Assessment of soil erosion risk within the Maasin Watershed Forest Reserve, Iloilo, Philippines using the Revised Universal Soil Loss Equation (RUSLE) and Geographical Information System (GIS)

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Abstract

Soil erosion is the leading cause of watershed degradation. It affects the Maasin Watershed Forest Reserve (MWFR), the main source of domestic water to Iloilo, as evidenced by reports of sedimentation that degrade the water supply of receiving communities. Hence, this study aims to assess the soil erosion risk within the MWFR using the Revised Universal Soil Loss Equation (RUSLE) and Geographical Information System (GIS) data. Geospatial data were processed to calculate the RUSLE factors using ArcGIS. The soil loss rates were determined by multiplying the factors, and were classified into erosion risk classes whose area covered was also measured. It was estimated that the erosion rate in the watershed is 40.7 tons/ha/yr. High to very severe soil erosion risks occur in 63.6% of the MWFR which accounts for the watershed degradation The erosion map can be used in monitoring the soil erosion within the MWFR.

Introduction. - Soil erosion is one of the primary causes of land degradation around the world [1]. It is generally defined as the deterioration of the topsoil by physical forces such as rainfall, flowing water, ice, wind, gravity, or other natural agents that deposit soil elsewhere [2]. Among these factors, high erosive rainfall and consequent runoff due to slope steepness play a role in the displacement of the fertile topsoil [3]. The Philippines is highly susceptible to this problem with its steep topography, deforested uplands, and heavy rainfall events [4]. It is one of the country's most pressing environmental issues and it has gravely threatened the sustainability of agricultural systems [5]. Watersheds sustain these systems by serving as a water source that farmlands receive in the form of irrigation [6]; however, soil erosion in watersheds has also become a widespread phenomenon [7].

Soil erosion causes significant changes in the water quality of watersheds [8]. It affects the hydrological cycle of watersheds through soil compaction, overground vegetation change, evapotranspiration change, infiltration change, and water holding capacity [9]. In addition, the continuous removal of the topsoil has led to soil degradation evidenced by the increasing sediment loads in rivers and water reservoirs [10]. Soil monitoring through mapping of soil erosion-prone areas has been identified to be an essential part of planning for dealing with environmental and natural resource management [11,12]. Through this, different model-based methods have been developed for soil erosion assessment. One of the most widely accepted empirical models for estimating soil erosion rate is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith [13] due to its relative simplicity and standardized approach; however, an improved version of this has been developed, the Revised Universal Soil Loss Equation (RUSLE). The RUSLE [14] was developed due to the added availability of data and resources with a deeper understanding of the erosion process since the publication of USLE. It retains the equation of its predecessor with modifications in several of its factors. The factors of RUSLE are rainfall erosivity (R), soil length and steepness (LS), soil erodibility (K), cover management (C), and conservation practice (P).

Previous studies have been conducted to map soil erosion with the use of RUSLE and GIS. The studies of Belayneh et al. [1] and Da Cunha et al. [15] both used RUSLE and GIS techniques to estimate the soil loss due to water erosion in the Gumara Watershed in Ethiopia and the watershed stream Indaia in Brazil, respectively. They were able to identify areas within the watersheds that had the highest risk of soil erosion making these areas possible priorities for soil erosion prevention programs. Mapping soil erosion-prone areas through RUSLE and GIS is an efficient way to help the local governments monitor and prevent watershed

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degradation [7,16].

The Maasin Watershed Forest Reserve (MWFR) is the main supplier of domestic water to Iloilo City and adjacent municipalities, as well as irrigation to agricultural lands within Central Iloilo, therefore it is urgent to address problems caused by soil erosion within the watershed such as siltation which may affect the water supply of the receiving communities. However, no published studies have been done to assess the soil erosion-prone areas within the MWFR even with its location, being at high risk for soil erosion [17].

With this, the research aimed to identify soil erosion risk areas within the MWFR using RUSLE and GIS. It specifically aimed to:

(i) collect data on the RUSLE factors of rainfall erosivity (R), soil slope and length (LS), soil erodibility (K), cover management (C), and conservation practice (P) within the MWFR;

(ii) estimate the annual soil erosion rate within the MWFR using the RUSLE based on available GIS data from 2010–2020; and

(iii) assess the spatial distribution of soil erosion risk areas within the MWFR using the estimated annual soil erosion rates.

Methods. - The data gathering procedure was divided into four parts: (1) collection of geospatial data for the RUSLE factors from online sources from 2010–2020, (2) calculation of the RUSLE factors by processing the geospatial data, (3) calculation of the soil erosion rates and, (4) classification of soil erosion rates into erosion risk classes and assessment of its spatial distribution.

Study Area. The site studied was the Maasin Watershed Forest Reserve (MWFR) which is found in an aggregate of two critical watersheds found in Iloilo, the Tigum-Aganan Watershed, and is located within the municipalities of Maasin, Alimodian, and Janiuay, Iloilo. The MWFR is found at the UTM coordinates from 422,690 m to 435,800 m East and 1,203,730 m to 1,214,480 m North with an area of 6,539.352 ha.

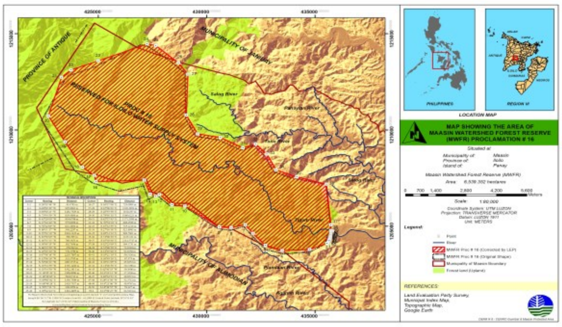

Figure 1. Boundary of MWFR from City Environment and Natural Resources Office (CENRO) Region 6.

Geospatial Data Collection. The data for the mean monthly rainfall were collected from WorldClim, an online database. The Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) for the Philippines was downloaded from the United States Geological Survey (USGS) database. The soil type map and boundary shapefile of MWFR were obtained from CENRO Region 6. The 2010 land cover map from the PhilGIS website was also downloaded. The files were then clipped in ArcGIS, version 10.4 to focus on the MWFR. To ensure uniformity, all the raster layers were ensured to have pixel sizes of 30 m by 30 m through resampling by bilinear interpolation and were aligned with each other with the on-the-fly projection of ArcGIS.

Calculation of RUSLE Factors. For the R factor, the mean annual precipitation was first calculated by adding the raster layers for the mean monthly precipitation in the raster calculator before being clipped and resampled. The R factor was then calculated following the model by El-Swaify et al. [18] where P is the mean annual precipitation in mm and the R factor is measured in MJ·mm·(ha·h·year)$^{-}$.

$$R = 38.5 + 0.35\,P$$

Equation 1. Formula for the R factor.

For the LS factor, the model by Moore and Burch [19] was followed. The clipped SRTM DEM raster layer was processed to calculate the flow direction, flow accumulation, and slope in degrees which were required as inputs for the model.

Table 1. Representative values of soil erodibility (K) for various Philippine Soils (David 1988).

Soil Texture	K Value
Clay loam	0.30
Clay	0.26

For the K, C, and P factors, the categories within the soil type map and land cover map were assigned corresponding K, C, and P values obtained from previous studies. The K values taken from the study of David [20], shown in Table 1 above, were assigned to each soil type present. The C values assigned to the different land cover categories were based on the study of David [20] in Table 2 while the P values were based on the study of David [20] and Delgado and Canters [21].

Table 2. Estimated crop cover coefficient or C values for the common cover conditions of Philippine watersheds [18].

Land Cover	C Value
Bare soil	1.0
Primary forest with dense undergrowth	0.001
Second growth forest with good undergrowth and mulch cover	0.006
Perennial crops	0.1–0.3
Grassland, moderately grazed, burned occasionally	0.2–0.4
Shrubs with open, disturbed grassland	0.15
Built-up	1.00
Inland water	0.00

Calculation of Soil Erosion Rates. The soil loss empirical model RUSLE is shown by Equation 1 below with A being the average soil loss per unit area measured in ton ha^{-1} yr^{-1} and the rainfall erosivity (R), slope length and steepness (LS), soil erodibility (K), land cover (C) and conservation practice (P) factors being the key parameters of the model. ArcGIS was used to multiply all the raster layers of the RUSLE factors to obtain a single raster file where the rates of soil loss within MWFR were shown.

$$A = R \, x \, LS \, x \, K \, x \, C \, x \, P$$

Equation 2. Formula for the RUSLE model.

Erosion Risk Classification and Spatial Distribution. The soil erosion rates were classified into low to very severe erosion risk classes following the classification from the study of Singh et al. [22] as reported by Salvacion [23] as shown in Table 3.

Table 3. Classification of soil erosion rates into classes of soil erosion risk.

Soil erosion rates (ton ha^{-1} yr^{-1})	Erosion risk class
0 – 5	Low
5 – 10	Moderate
10 – 20	High
20 – 40	Very high
40 – 80	Severe
> 80	Very severe

To find the area covered by each erosion risk class, the raster layer of the soil erosion rates was first digitized into a vector layer. Polygons belonging to the same risk class were merged and their area covered in sq. km. was then determined using the field calculator feature in ArcGIS which calculates the polygon areas for each soil erosion class. The percentage of the area covered by each class was also calculated following Equation 3 below.

$$\% \text{ area covered} = \frac{area\ of\ soil\ erosion\ risk\ class}{land\ area\ of\ MWFR}$$

Equation 3. Formula for percentage of area covered by soil erosion risk class.

Results and Discussion. - The collected geospatial data were used to determine the RUSLE factors needed in calculating for the soil erosion rates within the boundary of the MWFR. The raster layers containing pixel values embedded and assigned for all the RUSLE factors were multiplied to generate the estimated soil erosion rates. These rates were then used to determine the erosion risk classes and their spatial distribution within the watershed.

RUSLE Factors. For the R factor, the annual rainfall data had values which ranged from 2,265–3,088 millimeters within the MWFR. Using the model by El-Swaify et al. [18], it was found that the R factor had values ranging from 831.25–1,119.3 MJ·mm·(ha·h·year)$^{-1}$. The R factor within the MWFR generally increases from the south to the north of the watershed. Higher rainfall erosivity, which is due to higher annual rainfall, was observed in the mid or mountainous portion of the watershed as seen on Figure 2.

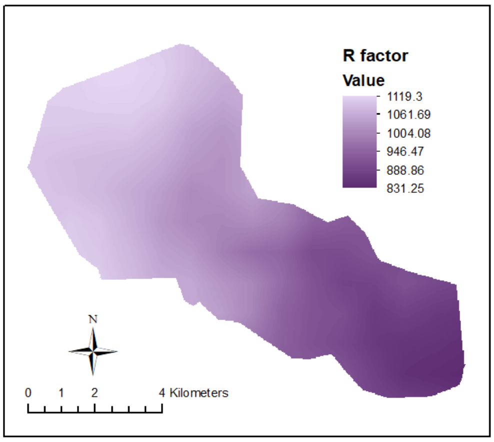

Figure 2. Rainfall erosivity (R) factor for the MWFR.

For the LS factor, the DEM file was found to have values ranging from 97–1,583 m above sea level. Following Moore and Burch [19], the calculated LS factors were found to range from 0–38.4307 with a mean of 1.04 as seen in Figure 3. The highest LS values were found in areas near the river, especially in the northwestern region of the MWFR where the elevation is relatively higher than the southeastern region of the MWFR.

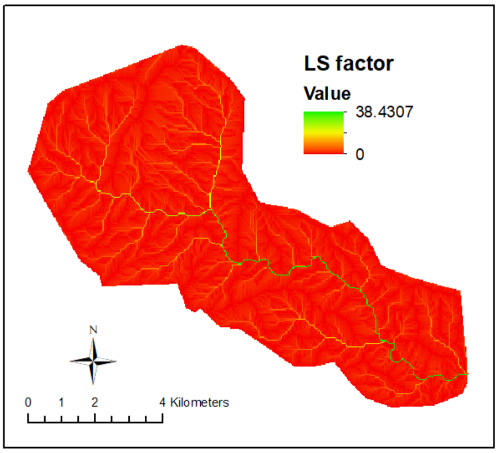

Figure 3. Slope length and steepness (LS) factor for the MWFR.

The soil types present in the MWFR were identified to be the following: Alimodian clay loam, Alimodian soil, Umingan clay, and Mountain soil as seen in Figure 4. Undifferentiated soil types such as those of Alimodian and Mountain soil were also classified as clay loam. The values assigned were 0.3 for the clay loam and undifferentiated soil, and 0.26 for clay. In terms of soil textural class, the watershed is highly dominated by clay loam as seen in Figure 5.

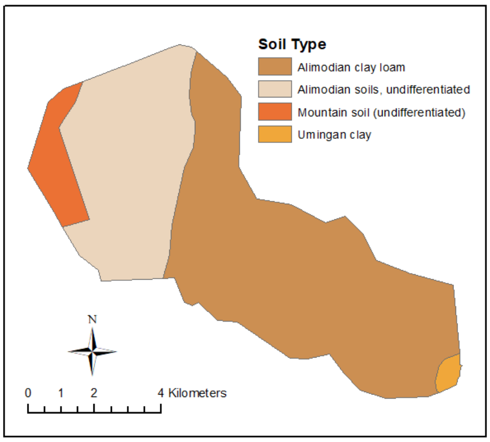

Figure 4. Soil types within the MWFR.

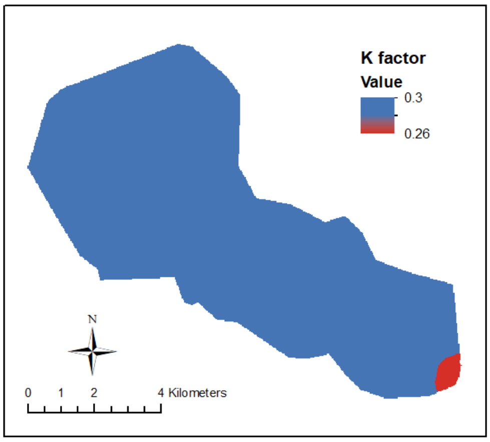

Figure 5. Soil erodibility (K) factor within the MWFR.

The C factor values were assigned to each of the land cover categories. The vegetation cover found within the MWFR are of the following: annual crop, built-up, closed forest, inland water, mangrove forest, open forest, open or barren, perennial crop, shrubs, and wooded grassland as seen in Figure 6. The values assigned ranged from 0–1 based on Table 2. Based on the acquired land cover map, the northern areas and some areas at the south of the watershed are occupied by open forests which have a very low C value of 0.001, thus its presence can greatly reduce the soil erosion rates within these areas.

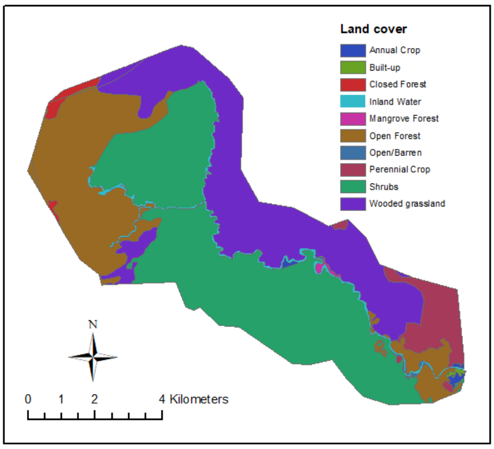

Figure 6. Land cover within the MWFR.

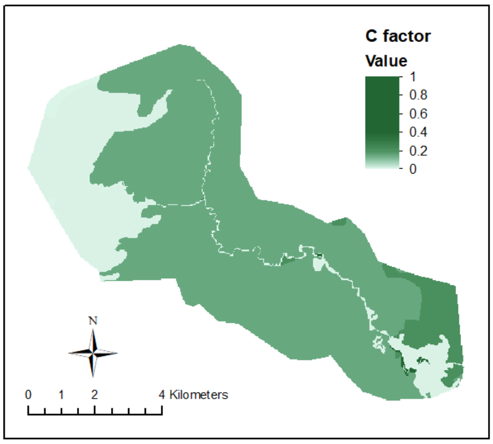

Figure 7. Land cover management (C) factor for the MWFR.

Due to the lack of information and data on the conservation practices within the MWFR, the P factor values were set to 1 for the land cover categories with the exception of the areas classified as inland water, which along with the C factor, were assigned the value 0.

Soil Erosion Rates. The estimated soil loss rates found within the MWFR ranged from 0–9,406.37 tons/ha/yr with a mean of 40.74 tons/ha/yr. After classifying the soil erosion rates, it was observed that all the erosion risk classes were present within the boundary of the MWFR as reflected in Figure 8. This data coincides with the raw geospatial data of each RUSLE factor multiplied to yield the soil erosion rates. Low erosion rates in the boundary of MWFR were mainly due to the presence of forests as based on its land cover map. According to the study of Gharibreza et al. [24], the absence of forests in the land cover management of catchments or watersheds hastens land degradation. Meanwhile, high to very severe soil loss rates were mostly found in mountain sides and around rivers where the slope is long and steep.

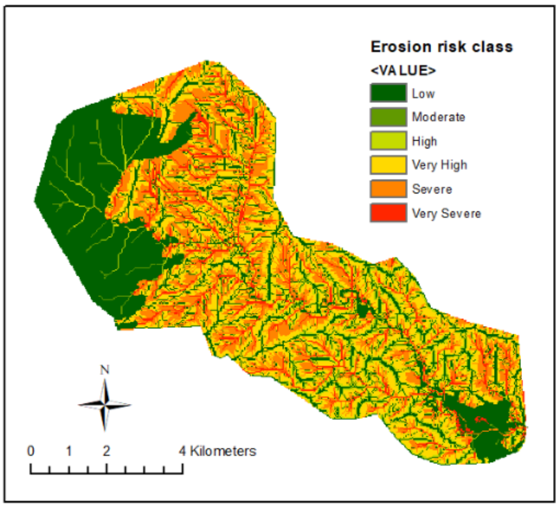

Figure 8. Soil erosion rates and classes within the MWFR.

Spatial Distribution of Erosion Risk Classes. The area covered by each erosion risk classification was also determined. Using the area of the MWFR which is 65.39 sq. km., the percentage of the area covered by each erosion risk class was found to be 35.49% for low risk, 0.50% for moderate risk, 4.80% for high risk, 31.43% for very high risk; 20.38% for severe risk; and 6.99% for very severe risk. The remaining 0.42% were the areas set to zero which are areas classified as inland water such as the river.

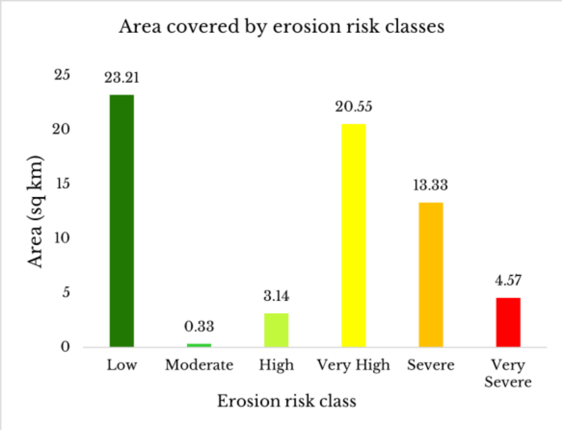

Figure 9. Area covered by each soil erosion risk class in sq. km.

It was found that the majority of the area within the boundary of the MWFR is at low risk of erosion with 35.49%; however, soil erosion is still imminent with the combined areas having high to very severe erosion risk composing 63.60% of the MWFR as shown in the graph in Figure 9. The mean soil erosion rate for the MWFR also falls under the severe erosion risk class which means that the MWFR generally experiences severe soil erosion. The severity of the soil erosion within the MWFR coincides with the information about its location according to recent hazard assessment reports and studies. The MWFR is found within an aggregate of two critical watersheds, the Tigum-Aganan watersheds. The presence of MWFR in these two critical watersheds explains the prevalence of soil erosion within the MWFR. Additionally, findings of a study by Bito-onon [17] identified the municipality of Maasin as having a very high hazard index when it comes to typhoons, floods, and soil erosion, while Alimodian and Janiuay, have high and moderate hazard indices, respectively. The high hazard index to soil erosion of Maasin, the location of the MWFR, supports the presence of severe soil erosion risk within the watershed.

Limitations. The study used the most recently updated data available from different online sources and databases, and government agencies, and coming from different years between 2010–2020. The researchers mainly relied on information that is available online. Furthermore, the soil erosion rates are only estimations which rely on the available data online without any on-site inspection of the MWFR due to the COVID-19 pandemic. Moreover, due to the absence of any recorded data on the conservation practices of the watershed, the values assigned for the P factor were only based on the C factor. Another limitation is the use of RUSLE which only accounts for soil loss through sheet and rill erosion, while ignoring the possibility of gully erosion and dispersive soils in a certain area. There is also no accounting for the deposition of sediment before reaching a waterway; hence, RUSLE is only a predictor of erosion for topsoils [25].

Conclusion. - This study demonstrates the utilization of RUSLE with GIS to model soil erosion rates within the MWFR. The MWFR was found to have a mean soil erosion rate of 40.74 tons/ha/yr, which generally classifies the MWFR as having severe soil erosion risk. Based on the soil erosion map and the spatial distribution for the erosion risk classes, 63.6% of the MWFR was found to be at high to very severe risk of soil erosion and this may account to the degradation of the watershed. The results emphasize the urgent need to address the soil erosion in the watershed. The geological location of Maasin may contribute to the watershed degradation since the municipality has a high hazard index making it susceptible to natural disasters. Although the erosion rates are estimations, this soil erosion map can help the local government get a gist of priority areas in monitoring the soil degradation of the MWFR to prevent its adverse effects on the ecosystem and water quality. It can also show what causes the soil erosion in the area and provide visualization as to which parts of the MWFR may have high to very severe cases of erosion. With this, the government can be guided in preventing and addressing any rising problems within the watershed.

Recommendations. - For further studies involving the soil erosion rates within the MWFR, an on-site inspection may be conducted for the cross-referencing of the estimated soil erosion rates generated from the use of RUSLE and GIS data. A survey with the locals may also be conducted to verify the data for the RUSLE factors and identify the areas that experience severe soil erosion. This is to take note of essential information on the factors of soil erosion within the watershed which are not available online such as the conservation practices. Other sources of GIS data aside from those mentioned in the study may also be used. The application of the RUSLE model with readily available GIS data should be utilized more in monitoring the occurrence of soil erosion in critical watersheds in the country. Using the same methodology, comparisons may also be made between the soil erosion rates within the MWFR and other critical watersheds.

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