A GIS-RS Approach for RUSLE-Based Method of Mean Estimation of Mean Annual Soil Loss of the Tagoloan River Basin, Philippines

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Abstract

Soil erosion is a serious environmental concern in Tagoloan River Basin (TRB), a major watershed in Northern Mindanao, Philippines. It leads to soil loss causing detrimental impacts such as decreased soil productivity, nutrient loss, siltation, and water quality degradation among others. These impacts are better understood by estimating the degree of soil loss in the watershed and visualized in a GIS-based and factor-based approach using the Revised Universal Soil Loss Equation (RUSLE) model. Thematic maps of soil loss were generated with factors for rainfall erosivity (R), soil erodibility (K), topographic (LS) consisting of slope length (L) and slope steepness (S), cover management (C), and support practice (P). Factors were calculated separately and multiplied together to develop combined soil loss maps. Results show that TRB has an actual mean annual soil loss of 153.20 tons/hectare/year with 47.15% of the study area having very high to very severe susceptibility to soil loss. Further, a comparison of the potential (RKLS) and actual (RKLSCP) soil loss maps indicates the significance of cover management and support practices to the resulting mean annual soil loss. The present characterized soil loss level maps and its understanding driving forces of soil erosion for the planning of management practices and mitigating environmental hazards in the watershed.

1. Introduction

1.1 The Problem and Its Setting

Soil erosion is a global environmental issue affecting all kinds of landforms. It causes the removal of the net mass of the soil called soil loss, resulting in reduced cropland productivity, an increase in pollution of adjacent watercourses, land degradation, and other environmental issues like flooding (Ritter, 2012). Globally, about 75 billion tons of soil are lost every year due to wind and water (Myers, 1993; Gabathuler et al., 2009). In the Philippines alone, an estimated 74-81 million tons of soil are lost annually, affecting 63%-77% of the country’s total land area (DENR & FAO, 2003). Factors affecting soil erosion by water include climate, vegetation, topography, soil structure, and human activities like soil management practices and tillage systems (Hajigholizadeh et al., 2018).

A number of watersheds in the Philippines are facing invariable degradation, characterized by degraded forest, soil erosion, erratic streamflow, declining groundwater resource, loss of biodiversity, microclimate deterioration, and declining land productivity (DENR & FAO, 2003). These along with a changing variability of rainfall has been shown to increase the rates of flooding such as the case in Cagayan de Oro when TS Sendong brought down an immense amount of rainfall (Franta et a., 2016). Tagoloan River Basin (TRB) is not an exemption to this continuous deterioration of watersheds in the country. The Department of Environmental and Natural Resources classifies TRB as among the 8 (eight) major river basins in Mindanao, Philippines, situated in the provinces of Bukidnon and Misamis Oriental. Its relevance is shrouded by a major concern in TRB in issues of soil erosion (JICA, 2010), which is caused by conflicting resource uses, over-extraction of resources, and unsustainable land-use conversion, to name a few (DENR, 2014). Instances of those mentioned are aggravated by the conversion of forests into agricultural zones, especially in the upper portions of the river basin have resulted in soil erosion as well as consequent siltation of rivers. Meanwhile, local stakeholders associated riverbank erosion with quarrying and unregulated small-scale mining (DENR, 2014). To add to that, soil erosion in the riverbanks combined with sediment accumulation in the lower catchments of the basin are the main cause of flooding and land degradation of the watershed (JICA, 2010). The potential flooding in TRB is a critical concern that necessitates the identification and development of appropriate mitigation measures. The lack of sound baseline information such as an estimation of TRB’s soil loss would allow for the implementation of sustainable management practices in the area is another problem that needs to be tackled (DENR, 2014).

Methods developed to assess the erosive potential in any particular region using a soil loss model have been developed by scientists. These models are done to predict and address soil loss by observing the behaviors of many factors associated with erosion. One of the widely-used soil loss models is the RUSLE model which takes into account five soil loss factors namely rainfall erosivity (R), soil erodibility (K), topographic (LS) consisting of slope length (L) and slope steepness (S), cover management (C), and support practice (P) factor. With all these factors, the researchers were able to (1) estimate the mean annual soil loss using the RUSLE Model through GIS environment, (2) collect a baseline profile, (3) assess the soil loss parameters, (4) develop soil loss maps, and (5) characterize the levels of soil loss in TRB. With the literature available, the study aims to estimate the mean annual soil loss of the Tagoloan River Basin through the RUSLE method. To do this the soil erosion factors are generated to develop soil loss maps. Using the maps and the factors the levels of soil loss in the basin are characterized. The results of this study will allow the identification of areas in the basin that are more susceptible to soil loss. This will aid in the development of land conservation practices and policies to effectively manage natural resources in the basin.

2. Methodology

2.1 RUSLE Factors

The study utilized the basin area from DENR with a total area of 1,789.33 sq. km and applied the soil loss factors using this boundary. Each factor was determined using secondary data with consideration to values that were used previously in the Philippines. These factors were then calculated using the following formulas derived from existing studies.

R-Factor (El-Swaify et al., 1987)

$$R = 38.5 + 0.35P \tag{1}$$

K-Factor (Wischmeier & Mannering, 1969; David 1988)

$$K = S \times (0.043 \times pH + 0.621/OM + 0.0082 \times Sa + 0.0062 \times C) \tag{2}$$

LS-Factor (Moore & Burch, 1986)

$$LS = (m + 1)\left(\frac{U}{L_0}\right)^m \left(\frac{\sin\beta}{S_0}\right)^n \tag{3}$$

Mean Annual Soil Loss A (Ganasri & Ramesh, 2016)

$$A_P = RKLS \tag{4}$$

Potential Mean Annual Soil Loss, AP (Ganasri & Ramesh, 2016)

$$A_A = RKLSCP \tag{5}$$

The C and P factors were calculated by assigning approximate values reported by literature for typical land covers found in the Philippines, with values ranging from 0 to 1. All datasets in this study were rasterized and resampled to the same spatial resolution of 10m × 10m.

The soil loss maps were obtained by multiplying the thematic maps using GIS software such as QGIS and ArcGIS Pro's raster calculators. Using the RUSLE factors, each of the soil loss factors was computed for the TRB to estimate the potential and actual mean annual soil loss. The actual soil loss was classified into six categories based on the (t) $(ha)(yr)$ rate of loss which are none to slight, moderate, high, very high, severe, and very severe. Adapting the classification levels proposed by Ganasri and Ramesh (2016) and equations 4 and 5, the highest value would mean the highest susceptibility, while the lowest value would mean the lowest susceptibility to soil loss.

3. Results and Discussion

3.1 Rainfall Erosivity (R) Factor

For the study area, the Precipitation (P) values ranges from 2,438.77 to 2,824.34 $\frac{mm}{yr}$ with a mean of 2,569.26 $\frac{mm}{yr}$. P values were used in calculating the R factor using rainfall data from 2011 to 2020. This rainfall data was acquired from NASA/GSFC/HSL (2020) which allows researchers to access the latest Integrated Multi-satellite Retrievals for Global Precipitation Measurement GPM (IMERG) algorithm which combines information from the GPM satellite constellation database. Using these precipitation values, the results for R were then calculated as shown in Figure 1, with values ranging from 892.07 to 1027.02 $\frac{(MJ)(mm)}{(hr)(ha)(yr)}$ with a mean of 937.74 $\frac{(MJ)(mm)}{(hr)(ha)(yr)}$. Areas with higher values of P have higher rainfall erosivity values.

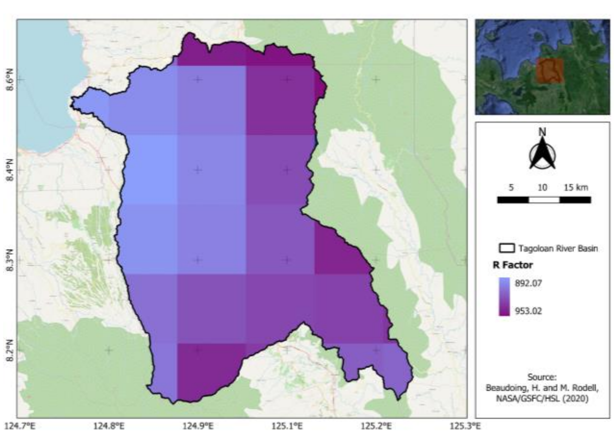

Figure 1. Rainfall Erosivity map of TRB

3.2 Soil Erodibility (K) Factor

Considering the Bureau of Soils and Water Management soil data for TRB, the basin is composed of 12 distinct soil types with K factor values ranging from 0.15 to 0.40, with a mean of 0.22 for the soils of Mt. Kitanglad Range Natural Park and its affecting watersheds (DENR, 2015).

Soil	K-Factor	Area (ha)	Proportion (%)
Adtuyan Clay	0.15	48271.12	26.98%
Alimodian Clay	0.18	1234.42	0.69%
Beach Sand	0.15	115.40	0.06%
Calauag Clay	0.19	744.00	0.42%
Faraon Clay	0.23	5565.05	3.11%
Jasaan Clay	0.15	7969.01	4.45%
Jasaan Silt Loam; Jasaan Clay Loam	0.40	2040.56	1.14%
Kidapawan Clay; Kidapawan Clay Loam	0.20	8113.74	4.53%
Mountain Soil (Undifferentiated)	0.30	70613.92	39.46%
Rough Broken Land	0.22	33227.05	18.57%
San Manuel Loam	0.25	516.23	0.29%
Umingan Clay Loam	0.28	523.08	0.29%
	Total	178933.57	100.00%

Table 1. K-Factor used for different soil types found in TRB.

Source: DENR (2015)

Closely observing clay soils, it is between 0.15 and 0.23 which indicate soils that are least prone to erosion, due to resistance to detachment (Ganasri & Ramesh, 2016). Silt loam soils have moderate to high K values, ranging from 0.25 to 0.40, due to their moderate to easy detachment, moderate to low production of moderate to high runoff, and moderate to easy transportation of soil particles, all of which indicate a high susceptibility to erosion (MSU-IWR, 2002).

The high K factor values cover 41.18% of the basin and are concentrated in mountainous areas, where the soils are volcanic and have a low bulk density (Calalang & Colinet, 2014), all of which are associated with soil erodibility, resulting in a land capability limited to pasture or forest.

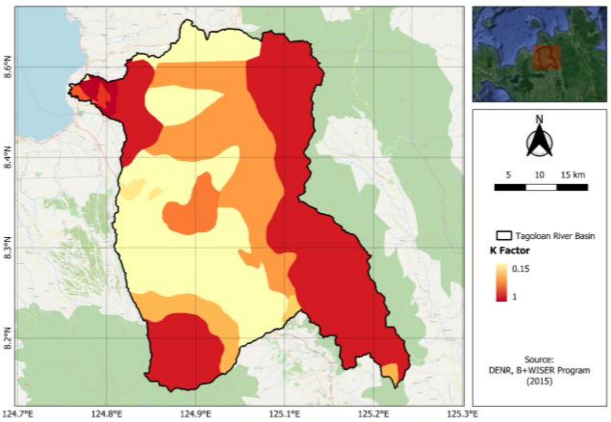

Figure 2. Soil Erodibility map of TRB

Further, the risk of soil erosion increases if poorly cultivated (NSO, 1996), and in floodplains near the river's mouth, where soils are found in mountainous rugged terrain and upland areas developed from hard igneous rocks (NWRC, 1983) and underlain by clay with highly weathered volcanic tuff (Carating, Galanta, & Bacatio, 2014), where highly weathered tropical soils are associated with low soil loss tolerances (EI-Swaify et al., 1982).

3.3 Topographic (LS) Factor

The Topographic (LS) Factor takes into account the slope length and steepness of a given area, both determined from the DEM of TRB, which is obtained using the data gathered from DOST and using ArcGIS Pro for the TRB Boundary File. The map in Figure 3 illustrates areas in Bukidnon showing longer and steeper slopes compared to areas in Misamis Oriental, due to the fact that Bukidnon has numerous mountains surrounding the basin. With that, the Bukidnon area is more prone to the transport of soil particles that may cause a higher risk of soil erosion.

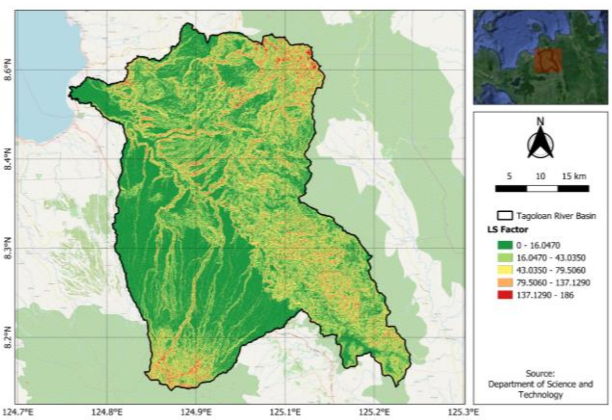

Figure 3. Topographic map of TRB

3.4 Cover Management (C) Factor

The major land covers of TRB taken from the ESRI 2020 land cover map were trees/forest, scrubland, grassland, cropland, built-up areas, flooded vegetation, water body, and bare land. The corresponding C-factor values were obtained from different studies that report approximate C-factors for land covers typically found in the Philippines.

Land Cover Type	C-Factor	Area (ha)	Proportion (%)
Water	0	673.73	0.38%
Trees/Forest	0.006	95634.83	53.45%
Scrub	0.010	3430.93	1.92%
Grass	0.200	0.80	0.00%
Crops	0.300	31768.12	17.75%
Built-up Area	0.200	41439.01	23.16%
Flooded Vegetation	0	5545.53	3.10%
Bare	1.000	440.29	0.25%
	Total	178933.24	100.00%

Table. 2. C-Factor values and their proportions in the river basin

The river basin is dominated by trees or forests which is most evident in the Bukidnon area. This land cover classification was represented by a relatively low C-factor value. Conversely, the lowermost portion of the basin or the Tagoloan municipality is mostly covered by built-up areas and crops which have relatively higher C-factor values due to loss of vegetative soil cover and inadequate agricultural practices to protect topsoils. The scattered bare land has the highest C-factor value, however, it aggregately occupies just a little portion of the basin. This type of land cover is very prone to soil loss and does not reduce the direct impact of rainfall on soil resources, unlike vegetation covers and forests which provide protective cover on land and reduce the run-off potential of water. A higher proportion of land covers with relatively low C-factor values suggests that there are enough vegetation covers in TRB, especially in elevated areas that can help reduce soil erosion.

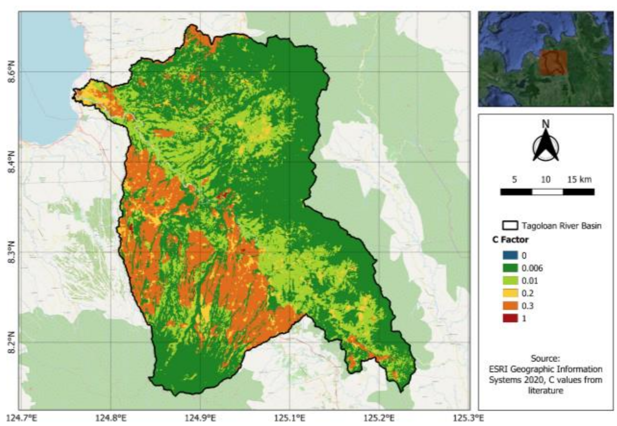

Figure 4. Cover Management map of TRB

3.5 Support Practice (P) Factor

Due to limitations in data collection on conservation practices in the TRB, the P-factor value was set to 1, as the majority of the study area is covered by natural vegetation; and while crops cover a significant portion of the study area, the global LULC map does not specify the types of cropland and agroforestry. Moreover, the majority of agricultural areas, particularly those with sloping land used for crops and where monocropping is commonly practiced, are rarely implemented with conservation practices. This may be due to the hesitance of many farmers to adopt conservation farming, due to a lack of information on the importance of conservation practices and their technologies (Lucas, 2021).

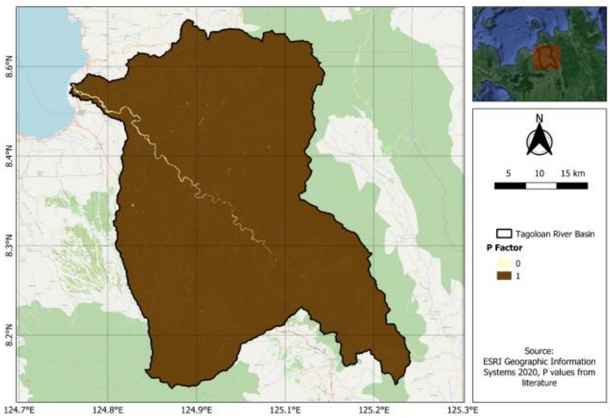

Figure 5. Support Practice map of TRB

3.6 Mean Annual Soil Loss

The mean annual soil loss for the TRB ranges from 0 to 53,969.89 $\frac{(t)}{(ha)(yr)}$ with an average of 153.20 $\frac{(t)}{(ha)(yr)}$ adn standard deviation of 569.32. The results indicated that mean annual soil loss was very much higher than the considered tolerable soil loss of 3-10 $\frac{(t)}{(ha)(yr)}$ (Paningbatan, 1987) and about 5-12 $\frac{(t)}{(ha)(yr)}$ estimated by USDA in 1950 (Schertz, 1983) for Philippine conditions (FAO & ITPS, 2015). Values exceeding soil loss tolerance mean that the soil is potentially subjected to erosion risk, productivity loss, and off-site effects such as downstream over-sedimentation in the basin scale, implying the need for conservation measures (Stefano & Ferro, 2016).

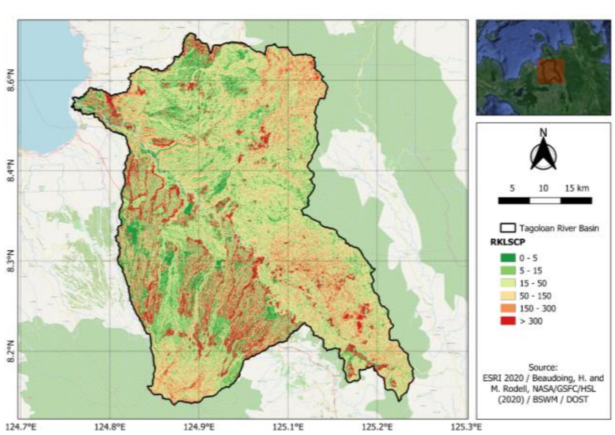

Figure 6. Mean Annual Soil Loss map (A) of TRB

The mean annual soil loss map shows the RKLSCP values wherein lower values are found in areas with flat to gentle slopes, are largely covered with natural vegetation and have lower R and K factor values. Higher soil loss values are mostly concentrated in agricultural and built-up areas with high soil erodibility and cover management values, and in mountainous areas with high rainfall erosivity, soil erodibility, and slope values.

Classes	Soil loss (t/ha/yr)	Area (ha)	Area (%)
None to slight	0 - 5	30553.67	17.13%
Moderate	5 - 15	16678.64	9.35%
High	15 - 50	47017.44	26.37%
Very high	50 - 150	51552.10	28.91%
Severe	150 - 300	17115.69	9.60%
Very Severe	>300	15409.48	8.64%
	Total	178327.02	100.00%

Table 3. Mean annual soil loss values and their proportions in the river basin

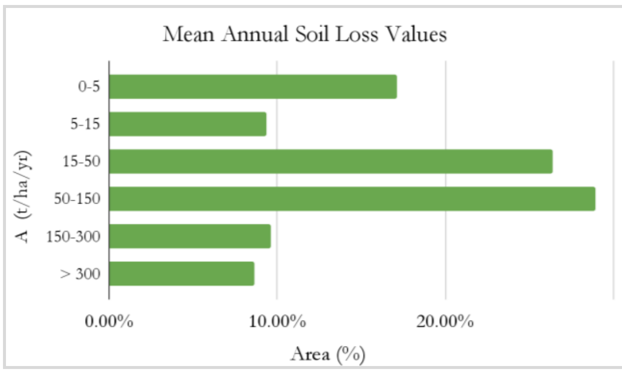

Figure 7. Mean annual soil loss values and their respective proportions in TRB

Soil loss levels of the TRB were classified into different classes based on the severity of soil loss. Areas with none to slightly severe soil loss with values of 0-5 $\frac{(t)}{(ha)(yr)}$ cover 17.13% of the river basin's total area. Meanwhile, moderate annual soil loss (5-15 $\frac{(t)}{(ha)(yr)}$) has covered only 9.35% of the basin. These areas have flat to gentle slopes, are largely covered with natural vegetation, and have lower R and K factor values. Areas with high to very high susceptibility with soil loss values of 15-50 $\frac{(t)}{(ha)(yr)}$ and 50-150 $\frac{(t)}{(ha)(yr)}$ have the greatest proportion accounting for 26.37% and 28.91% respectively. This is due to high R and K factor values, moderately steeper slopes, and low C factor values, as the bulk of these areas are covered by trees, grass, and scrub. Severe (150-300 $\frac{(t)}{(ha)(yr)}$) and very severe soil loss (>300 $\frac{(t)}{(ha)(yr)}$) has lower proportions covering 9.60% and 8.64% respectively. This can be due to the effect of high K and C factor values on agricultural and built-up areas with low R and LS values, and the effect of high R, K, and LS factors on mountainous areas covered with natural vegetation. High to very severe soil loss susceptibilities exceeding tolerable soil loss (<12 $\frac{(t)}{(ha)(yr)}$) which accounts for 73.52% of the study area necessitates the need for policy planning.

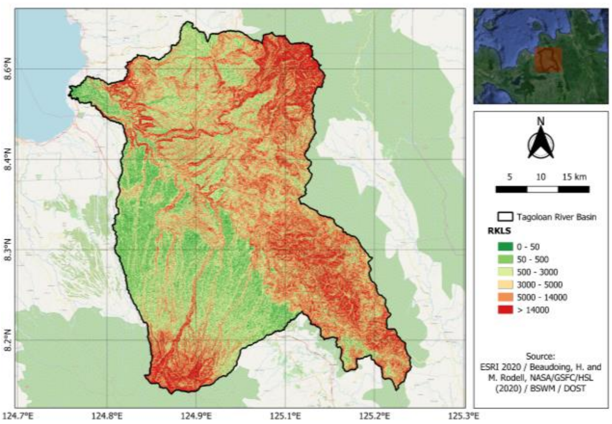

Figure 8. Potential Mean Annual Soil Loss map (A_P) of TRB

The potential mean annual soil loss for the TRB ranges from 0 to 67,912.547 $\frac{(t)}{(ha)(yr)}$ with a mean of 6,898.80 $\frac{(t)}{(ha)(yr)}$ and standard deviation of 9,346.14.

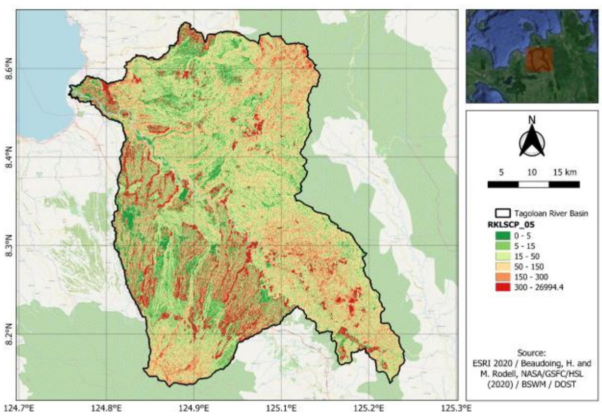

Figure 9. Mean Annual Soil Loss map (A) of TRB with 5% increase in rainfall

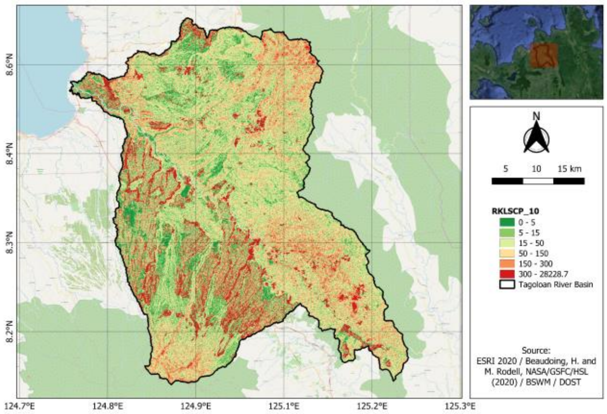

Figure 10. Mean Annual Soil Loss map (A) of TRB with 10% increase in rainfall

Without accounting for the land cover management and soil conservation practices, the RKLS values show the potential loss of soil in the surrounding area. The RKLS map shows that areas with mild slopes have the lowest values, while the mountainous areas are represented by the highest values.

The comparison of the potential mean annual soil loss (A_P) map and the mean annual soil loss (A) map shows that adding the cover management factor and support practice factor into the equation results in a decrease in soil loss values in regions covered by natural vegetation due to low C values, and an increase in soil loss severity in agricultural and built-up areas. Meanwhile, the P-factor did not affect the resulting values as it was assigned with a value of 1.

4. Conclusion

This study is conducted to create a GIS-RS estimate through the factors and maps of the mean and potential annual soil loss of TRB using the Revised Universal Soil Loss Equation (RUSLE) model. The process considers rainfall erosivity, soil erodibility, topographic, cover management, and support practice factors. The increase in soil loss values is characterized by intense rainfall, mountainous terrain, steep slopes, barren lands, and poor plant cover and conservation practices. The comparison of potential mean annual and mean annual soil losses also shows the significance of land cover and conservation support practices in TRB, where agricultural regions lacking soil conservation practices have higher susceptibility and forest-covered regions have lower susceptibility to soil loss. The presumed increase in precipitation values emphasizes the severity of soil loss in at-risk areas with poor cover management and support practices. The mean annual soil loss of TRB indicates severe susceptibility and the majority of the area of the river basin has resulting values much higher than the accepted tolerable soil loss. This implies the need for conservation measures and policy planning in the basin, with much priority given to areas with very severe susceptibility, which are subject to decreased soil productivity, nutrient loss, siltation, water quality degradation, and environmental hazards like flood and landslide. Lastly, the findings call for the local government units and stakeholders to focus on: improving land conservation and management policies to reduce erosion, enhancing and developing better infrastructure, programs, regulations and policies to protect the ecosystem of the river basin, and funding research studies to further improve the knowledge on soil erosion and other environmental issues in the area.

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