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# Geospatial analysis of soil erosion rates using RUSLE and GIS model in Bong-bong Subwatershed Pangantucan Bukidnon

**Dr. Ricardo G. Villar***, **Neli Jean L. Remotigue**

*Central Mindanao University, Maramag, Bukidnon, Philippines*

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**Key words:** Geospatial, Soil erosion, Model

## Abstract

The Accelerated rate of soil erosion is a severe and continuous endemic environmental problem of the farmers in Barangay Adtuyon. The present study of soil erosion is carried out in the upper stream of Muleta watershed of Pangantucan, Bukidnon locally called Bong-bong sub-watershed. It is fact that the surface runoff of seasonal rainfall is intense in this area due to its sloping terrain characteristics. Average annual soil erosion has been estimated based on the five parameters defined in the Revised Universal Soil Loss Equation (RUSLE) and with the help of Geographical Information Technology. Overlay of five parameters, rainfall erosivity factor (R), soil erodibility factor (K), slope length and steepness factor (LS), cover and management factor (C) and support and conservation's practices factor (P) has been done in GIS platform. Predicted average annual soil erosion of the sub-watershed has been classified using three land uses of the of the study site. The resulting simulated maps by RUSLE was derived indicating spatial variability of soil erosion within the perimeter of each study site. The soil erosion in Bong-bong sub-watershed based on simulated findings of the RUSLE model ranges from 0-400 ton/year. This indicates that the area is prone to soil erosion as contributed by the five erosion factors identified by RUSLE model. A spatial map was generated presenting the erosion in the whole sub-watershed. Statistical analysis showed very good model results acquiring <.50 RSR value comparing the field erosion measurements to the RUSLE-GIS simulated results.

***Corresponding Author:** Gerlie U Bayani ✉ gerliebayaniseiya@cgmail.com

**Introduction**

Land degradation is a primary global concern as the ecological integrity and productivity of about 2 billion ha. of land anthropogenic ally use is seriously affected (Saha, 2003). By way of water or wind erosion, water logging, salinization and soil compaction, soil the structure is damaged leading to the depletion

Soil erosion is a natural process where the extent and magnitude of soil loss are controlled by various environmental determinants such as climate, soil, topography and vegetation (Wischmeier and Smith, 1978). The risk of erosion occurs wherever soils particularly those with a high sand or silt content are exposed to heavy and prolonged rainfall (Morgan, 2005). Soil erosion and surface runoff that runs through watersheds generate environmental and economic problems (Lal, 1995; Pimentel *et al*., 1995).

It is associated with adverse environmental impacts and crop productivity loss making it an important concern that should be addressed (Daily *et al*., 1998).

Soil erosion models and GIS applications are indispensable tools in erosion studies. Erosion models help evalute the effectiveness of different management methods for conservation planning, project planning, and soil erosion inventories and for regulation (Nearing *et al*., 1994). of all the erosion models, RUSLE model is used in predicting soil loss in the study area. RUSLE model is widely used for the study of soil erosion by water because of its simplicity, despite some inconveniences due to its extensive requirement for input data. RUSLE methods predict the long term the annual average rate of erosion on a field based on rainfall pattern, soil type, topography, crop system and management practices.

This study will apply a processed based erosion model using RUSLE and GIS tool to simulate the soil erosion in the Bong-bong sub-watershed. The importance of producing such information is to guide foresters and watershed conservation planners in the site to address the problems on soil erosion.

**Materials and methods**

*Location of the area*

The study was conducted in Bong-bong sub-watershed, a river that is situated in the upper stream of Muleta watershed located in Barangay Adtuyon Municipality of Pangantucan, Bukidnon. The river is surrounded by agriculture and few households under the Municipality of Maramag and Pangantucan.

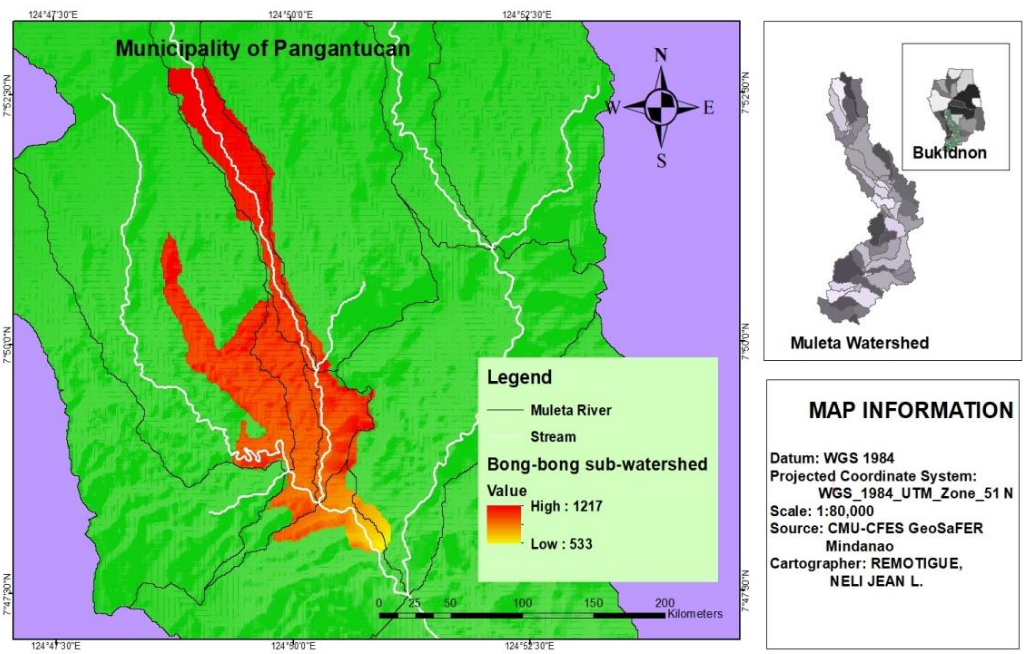


**Fig. 1.** Location Map of study area.

Bong-bong sub-watershed was characterized as a slightly undulating terrain, rolling and hilly areas with the slope ranging from 18% to 50% mostly comprised of agricultural areas devoted to agricultural crops. According to the classification the assessment conducted by Mariano and coworkers (1995), the general soil type dominating the area is Adtuyon clay. Observations by the Modified Corona's Climate Classification of PAGASA, Barangay Adtuyon of Pangantucan province of Bukidnon belongs to the third climatic type in which characterized as no very pronounced maximum rain period, with a short dry season lasting from 1 to 3 months.

*Data Management*

*Land use*

The information of the vegetation for land use/cover of the area was obtained during field reconnaissance using handheld GPS by acquiring the coordinates of the experimental site. Land area of the Bong-Bong sub-watershed is comprised of cornland, cropland, grassland, and plantation of banana, pineapple and papaya.

*Digital Elevation Model (DEM)*

The Digital elevation model is generically described as a spatial Geo-referenced data set that is a popular way of encoding the topography for environmental purposes (Puno, 2009). The digital Elevation Model (DEM) used for the study was obtained from CFES-GeoSafer research in Central Mindanao University. Using the spatial analysis function in ArcGIS, the DEM of the area was extracted with 5 meter resolution, which was applicable resolution on study area. The extracted DEM was then re-projected to WGS_1984, Universal traverse Mercator Zone 51N in order to obtain a unified coordinate and projection system.

*Based GIS Map Generation*

Soil erosion is influenced by a variety of factors such as rainfall intensity and distribution, soil types, the topography of watershed, land use types, etc. These factors are presented very well using the GIS technique. Parameters of the data used for the modeling purposes of the study will be collected from available spatial datasets such as DEM. Other spatial datasets will be generated from measured field observations of other erosion factors.

*Slope data collection*

Relevant information of the slope is needed such as segment, a gradient in percent, length, and aspect. These are all needed parameters for the slope input file. These parameters are automatically extracted from the DEM.

*Parameter estimation*

The extent of erosion, specific degradation, and sediment yield from watersheds are related to a complex interaction between topography, geology, climate, soil, vegetation, land use, and artificial developments (Shen and Julien, 1993). Thus, the RUSLE model is applied to the study by presenting the average erosion rates. RUSLE (Wischmeier and Smith, 1978) computed the average annual erosion expected on-field slopes using the equation $A = R \times K \times LS \times C \times P$, where;

A = computed spatial average soil loss and temporal average soil loss per unit of area (tons per hectare).

R = rainfall erosivity index

K = soil erodibility factor

LS = topographic factor- L is for slope length and S is for slope steepness

C = cropping factor

P = conservation practice factor

The equation is designed for soil erosion modelling used in GIS model (RUSLE) based on the empirical research and statistical analysis of field experiments.

*Rainfall erosivity factor ®*

Rainfall erosivity (R factor) is the rainfall erosivity parameter. This is highly affected by storm intensity, duration, and potential. To calculate R factor, another equation will use that has been developed to determine the relationships between rainfall intensity and energy.

The climatic data used in this study were field observations of the rainfall activity monitored using a rain gauge. The obtained total amount of the precipitation data of the area are observed from six months study from September to February. The measured rainfall amount was obtained by summing the precipitation data.

*Soil erodibility (K) factor*

Soil erodibility factor is a measure of potential erodibility of soil and it depends on the inherent properties of the soil. The K factor is related to the integrated effects of rainfall, runoff and infiltration on soil loss, accounting for the influences of soil (Renard *et al.*, 1997). To produce a K factor map, the soil type classification in the study area was used and reflected on David (1988) for soil erodibility (K) factor values, wherein the soil erodibility represented values from the generated land uses/cover of the area were estimated and described exclusively for the Philippine soil types (Table 1).

**Table 1.** K factor values from David (1998) for soil textures in the Philippines.

| Land uses | Soil texture | K factor value |
|---|---|---|
| Cultivated Area mixed with brush land/grassland | Silt loam | 0.3 |
| Arable land, crops mainly cereals and sugar | Loam | 0.19 |

*Topographic factor – slope length (L) and steepness (S)*

The *L* and *S* factors represent the effects of slope length (*L*) and slope Steepness (*S*) on the erosion. The L factor (slope length factor) is the ratio of soil loss from a slope length relative to the standard erosion plot length of 22.1 m (Wischmeir and Smith 1978).

In this study, two different parameters are used to calculate the LS-factor, flow direction and flow accumulation. With the help of ArcGIS, the extracted DEM of the study area was first converted to slope map in degree and flow direction map. On the other hand, the flow accumulation grid was created by calculating the flow direction. The flow direction grid served as input in determining the flow accumulation. Then the LS Factor were then computed in the raster calculator using the following formula of Moore and Burch (1986).

$$LS = \left(\text{Flow Accumulation} \times \frac{\text{Cell Size}}{22.13}\right)^{0.4} \times \left(\frac{\text{Sin Slope}}{0.0896}\right)^{1.3}$$

*Crop cover (C) factor and Conservation/Support practice (P) factor*

The land-cover management (C factor) is a ratio comparing the soil loss from a specific type of vegetation cover. It is used to determine the effectiveness a crop/vegetation management system in preventing soil loss in the area. Meanwhile, the conservation practice represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope (Kim, 2014). The P factor reflects the impacts of support practices in the average annual soil loss. Thus, the lower the P-value, the more effective conservation practices (Omuto, 2008; Renard *et al.*, 1997).Based on the generated land uses/cover of the area the representing land cover management for C factor and P factor values were based on related erosion modeling studies in tropical countries. In the generating process, the classified factor values were encoded unto the attribute tables of land cover and converted into a raster file by conversion tools, to generate a factor map.

**Table 2.** Land use/cover and cropping management factor values.

| Land uses/cover | C values (Morgan 2005 and David 1988) | P values (David, 1988) |
|---|---|---|
| Cultivated Area mixed with brush land/grassland | 0.3 | 0.8 |
| Arable land, crops mainly cereals and sugar | 0.2 | 0.36 |

*Erosion Plot Measurement*

The experimental plot of soil erosion was established in three different land uses with two replications (A and B). Plot 1 is placed in agro-ecosystem (cornfield plantation), Plot 2 for grassland, and Plot 3 is positioned in trees covered vegetation. The experimental plots are established using the posts which were driven 18 inches in the ground and given enough width for the prepared post diameter in every identified plot.

Collected data of soil erosion was measured using modified erosion bar designed by Ramirez (1988) as cited by Marin and Casas (2017). Three sampling points that were established in situ was based in the variability parameters of the RUSLE model. The modified aluminum long bar having 1.5-meter long with ten holes spaced 15cm apart throughout the whole length of the bar is used in data gathering. Erosion measurement was gathered in every storm activity or rain activity in the study site.

The data gathered from the field area is computed to identify how much of the eroded soil was lost per year. The calculated data is converted into tons per hectare using the formula used in the study of Talucdo (2018).

$$\frac{soilerosion\ (\frac{tons}{ha})}{181 days} x \frac{365\ days}{1\ yr.}$$

*Soil erosion (tons/ha/yr.)=*

*Model simulation*

In order to estimate annual soil loss, the five factors were multiplied according to the relationship in RUSLE model. In total six layers with annual soil loss were computed using the GIS raster calculator tool. The soil loss was classified into soil erosion risk maps with five different soil erosion risk levels according to Morgan (1995).

**Table 3.** Soil vulnerability classification by Morgan (1995).

| Class | Description | Potential Soil Loss |
|---|---|---|
| 1 | Very Slight | 0-2 |
| 2 | Slight | 2.1-5 |
| 3 | Moderate | 5.1-10 |
| 4 | High | 10.1-50 |
| 5 | Severe | 50.1-100 |
| 6 | Very Severe | >100 |

*Model Validation*

To complete the calibration of the study, the output of the model was validated to identify the reliability of the data. In this study, the validation process of the model performance was used to compare the monthly and annual soil losses between the measured observation and predicted simulation from Grassland and Agricultural land, together with the value of statistical performance of the model "Standard Deviation Ratio (RSR)". In most studies, the effective and efficient model validation for the study was observed for long term (yearly) assessment studies and having the large span of data collections to obtained satisfactory simulation analysis and good model validation. However, this assessment study was primarily based on short-term studies so there is an expected consideration described on the validation processes.

*Statistical analysis*

The analysis of data primarily used simple descriptive statistics and data sets from the RUSLE model. To validate the model the "The Root Mean square error" that will represent the variability of error between the observed and predicted values were used. This method can observe the standard deviation ratio (RSR) to incorporate the benefits of error index statistics, so that the resulting statistic value that is reported can apply to the various constituents.

**Table 4.** General Performance Rating.

| Performance rating | RSR |
|---|---|
| Very good | 0.00 < RSR < 0.50 |
| Good | 0.50 < RSR < 0.50 |
| Satisfactory | 0.60 < RSR < 0.70 |

## Result and discussion

Factors influencing soil erosion which include soil type, land use, rainfall, and topography of the sub-watershed were used to simulate soil erosion using RUSLE equation and implemented in GIS. The result of erosion modelling is discussed below.

*Generated Spatial Data Sets of RUSLE Model*

*Rainfall erosivity (R factor)*

R-Factor is the rainfall erosivity parameter is highly affected by storm intensity and the long duration of rain. According to Wischmeier & Smith (1965), rainfall erosivity is the primary and primary factor in assessing soil erosion. However, the daily rainfall is a better indicator of variation in the rate of soil erosion to characterize the seasonal distribution of soil loss.

Rain gauge was positioned in the area to get the rainfall amount in the three land uses. The rainfall data presented in table 5 is based on the six-months observation which gains25mm every storm event and summed up for monthly basis factor values.

The calculations were adopted from rainfall factor equation of Mihara (1951) and Hupson (1971), which was also recommended by David (1988)that appropriate for tropical climate as of Philippine country. The obtained values of the rainfall are presented in Table 5 below.

**Table 5.** Rainfall erosivity factor value for the six month study.

| Month (2018-2019) | No. of Rainfall Activity | Total Monthly Rainfall Factor Amount (mm) |
|---|---|---|
| September | 2 | 44 |
| October | 12 | 326 |
| November | 7 | 153.5 |
| December | 5 | 104 |
| January | 4 | 99 |

As indicated in the results of the table above, average monthly rainfall was observed that rainfall is high during October and slowly decreasing during the following months. Shown in table 5, are the following encoded rainfall data from the collected measurements of September to January. These collected measurements were prepared and tabulated unto attribute tables of ArcMap to generate rainfall shape files to used and produced rastered rainfall erosivity factor.

In the analysis, rainfall erosivity was prepared using the cell size of 10m resolution in the raster map calculation. Digitized polygon of a distributed map for rainfall ersosivity factor of the area was prepared using collected coordinates and overlay to ArcGIS 10.1 considering the three land uses;cornfield, grassland and trees were generated using ArcGIS.

*Soil erodiblity(K factor)*

Soil erodibility factor is one of the major factors represents the susceptibility of soil to erosion. The higher the value of soil erodibility indicates higher susceptibility to erosion (Evan, 1980). The Rate of soil erosion also depends on soil characteristics and the natural appearance of the landforms. The phenomenon of soil erosion depends on the soil characteristics of the area wherein this includes the soil composition, color, texture, structure, soil water, organic matter, and chemistry. These characteristics play a different role in soil erosion.

The extent and laboratory of soil analysis of the three different land uses and assigned values is given in Table 6 below. The table shows the result of physicochemical properties of soil on the selected land uses along Bong-bong sub-watershed in Barangay Adtuyon, Pangantucan Bukidnon.

**Table 6.** Soil properties of three land uses/cover of the study area.

| Land uses/cover | Particle density | Water Holding Capacity (%) | Bulk Density | Soil type and Texture |
|---|---|---|---|---|
| Agro-ecosystem (cornfield plantation) | 1.8571 | 98.936 | 0.738 | Loam |
| Grassland | 1.8964 | 89.192 | 0.94 | Silt loam |
| Trees | 2.1146 | 94.509 | 1.07 | Loam |

Based on the study, the highest water, holding capacity with a value of 98.936 % is the agro-ecosystem in the cornfield area. According to Ball (2001) water holding capacity is controlled primarily by soil texture and organic matter. A soil with smaller particles like clay and silt which has many tiny pores makes the water move slowly. On the other hand, the soil texture like sand has a low water holding capacity because its particles are large which allows water to drain easily and quickly.

In analysis the vulnerability of erosion rate in the area is higher, since silt soils have a modest to highest soil erodibilty as the soil particles is moved simply during long duration of rain (Morgan *et al.*, 1998). Soil erodibility of the area is expected to be higher because of the textural type and the disturbances by people.

For the bulk density, plot-3 of trees-covered vegetation has the highest value of 1.07 g/cc, followed the plot-2 of grassland with a value of 0.94 g/cc. Agro-ecosystem –cornfield of plot 1 has the least bulk density with a value of 0.738 g/cc. According to Ffolliott*et al.* (2013) bulk density reflects the soil's ability to function for structural support, water and solute movement, and soil erosion. Moreover, high bulk density indicates of low soil compaction where it has less organic matter, less aggregation and less penetration. Furthermore, compaction of soil can result to increase erosion rate especially in sloping area and cause water log in flat areas. Fig. below represents the values of soil erodibility in the area.

In the analysis, soil erodibility factor depends on the soil characteristic such as soil texture, grain size and organic content. In this study, the soil erodibility factor values for the study area were based on soil type representative factor values by David (1988) exclusively in Philippines soil type's information, wherein the loam and silt loam have factor values of 0.19 and 0.3 respectively.

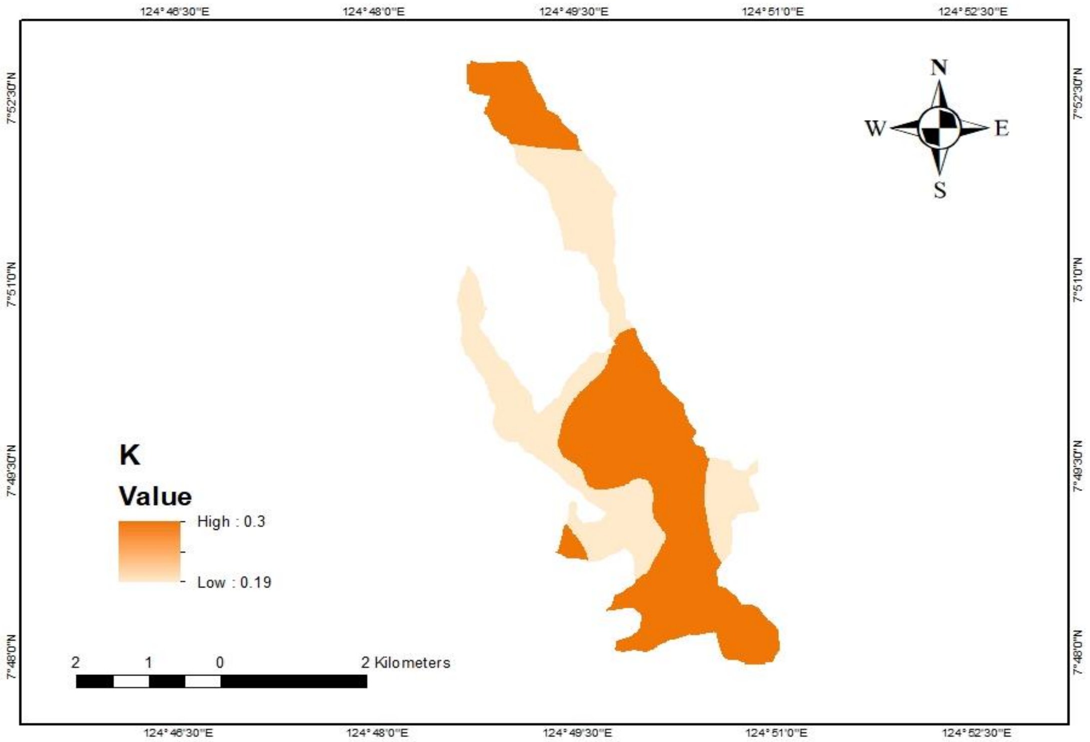


**Fig. 2.** Soil erodibility (K) factor map.

*Topographic factor (LS)*

The LS factor depends on the slope length and the steepness of the area and has played an important role in soil erosion.

They produce the topography on the topsoil erosion and it contains the length and steepness of the slope that persuade the surface runoff speed (Beskow *et al.*, 2009 and Risse *et al.*, 1993). Topography on soil erosion is accounted by the topographic factor which is sensitive to slope factor. According to Sharma (2015), slope length increases soil erosion per unit area due to surface runoff. And as the slope steepness increases, the velocity and soil erosion of surface runoff increases. Slope values in identified land use of Bong-bong sub-watershed was presented in table 7 below.

**Table 7.** Slope steepness of the Land uses/cover of the area.

| Land Uses/Cover | Slope Steepness (%) |
|---|---|
| Agro-ecosystem (cornfield plantation) | 11.33 |
| Grassland | 8.67 |
| Trees | 4.1 |

The topographic factors slope length (L) and slope steepness (S) represents a ratio of soil loss below specified condition to that at a site with the standard slope steepness of 9% and the slope length of 22.6 m (Ganasari and Ramesh, 2015). In the study, cornfield area identified as prone to soil erosion having a value of more than 9% slope. It is expected that this would strongly influence the rate of erosion in the site. On the other hand, grassland and trees have a slope steepness of less than 9% which would imply a low contribution on the erosion rate.

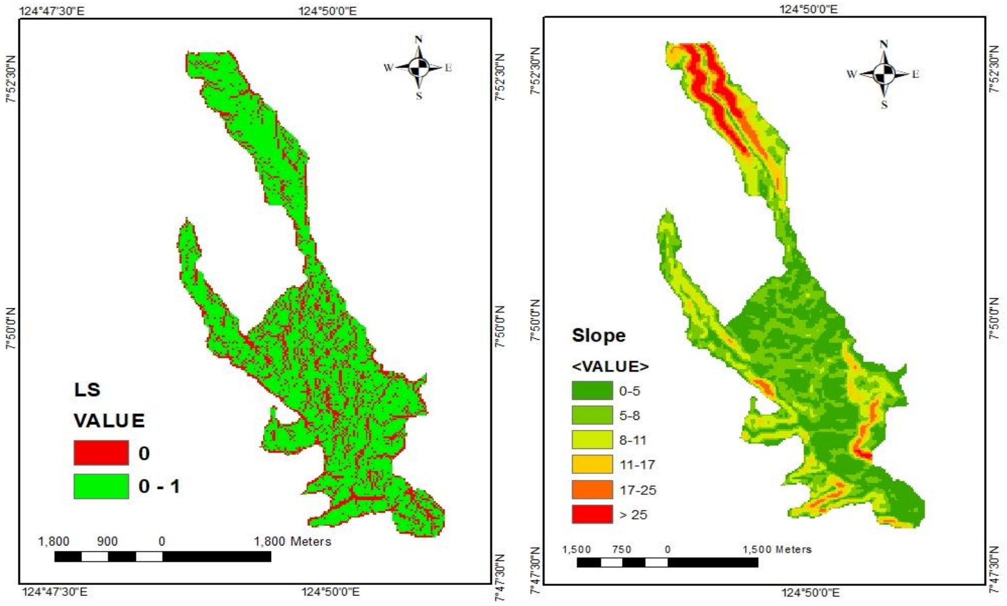


**Fig. 3.** Slope map (LS) factor map.

Presented in Fig. 3, the combined measured effect of the LS factor on Agricultural crops (corn and rice) and grassland with shrubs and trees was ranges from 0-1.

*Cropping management (C) and Conservation practice (P)*

The C and P factor was described as the most essential factor in processing the RUSLE model since it represents conditions that can easily be managed to prevent or reduce soil loss according to Cool *et al.*, (1995). In the study, generated land uses/cover map was derived from the Bureau of Soil and Water Management (BSWM) of which the cropping management (C) and conservation practice (P) values derived by Morgan (2005) and David (1998) were used in allocating the values of different land uses.

Accordingly, the values for cropping management (C) the factor that the values closer to 1 implies lesser manage areas and constantly disturbed while values closer to zero implies a relatively stable undisturbed area. Zero (0) values of conservation practice (P) indicates good conservation practice and the value approach to one (1) indicates poor conservation practice.

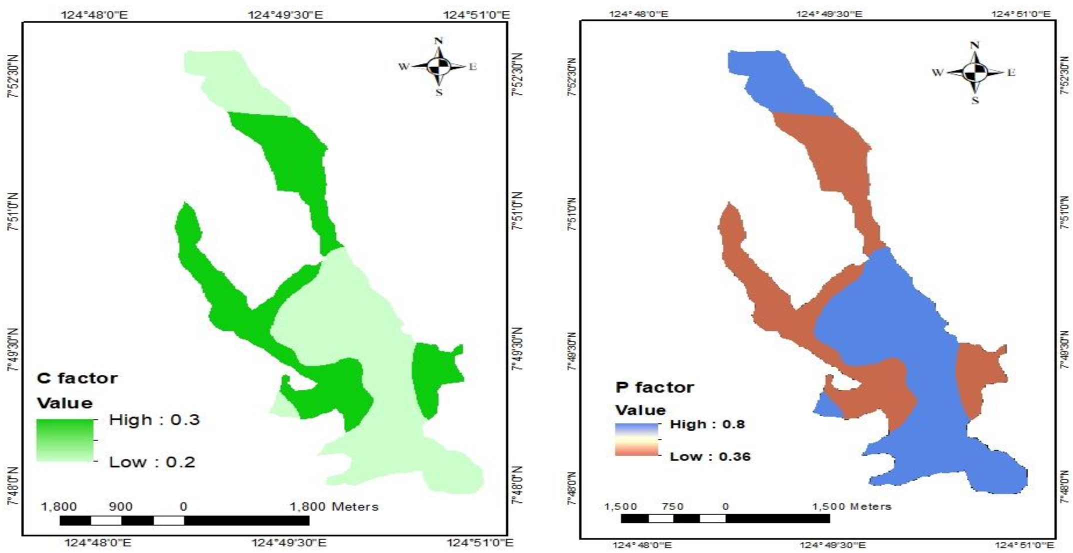


**Fig. 4.** Cover management and Conservation practice map.

In the analysis, land uses as agricultural crops have the highest impacts on soil erosion. As observed in the field study, cornfield plantation was constantly disturbed and has no conservation practice as it was planted along with slope areas without contour practices. Grassland contains minimum values for cropping management and conservation practice, but because of the presence of the vegetative cover, it is available to protect soil from erosion and can decrease the impact of the raindrops every storm event. Trees have the lowest value for cropping management and conservation practice, as cited in the study of Marin and Casas (2017), trees regulated soil movement as the root systems support the soil from erosion.

*Simulated annual soil loss based in the RUSLE calculated GIS model*

The data sets of the RUSLE model were used to compute the annual soil loss and generated using GIS techniques. The spatial interpolation of erosion on Bong-bong sub-watershed was done by multiplying the five (5) factors of the RUSLE model which includes rainfall (R), soil (K), topography (LS), cover management (C) and cropping management (P) factors. The simulated annual soil loss of the area is obtained by the revised universal soil loss equation, and their values vary notably an influence by the amount of rainfall. In this study, the simulated erosion values of the area generated from all the factors of the RUSLE model predicted that the soil erodes from 0-400 tons/year. In the whole study, the Bong-bong sub-watershed signifies that the sub-watershed is more prone to soil erosion. Its high erosion rate is highly influenced by anthropogenic activities and the climatic condition of the site. Fig. below represents the risk of soil erosion in the whole sub-watershed.

*Data validation*

Although literature's of soil erosion processes contains a large amount of data for the reliability of the RUSLE modeling soil erosion, it is still needed to test the validity of the simulated results values of soil erosion by comparing it to the actual field measurements. However, soil erosion takes days, months, or years to acquire the data of erosion. Since it is slow process and cannot be predicted by simple equation or numerical models.

*Validation of the model outputs*

To fit the available data set of erosion measurements for the three land uses, readings from the months of September-January were used to predict the reliability of simulation. Shown in table 8 below summarizes the monthly results of soil loss form measured values vs. simulated values of erosion based from the model output of the three land uses.

**Table 8.** Comparative Results of Measured erosion vs. simulated erosion (tons/month).

| Measured Erosion | | | |
|---|---|---|---|
| Months | Cornfield plantation | Grassland | Trees |
| September | 2.153 | 2.506 | 2.509 |
| October | 15.830 | 15.037 | 15.432 |
| November | 7.295 | 7.758 | 7.889 |
| December | 5.360 | 5.014 | 5.112 |
| January | 4.036 | 4.977 | 4.886 |
| Simulated Erosion | | | |
| Months | Cornfield plantation | Grassland | Trees |
| September | 0.903 | 0.950 | 0.602 |
| October | 6.690 | 7.042 | 4.460 |
| November | 3.150 | 3.316 | 2.100 |
| December | 2.134 | 2.246 | 1.423 |
| January | 2.031 | 2.138 | 1.354 |

*Statistical analysis*

Standard Deviation Ratio (RSR) was used to validate the predicted monthly results of the soil loss in the area. RSR determines the error between the gap of measured erosion and simulated erosion. Table 9 below shows the comparative results of measured and simulated erosion values.

**Table 9.** Statistical Analysis of the predicted and observed soil loss in study area.

| | Cornfield plantation | Grassland | Trees | Model Performance |
|---|---|---|---|---|
| Average Error | 0.040 | 0.084 | 0.191 | |
| RSR | 0.370 | 0.383 | 0.319 | Very Good |

Since the optimal value of RSR is zero (0) only shows a better simulation performance. In this study, evaluation of the model shows the performance rating of simulated erosion in three land uses was satisfied to the needed output for erosion modeling in having a good model performance.

The value of < 0.50 signifies that the statistical analysis of the study is acceptable level performance of the model.

*Recommendation on the validated result of RUSLE model in the study*

Based on the study, the highest erosion rate of the three land uses/cover that is prone to soil erosion is grassland area with an average of 18.191 tons/ha/year on simulated erosion using the GIS model. The agricultural land of the study area has a probability that the rate of erosion increased in the future. Therefore, proper land-use planning such as agroforestry practices must be advised to the farmers to have a suitable cropping pattern for agricultural land at the local level. It could lower the soil erosion rate in the area and also protect the areas from further erosion.

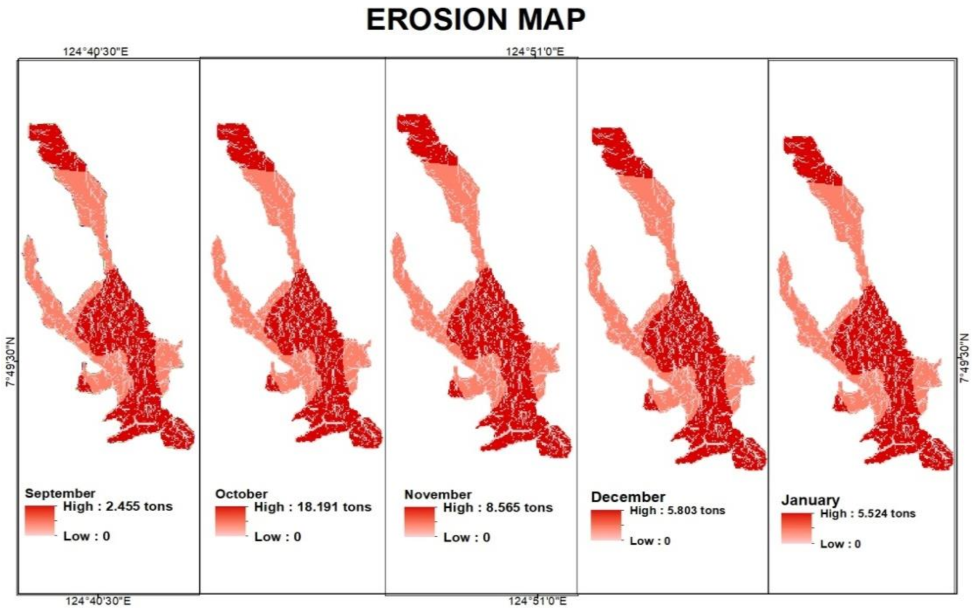


**Fig. 5.** Total Soil Erosion Map.

## Conclusion

Based on the results of the study, the following conclusions were drawn:

1. RUSLE factors such as rainfall, soil, topography, cover management and cropping factors can affect the extent of soil erosion in the area.
2. The simulated total erosion of the sub-watershed exceeds from 0-400 tons/year.
3. RUSLE model performance in the study showed excellent performance having a value of ≤ 0.50 and is therefore effective in predicting soil erosion in the site.

## Recommendation

From the conducted study, the following are recommended for the future studies of soil erosion using GIS techniques,

1. The landowner of the area should be applying any soil protection practices to a avoid large amount of soil loss
2. There should be an enhancement of the tool to further understand the modelling of soil erosion.

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