

Assessment of Soil Erosion in the Bangon and Binahaan River Basins, Leyte Through GIS-Based RUSLE Modeling

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Abstract: Soil erosion is an ongoing issue characterized by the movement and transport of soil. It has increased the impacts on water resources that could lead to the degradation of water quality, an increase of hydrogeological hazards, and a decrease in reservoir capacity that eventually could cause floods. With increased human activity and fluctuation of rainfall events, soil erosion is becoming a more significant concern in tropical regions, highlighting the need for soil erosion management and determination of critical spots. One of the most used methods for erosion estimation is the Revised Universal Soil Loss Equation (RUSLE), an enhanced version of USLE, which utilizes the rainfall erosivity, soil erodibility, slope length and steepness, land cover, and support/conservation practice factors for soil loss estimation. This research aims to assess soil erosion in a tropical watershed located in Leyte, Philippines using RUSLE and GIS. The study focuses on the Bangon and Binahaan River Basins, both delineated with outlets situated in Palo, Leyte. The R-factor was found to range from 542.0 to 545.3 $\text{MJ ha}^{-1} \text{mm hr}^{-1}$. The K-factor varied between 0.26 and 0.60 $\text{t ha hr}^{-1} \text{MJ}^{-1} \text{mm}^{-1}$. The LS-factor had a mean value of 3.502 with an SD of 10.072 for the Bangon RB, and 11.710 with an SD of 25.892 for the Binahaan RB. The C-factor showed a mean of 0.272 and an SD of 0.113 for the Bangon RB, while the Binahaan RB had a slightly lower mean of 0.241 and an SD of 0.069. The P-factor had mean and SD values of 0.181 and 0.233 for the Bangon RB, and 0.129 and 0.171 for the Binahaan RB. The study found that five sub-basins in both the Bangon and Binahaan River Basins are experiencing soil erosion beyond tolerable levels, affecting 38.91% and 57.93% of their respective catchment areas.

Key Words: erosion; geographic information system; land use land cover; revised universal soil loss equation; soil loss.

1. Introduction

Soil erosion is a global issue that imposes significant issues on the environment as it changes the inflow of sediment into the river ecosystem disturbing the local ecosystem and affecting soil fertility for agriculture. Although it takes place naturally under all climate conditions, its occurrence is significantly increased and accelerated by human activities through agriculture, deforestation, and unsustainable land use changes (FAO, 2015). Many studies have shown the effects of rainfall-induced soil erosion particularly on

soil and water resources, which include a decrease in agricultural productivity (Borrelli et al., 2017), degradation of water quality downstream (Vale et al., 2023), higher risk to geological hazards (Batumalai et al., 2023) and even the decrease of dam and river capacity causing floods (Ren et al., 2021). Assessments have also shown that sedimentation reduces global reservoir storage by 0.5–1% annually, and by 2050, may retain only half their current capacity, threatening water resource sustainability (Chuenchum et al., 2019). The need for erosion

assessment models necessary for many watersheds as soil is a finite resource and its loss and degradation cannot be naturally restored (FAO, 2020).

In addressing soil erosion, the establishment of equations and conceptualization of soil erosion prediction models have become a need for policy formation and implementation of mitigation strategies (Phinzi & Ngetar, 2019; Carollo, et al., 2024). The Revised Universal Soil Loss Equation (RUSLE) is one of the widely used GIS-based soil erosion assessment tools in the world (Renard et al., 1997). RUSLE is an enhanced version of USLE, a five-factor model that estimates the anticipated annual rate of soil erosion based mainly on terrain, land use and land cover (LULC), and meteorological conditions. RUSLE serves as a simplified method compared to other models and the estimated values best serve in identifying vulnerable areas and setting the baseline scenario of an area due to its simplicity.

Studies have reported that soil erosion is more unpredictable in tropical regions due to more intense and highly variable rainfall, as well as lesser organic matter in the soil (Kidd & Pimentel, 1992). In the Philippines, research on the integration of RUSLE and geographic information systems (GIS) for soil loss modeling has increased in recent years, in numerous locations such as Cagayan (Delgado & Canters, 2011), Marinduque (Salvacion, 2020), Bukidnon (Dapin & Ella, 2023), Aklan (Señeris et al., 2024), and Nueva Ecija (Alejo Jr. et al., 2024). Many regions, however, still lack soil erosion assessments and require further analysis to determine critical areas. This research aims to assess soil erosion in a tropical watershed located in Bangon and Binahaan River Basin using RUSLE and GIS. Since the soil erosion rate is spatially varying, the assessment aims to provide a soil loss map that determines the critical erosion hotspots for subbasin prioritization in the watershed. Additionally, the study results could provide a basis for the improvement of policies for national-scale planning and management, increasing awareness and knowledge of the risks of soil erosion in the country. This study could also support future research on how to improve the estimation of RUSLE factors in tropical countries like the Philippines.

2. METHODOLOGY

2.1 Study Site

The study site is the Bangon and Binahaan River Basins in Leyte, Philippines, with a total land area of 420.56 square kilometers. The watershed is primarily composed of crop fields, which serve as the main source of livelihood for local communities. The downstream areas of the watershed, located in the municipality of Palo, Leyte, are predominantly urbanized. The region experiences a Type IV Philippine climate with an average temperature ranging from 24°C to 32°C and an even distribution of precipitation with an annual average of 2,377 mm, commonly peaking in the months of December to January. Seasonal variations in rainfall, often driven by monsoons and tropical storms, can significantly impact soil erosion, water availability, and agricultural productivity in the selected site.

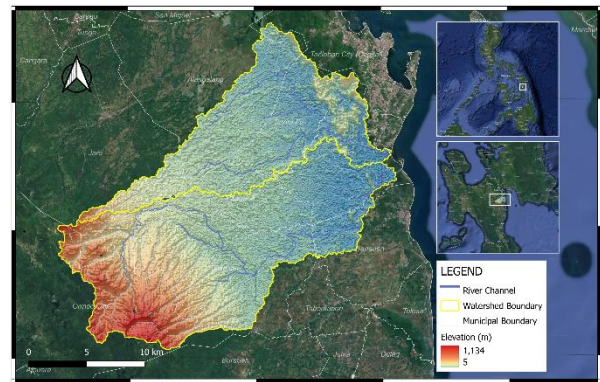


Fig. 1. Study Area

2.2 The Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) is an advanced and enhanced model of the USLE (Renard et al., 1997), which was originally developed by Wischmeier and Smith (1978). It is five-factor equation model that estimates the annual rate of soil erosion based on terrain, land cover, and meteorological conditions (Prasannakumar et al., 2012). Among the several models, RUSLE is the most frequently used model for estimating and predicting long-term rates of interrill and rill erosion in areas subjected to various management strategies. Its components are sub-factorized to allow greater

flexibility in calculating soil loss. The equation for the model as adopted from Renard et al. (1997) is shown in Equation 1.

$$A = R * K * LS * C * P \quad (\text{Eq. 1})$$

where:

- A = annual soil loss rate (t/ha/yr)
- R = rainfall erosivity factor (mj/ha mm/h)
- K = soil erodibility (k) factor
- LS = slope length and steepness factor
- C = land cover (c) factor
- P = support practice (p) factor

2.2.1 Rainfall Erosivity (R) Factor

Rainfall erosivity, or the R factor in the RUSLE equation, is the estimated measure of how rainfall could cause soil erosion. A large value would not necessarily indicate that the area is a high-risk region, although soil loss would be more likely if there are no conservation practices in the area (McGehee, et al., 2021). Rainfall data in the study was estimated from 2000-2023 was gathered from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). Since rainfall data is not homogenous and rain gauges are scattered throughout the site, the average rainfall data were interpolated to generate a representative rainfall distribution map. An equation of R-factor was provided by Dela Cruz et al., (2023) for a tropical catchment since existing R-factor equations vary depending on the climatic and geographical conditions and may not be suitable for different areas of interest. The R-factor equation adopted from Dela Cruz et al., (2023) is shown in Equation 2.

$$R = 0.1868 \times \text{Annual Rainfall Depth} \quad (\text{Eq. 2})$$

2.2.2 Soil Erodibility (K) factor

The soil erodibility (K) factor is a lumped parameter that estimates the annual value of soil reaction to the process of detachment and transport through raindrops and runoff and it represents the susceptibility of the soil to erode. K factor values in this study were adapted from the studies of David (1987) and Salvacion (2020) as shown in Table 2. This study used the soil map provided by FAO for the estimation of the K-factor.

Table 1. Soil erodibility (K) factor for each soil textural class (David, 1987)

Soil Texture	K Factor
Clay	0.26
Clay Loam	0.30
Loam	0.60
Sand	0.30
Sandy Loam	0.30
Silt Loam	0.60

2.2.3 Slope Length and Steepness (LS) Factor

The LS, C, and P factors are dimensionless units' representative of the topographic conditions, cover characteristics, and support practices of a given area, ratioed with soil loss values (Carollo, et al., 2024). The LS factor indicates the soil loss from the combined factors of topographic length and slope. This was based on the digital terrain model (DEM) with a resolution of 30m obtained from the USGS. The LS factor was calculated using the simplified equation in Equation 3 for three-dimensional terrain adopted from the studies of Moore and Wilson (1992) and Zhang et al., (2017).

$$LS = \left(\frac{A_s}{22.13} \right)^m \left(\frac{\sin(\theta)}{0.0896} \right)^n \quad (\text{Eq. 3})$$

where:

- A_s = flow accumulation x cell size, unit contributing area (UCA)
- θ = slope in radians
- m = 0.4 – 0.56
- n = 1.2 – 1.3

2.2.4 Land cover (C) factor and support practice (P) factor

The C is defined as the ratio between the soil loss with the land cover of an area, while the P factor is the ratio of soil loss under support practices that could impact the up and downhill tillage (Carollo, et al., 2024). Values for the two factors were based on the land cover map of Eastern Visayas (Region VIII), which was collected from the National Mapping and Resource Information Authority (NAMRIA) – GeoPortal Philippines (GeoPH). The land cover map was converted into C-factor map with values adapted from Sourn et al. (2022). The P-factor map, on the other

hand, was derived from the study of Delgado and Canters (2011) which further adapted by Salvacion (2020). These two factors refer to the influence of land cover and land management on the amount and rate of soil erosion.

Table 2. C factor and P Factor values for various land covers

LULC	C - factor (Sourn et al., 2022)	P - factor (Delgado & Canters, 2011)
Primary forest	0.001	0.03
Shrubs and grasslands	0.15	0.6
Built-up	0.2	1.0
Bare soil	1.0	0.6
Crops	0.3	0.1

2.3. Soil Loss Classification

In the Philippines, erosion rates with value of 10 tons per hectare per year were considered tolerable (PCARRD, 1991). This threshold limit was used as basis in several studies as the criteria to assess the soil sustainability in several studies conducted in the Philippines. Table 3 shows the criteria for soil loss criteria adopted in the study.

Table 3. Soil loss criteria

Soil Loss (t/ha/yr)	Description
< 2.5	Low
2.5 - 5.0	Slightly moderate
5.0 - 10.0	Moderate
10.0 - 25.0	High
25.0 <	Very High

3. RESULTS AND DISCUSSION

3.1 Watershed Delineation

The Bangon and Binahaan River Basins were delineated based on a DEM, with outlet points assigned at 11.1577814°N, 125.0074051°E for the Bangon RB, and at 11.142640°N, 125.011368°E for the Binahaan RB. Both outlet points are located in the downstream area of Palo, Leyte. The Bangon RB was subdivided into 8 sub-basins, covering a total area of 156.04 sq.km., while the Binahaan RB was delineated into 15 sub-basins with a total area of 264.52 sq.km.

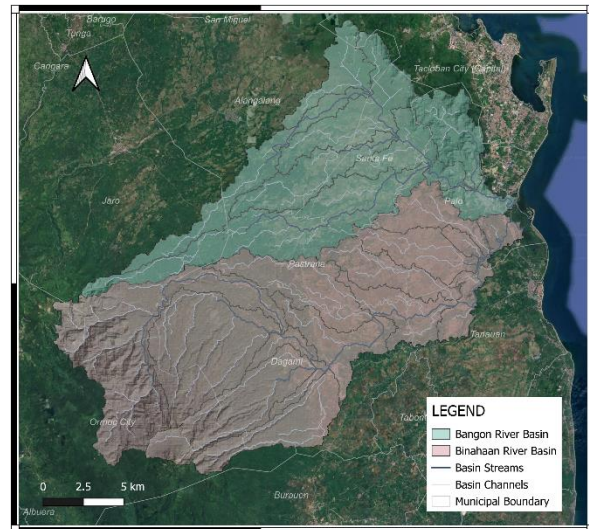


Fig. 2. Delineated Bangon and Binahaan River Basins

3.2. Estimation of RUSLE Parameters

The site's average annual rainfall from 2000 to 2023 is 2,911.95 mm. This value was estimated using Inverse Distance Weighting (IDW) interpolation based on data from three PAGASA weather stations located in Tacloban, Leyte (11.2256°, 125.0249°), Maasin, Leyte (10.1390°, 124.8604°), and Catbalogan, Western Samar (11.7750°, 124.8842°). The rainfall distribution map was then generated to estimate the erosivity (R) factor which is found to be ranging from 542.0 to 545.3 MJ/ha mm/hr. The highest R-factor is found to be at the northwest region while the lowest R-factor is found at the southern region of the watersheds

There are seven soil types identified in the Bangon RB with Guimbalaon Clay covering the largest area at 67.48% of the watershed. While in the Binahaan RB, eight soil types were identified, with Rough Mt. Land Soil dominating the watershed at 34.14% of the area. The soil erodibility (K) factor values in both watersheds range from 0.26 to 0.60 t·hr/(MJ·mm).

The Length-Slope (LS) factor values are found to be higher in the northeast region of Bangon River, due to the high terrain elevations in the Palo, Leyte. LS factor values in the Binahaan RB are found to be

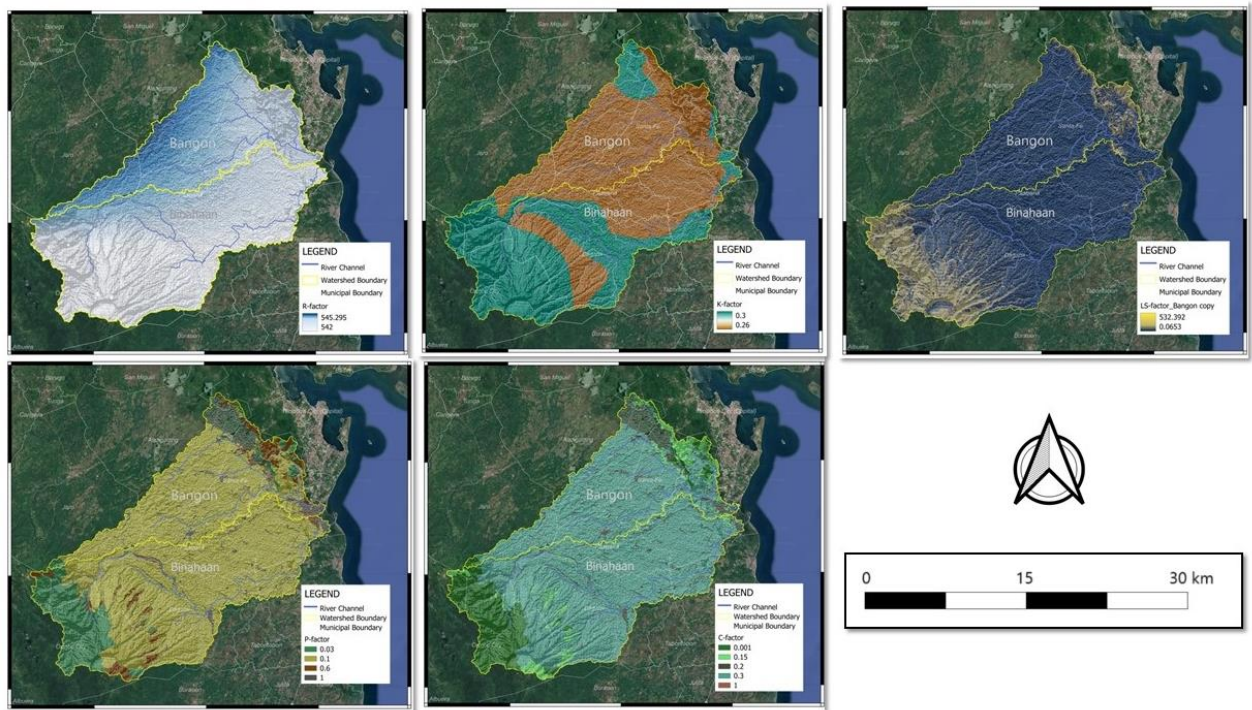


Fig. 3. RUSLE factor maps: (a) R factor, (b) K factor, (c) LS factor, (d) C factor, and (e) P factor

higher at its southwest region, due to the mountainous areas of Ormoc City. The mean and standard deviation (SD) of the LS factor for the Bangon RB are 3.502 and 10.072, respectively, whereas the values for the Binahaan RB are 11.710 and 25.892. The larger SD particularly in Binahaan RB suggests a wide variation in slope length and steepness within the watershed which implies diverse terrain conditions and potential uneven erosion risks across the region.

The cover-management (C) factor represents the ratio of soil loss from an area with a specified type of cover to that from a bare soil under identical conditions. In both watersheds, C factor values range from 0.001 to 0.3, with the value of 0.3, which primarily associated with annual crop fields covering the most of the study area. The mean and SD of the C factor for the Bangon River Basin are 0.272 and 0.113, respectively, while those for the Binahaan RB are 0.241 and 0.069. The higher SD suggests more spatial variability in land cover conditions across the Bangon RB compared to

the Binahaan RB, where values are more consistent and less uniform.

The results show P factor values ranging from 0.03 to 1.0, with a value of 0.10 covering the most of the study area. This large amount of area accounts for the agricultural crop lands. Higher P factor values are located in the lower downstream area of the site in both watersheds. This corresponds to built-up land uses and uncultivated lands in the Palo, Leyte, indicating greater runoff. The mean and SD of the P-factor for the Bangon RB are 0.181 and 0.233, respectively, while those for the Binahaan RB are 0.129 and 0.171. The higher SD indicates greater variability in the effectiveness of land cover to soil erosion.

3.3. Soil Loss

This study reveals that a total of 5 subbasins in the Bangon RB, which accounts for 38.91% of the catchment is experiencing soil erosion beyond tolerable amounts ($10 \text{ t/ha/yr} <$). Similarly, a total of 5

subbasins also in Binahaan RB, which accounts for 57.93% of the catchment is experiencing soil erosion exceeding the tolerable threshold. Sub-basins with significantly high soil erosion in the Bangon RB are located in the northeastern region, attributed to the steep mountainous terrain extending from Palo. In contrast, the southwestern region of the Binahaan RB exhibits high soil erosion, which primarily due to the mountainous areas extending from Ormoc City. These specific regions are characterized with the highest slope length and steepness (LS) factor values, which is one of the most influential factors in soil erosion (Chuenchum et al., 2019). Runoff occurring on these slopes generates greater kinetic energy, which enhances erosive and transport power and leads to intensified soil loss (Ni et al., 2021).

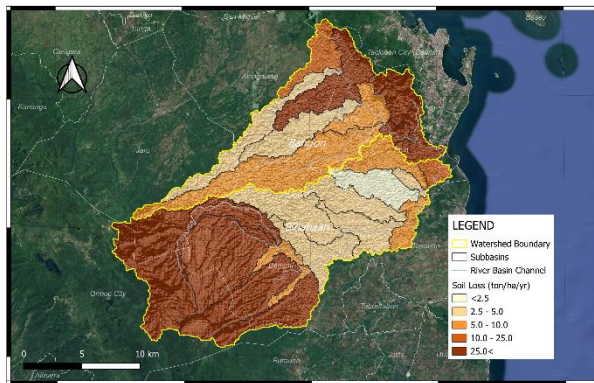


Fig. 4. Soil Erosion Map of the Bangon and Binahaan Watershed

Table 4. Soil Loss Classification and Distribution by Sub-Basin for Bangon RB

Soil Loss (t/ha/yr)	Description	No. of subbasins	area (ha)	Allocation
< 2.5	Low	0	0	0
2.5 - 5.0	Slightly moderate	2	3.767	23.81%
5.0 - 10.0	Moderate	2	5.898	37.28%
10.0 - 25.0	High	1	1.238	7.83%
25.0 <	Very High	4	4.916	31.08%

Table 5. Soil Loss Classification and Distribution by Sub-Basin for Binahaan RB

Soil Loss (t/ha/yr)	Description	No. of subbasins	area (ha)	Allocation
< 2.5	Low	1	1.468	5.57%
2.5 - 5.0	Slightly moderate	5	6.953	26.39%
5.0 - 10.0	Moderate	4	2.663	10.11%
10.0 - 25.0	High	1	0.441	1.67%
25.0 <	Very High	4	14.821	56.25%

It must be noted that critical subbasins are predominantly composed croplands upstream. Soil material eroded from the upstream may be deposited in flat and depressional areas which in this case are the built-up area of Palo, Leyte where the outlets of Bangon and Binahaan River are located. Soil erosion may damage croplands on which it occurs and traverses, and may affect water quality as it reaches the rivers. As it clearly suggests the need for sediment control measures (SCM), it is validated by the prior study of Garbanzos et al., (2024) at the site of Palo, Leyte revealing that the absence of SCM has led to a significant accumulation of road-deposited sediments (RDS), contributing to diffuse pollution in the stream. Their multi-criteria decision analysis (MCDA) has favored prioritizing the downstream areas. However, it is further discussed that studies on the upstream management have demonstrated more effective control measures, lessening the impacts on downstream subbasins. Thus, suggesting the need for a deeper understanding about the potential effects of management in both upstream and downstream areas.

The downstream region of Bangon River passes through the critical subbasins, making it vulnerable to sediment-related impacts. A study by JICA (2017) characterized the Bangon River based on its topological conditions, revealing that it is situated in an alluvial area in the upper to middle reaches with steep slopes, while the lower reaches consist of lowland, swampy, and residential areas, where the river channel meanders. The similar study reported that flooding occurs downstream due to low discharge capacity of meandered channels. This clearly indicates that the region is prone to erosion, which reduces the capacity of river channels due to sediment accumulation. To address the problem, dredging

operations along the Bangon River, along with the other rivers in Leyte are implemented as an intervention to mitigate flooding during wet season (DPWH, 2023).

On the other hand, a study by Naputo et. al. (2023) reveals that Binahaan River is prone to accretion due to soil loss which causes the narrowing of channel widths and decreasing of channel areas. This decrease in the river capacity revealed that Bangon River traversing Palo Leyte is prone to flooding and was identified to encounter flood levels of 0.20m to 2.0< m across the municipality.

5. CONCLUSION

This study maps out critically erosive areas in the Bangon and Binahaan river basins using RUSLE and GIS, showing that around 31% of the Bangon RB and 56% of the Binahaan RB could be erosive, based on river, elevation, urbanization, and soil data. The results indicate that upstream and downstream regions have soil erosion risks, which could lead to increased risks from accumulated sediment buildup in rivers and streams. Likewise, in more elevated areas, landslides could be an issue. Modeling practices like RUSLE and GIS could help pinpoint critical areas where mitigation measures can be placed in advance. This study promotes sediment-related research in the Philippines to protect the surrounding environment and ecosystem and to prevent the issues brought upon by uncontrolled sediment buildup.

5. ACKNOWLEDGMENTS

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