological boundary of the Bagmati river considering Gaurighat as outlet is selected for this case study which can be called as Upper Bagmati river basin area. The total area of the study watershed is 65.43 $km^2$ (Figure 1).

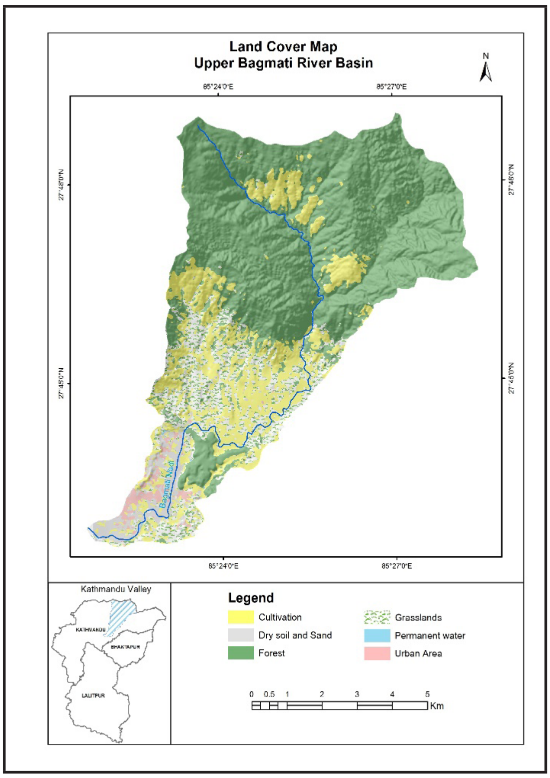


*Figure 1: Study area.*

The area is chosen for the study with the reason that the north facing mountains of the Kathmandu receives high rainfall than other facing mountains (Pokharel & Hallett, 2015) and hence can be assumed that there must be higher soil erosion.

## 2.2. Data collection

Secondary data for Upper Bagmati watershed which includes rainfall, digital topographical database, land cover data were collected from Department of Hydrology and Meteorology (DHM), Survey Department (DoS), National Land Use Project, Ministry of Agriculture and Co-operatives. Crop pattern and conservation practice were taken from the literature.

## 2.3. Soil erosion estimation

Annual soil loss in the form of runoff from different land forms and land uses of the watershed was estimated using USLE (*Wischmeier and Smith, 1978*).

$$A = R * K * L * S * C * P$$

Where;

*A = estimated soil loss (t $ha^{-1}$ $yr^{-1}$), R = Rainfall Erosivity factor, K = Soil erodibility factor, L = Slope length factor, S = Slope gradient factor, C = Land cover factor, P = Management practice factor.*

All the processing was done in raster data format. Integrated Land and Water Information System (ILWIS, 3.4) was used for all the processing.

### *2.3.1. Rainfall factor (R)*

The R-factor is defined as the measurement of the kinetic energy of a specific rain event or an average year's rainfall (Wischmeier and Smith, 1978). In this study, to determine the value of the R-factor, the average of annual historic rainfall event of 17 stations were collected from Department of Hydrology and Meteorology within the watershed. The rainfall distribution is not homogeneous all over the study area. For this reason, an interpolation of annual precipitation data was applied to have a more representative rainfall distribution. Once the interpolation is performed a map representing annual rainfall in the region is obtained. This map was the input source ($P_a$) for the R calculation using the Renard and Freimud (1994) equations for Pa < 850 mm:

$$\text{R factor} = 0.04830\ P_a\ 1.610 \ldots\ldots\ldots \quad (i)$$

Where Pa is mean annual precipitation.

Monthly precipitation data can give reasonable estimates of R-values for many regions throughout the world (Renard and Freimud, 1994). For this study also, monthly rainfall data of 17 stations were used for this. Regression analysis in Microsoft Excel was done to get the relation between elevation and mean annual rainfall. The equation derived for the relation is

$$P_a = 0.1122\ Z - 24.185 \ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where $P_a$ is mean annual rainfall and Z is elevation.

The map of this $P_a$ value was prepared on the basis of DEM and on the base of this map, R-factor map was prepared with the equation i.

### *2.3.2. Soil erodibility factor*

The soil erodibility reflects the fact that various soils erode at different rates due to different physical characteristics such as texture, organic matter, structure, and bulk density and hence is defined as the rate of soil loss per unit of R-factor on a unit plot (Reinard *et al.,* 1997). This is the susceptibility of the soil or surface material to erosion, transportability of the sediment and the amount and rate of runoff given a particular rainfall input (Sheikh, *et. al.,* 2011). Table 1 presents the soil erodibility factor (K) based on the soil texture class by Shrestha (1997). A land system map prepared by Land Resource Mapping Project (LRMP) of the study area was used to define the soil texture and on the basis of the K value from the table and the soil texture, erodibility of the study area was determined.

*Table 1: Soil erodibility value for different soil texture.*

| S.N. | Soil Texture | K - value |
|---|---|---|
| 1 | Gravely Loam, Hill | 0.45 |
| 2 | Loam, Hill | 0.5 |
| 3 | Gravely Sandy Loam, Mountain | 0.43 |
| 4 | Loam | 0.4 |
| 5 | Loamy sand, plain | 0.3 |
| 6 | Loam, plain | 0.41 |
| 7 | Sandy loam, plain | 0.35 |

### *2.3.3. Slope gradient (LS) factor*

LS is the topographic factor expressed as the expected ratio of soil loss per unit area from a field slope to that from a unit lot under otherwise identical conditions. The rate of soil erosion by flowing water is a function of slope length (L) and gradient (S). For the practical purpose, these two topographic characters are combined into a single topographic factor (LS). However, in this research both the factors are estimated separately. Since the input requirement is DEM, slope length and slope gradient factor is calculated as follows (*Wischmeier and Smith, 1978*).

$$L = (\lambda/22.13)^m \ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

Where L is slope length factor, λ is field slope length and 'm' is the constant defined according to the slope gradient which range from 0.2 to 0.5 (Table 2).

*Table 2: Constant (m) value according to slope gradient.*

| S.No. | Slope Gradient | Value of m |
|---|---|---|
| 1 | < 1% | 0.2 |
| 2 | 1% - 3% | 0.3 |
| 3 | 3% - 4.5% | 0.4 |
| 4 | > 4.5% | 0.5 |

*Source: Wischmeier and Smith, (1978).*

Map of 'm' was created using the slope map prepared in percent. Similarly, for the slope gradient, following relation was used as defined by Wischmeier and Smith (1978) cited by Jain *et. al.* (2001).

$$S = (0.43+0.3s+0.043s^2)/6.613 \ldots\ldots (iv)$$

Where 'S' is slope gradient factor and 's' is slope in percentage.

The combined LS factor was calculated by multiplying the L and S factor from the created maps. The factor of slope length (L) and slope gradient (S) are combined in a single topographic erodibility factor (LS).

### *2.3.4. Crop management (C) factor*

The Crop management factor (C) is the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978). It is a crucial factor to the erosion since it is a readily managed condition to reduce erosion (Bera, 2017). C factor reflects the reduction in soil erosion that will result from growing a crop as compared with leaving the land fallow. The amount of reduction depends upon the type of crop grown, the cropping system, tillage practices, crop yield, and residue management. The C factor was calculated from literature review, since there was no local data available regarding this factor. Based on the land cover data of the study area, C value was assigned to the ones existing in the study area (Table 3). C value ranges from 1 to approximately 0, where higher value indicate no cover effect and lower value means very strong cover effect resulting in no erosion (Erencin, 2000).

#### *2.3.5. Protection measure (P) factor*

The P-factor gives the ratio between the soil loss expected for a certain soil conservation practice to that with up-and down-slope ploughing (Wischmeier and Smith, 1978). Specific cultivation practices affect erosion by modifying the flow pattern and direction of runoff and by reducing the amount of runoff (Renard and Foster, 1983). The tillage and cultivation of agricultural soils on sloping land needs to be supported by practices that will slow the velocity of runoff water. This will reduce its erosive power and the amount of soil it is capable of transporting. The most commonly used erosion control practices are; contour tillage, strip cropping on the contour, and terrace systems. P value for the study area was also determined on the basis of literature review. Based on the land cover data of the study area, P value was assigned to the ones existing in the study area (Table 3).

Table 3: Value of C factor P factor according to land cover.

| S.N. | Land Cover | C Factor | P Factor |
|---|---|---|---|
| | Open scrub | 0.1 | 0.8 |
| | Degraded forest | 0.03 | 0.8 |
| | Dense forest | 0.004 | 0.8 |
| | Mixed forest | 0.05 | 0.8 |
| | Cultivation | 0.3 | 0.6 |
| | Fallow | 0.5 | 0.7 |
| | Water | 0 | 0 |
| | Urban | 0 | 0 |

*Source: Jain et. al., (2001)*.

## 3. Result and discussion

The soil erosion potential (A) has been computed by multiplying the developed raster data from each factor (A= R K L S C P) of USLE analysis. The final 'A' factor map displays the annual soil loss potential of the Upper Bagmati river basin is shown in figure 2.

### 3.1. Results

From the study it shows that the study area has high slope gradient. So, the erosion loss is obtained with high rate. Predicted annual mean soil loss of Upper Bagmati River basin ranged from 0 to 292.878 ton/ha/yr.

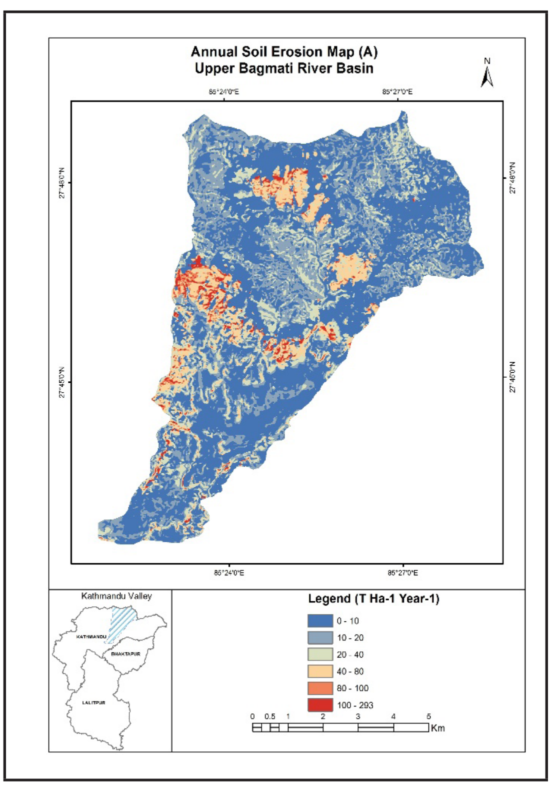


*Figure 2: Soil erosion map.*

Results shows that the study area has high slope so the erosion loss is obtained with high rate in compared to other research. Bera (2017) classified predicted annual soil loss into six erosion intensity classes to assess erosion potential severity. In this study also, same class has been adopted but the class value has been considered accordingly to the result (Table 4). Negligible soil erosion was found at the lower steep area and the high soil loss was found in steep areas. According to erosion risk classes, it is observed that 44.76 % area is under negligible class whereas only 1.4 % area is under extremely high class (Table 5).

Table 4: Soil erosion intensity type.

| S.N. | Soil loss class (t/ha/yr) | Erosion Intensity type |
|---|---|---|
| 1 | 0 - 10 | Very less erosion |
| 2 | 10 - 20 | Less erosion |
| 3 | 20 - 40 | Moderate erosion |
| 4 | 40 - 80 | Moderately high erosion |
| 5 | 80 - 100 | High erosion |
| 6 | > 100 | Extremely high erosion |

Table 5: Area according to soil erosion intensity type.

| S.N. | Erosion Intensity type | Area ($Km^2$) | Area (%) |
|---|---|---|---|
| 1 | Very less erosion | 27.39 | 44.76 |
| 2 | Less erosion | 18.42 | 30.09 |
| 3 | Moderate erosion | 8.63 | 14.09 |
| 4 | Moderately high erosion | 4.62 | 7.55 |
| 5 | High erosion | 1.29 | 2.10 |
| 6 | Extremely high erosion | 0.86 | 1.40 |

The analysis was also done for the erosion on the basis of land cover class. It is seen from the study that, cultivation has mean value of soil erosion with 40.40, dry soil and sand with 21.63, forest with 9.7, grassland with 15.48 and 0 for water and urban area (Table 6). Erosion at forest land might be because of the steepness of the area. The erosion at cultivation is very high in comparison to other. The reason must be less crop management practice and most of the cultivation area is also at high slope gradient. In comparison to this, erosion of dry soil and sand is less reason for which may be low lying land of this land cover category.

Table 6: Soil erosion probability according to land cover.

| S. N. | Land Cover | Max | Mean |
|---|---|---|---|
| 1 | Cultivation | 292.88 | 40.40 |
| 2 | Dry soil and sand | 265.63 | 21.63 |
| 3 | Forest | 261.16 | 9.7 |
| 4 | Grassland | 292.88 | 15.48 |
| 5 | Urban area | 250.4 | 2.34 |

This result is in line with the result of Jain *et. al* (2001) which showed that forested areas show less soil loss compared to other unprotected areas. Similar type of result was also found by Sheikh *et. al.* (2011), the study area was Himalayan watershed where average soil loss was highest (26 tons ha-1 year-1) in agriculture area and lowest soil loss rate was found in forest area (0.99 tons ha-1 year-1). Hence the result of this study can also be said as expected result, still field verification and calibration are always necessary.

Another analysis was done according to the slope of the study area. The slope category prepared for analysis is as shown in table 7. The result shows that, as the slope increases, the erosion rate also increases. For the slope 0-10, the mean value of erosion is 39.65 whereas, the mean erosion value is 162.77 for the slope degrees of 50-90. The result seems acceptable to the concept that the erosion increases with slope. However, this can also be related with cropping pattern and land cover.

Table 7: Soil erosion probability according to slope degrees.

| S. N. | Slope Degrees | Max | Mean |
|---|---|---|---|
| 1 | 0 - 10 | 171 | 39.65 |
| 2 | 10 - 20 | 216 | 66.91 |
| 3 | 20 - 30 | 258 | 80.88 |
| 4 | 30 - 40 | 281 | 84.30 |
| 5 | 40 - 50 | 206 | 80.84 |
| 6 | 50 - 90 | 292 | 162.77 |

### 3.2. Discussion

Result of this study gives an erosion range of 0.03-292.878 tons/ha/yr. Definitely, the value is dependent on different parameter values that were taken, in particular, the slope classes, the C and P-factor. For more comparable results, decisions regarding reasonable factor values must be made. This will require further empirical research to determine these values.

To analyze the result, we can see that the mean erosion value ranges between 2.34 in urban area to 40.40 in cultivation area. Analysis done by Shrestha (1997) in Likhu khola watershed shows that the soil erosion ranges from 3.4 in degraded forest to 34.6 in rainfed cultivation area. Research by Uddin et. al. (2016) in Koshi basin shows that the mean erosion values ranges from 3.9 in shrub land to 21.8 in barren land. The result of this research, Uddin et. al. and that done by Shrestha shows consistent range. This shows that the result obtained from this study is valid.

## 4. Conclusion

In conclusion, the potential source of prediction error is in selecting factor values. It is possible to spatially and quantitatively analyze multi-layer of data within a watershed using GIS. Using GIS technology in combination with remote sensing to generate land cover data can provide systematic data in dynamic manner for decision-support system. The annual soil loss predictions range between 0 and 292.878 tons ha-1 year-1. GIS platform provides a faster and better method for spatial modeling and gives output maps that can be understood better. Implementation of Universal Soil Loss Equation using integration procedures of GIS enabled the prediction of potential and actual soil loss rates and in the identification of units for suitable protection measures.

Geographic Information System (GIS) and Remote Sensing are emerging most effective tools for analyzing spatial distributed information in different dimensions. The use of the USLE model integrated to GIS and RS is an effective tool than the time-consuming conventional methods for assessing the soil loss vulnerability. The all USLE parameter R, K, LS, C and P factor maps were combined together for creating the annual average soil loss map of the upper Bagmati river basin.

There were no field data on soil erosion available, from the study area, hence, no calibration/verification of the results could be made. The study showed that forested areas show less soil loss compared to unprotected areas like fallow lands, which contribute to high soil loss. The soil erosion assessment technique used in the present study is helpful to evaluate the influence of different land cover and soil management factors in quantitative estimations of soil loss of the study area. The methods and the predicted amount of soil loss and its spatial distribution of the basin described in this study which are useful to formulate and further implement conservation program that will reduce soil loss from the basin.

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