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Using Rose' and Manning's Equations to Spatially Quantify Soil Erosion in Lagawe River Sub-Watershed, Ifugao, Philippines

ABSTRACT

A dynamic, physical model was created to predict soil erosion of Lagawe River Sub-watershed, a sub-watershed of Magat River Watershed, Philippines. Tipping-bucket rain gauge was installed to gather event-based rainfall data and a water-level recorder was installed on a straight segment of Lagawe River to gather water depth. Sediment samples were taken during rainstorm events and were used to calibrate the model. Manning's equation was used to calculate surface runoff and stream flow velocity. Rose' and Freebairn's Equation was used to calculate sediment mass. Geographic Information System was utilized as a tool for modelling using PCRaster Software. The model estimated a total of 57,905,000 m^3 of eroded sediments which was generated during Typhoon Koppu (local name, Lando) in year 2015. A Welch Two Sample t-value of -0.25 and a p-value of 0.81 was achieved on the statistical analysis between the measured sediment yield and the output of the model. Since the p-value is greater than 0.05 (5%), there is no significant difference between the output of the physical dynamic model and the measured value for sediment yield. Likewise, the correlation analysis supports this conclusion with a linearly positive R^2 value of 0.74.

Keywords: *PCRaster, GIS, remote sensing, Lagawe, Ifugao, sediment*

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INTRODUCTION

Soil degradation due to soil erosion results to hunger and poverty. Soil erosion adversely hinders the growth of plants, agricultural yields, quality of water, and recreation (*Issaka and Ashraf 2017*). The *Millennium Ecosystems Assessment Board* (*2003*) identified soil erosion as one of the important issues in nutrient cycling. The *Soil Science Society of America* (*2020*) defines soil erosion as the wearing away of the land surface by rain or irrigation water, or other natural or anthropogenic agents that abrade, detach and remove geologic parent material or soil from one point on the earth's surface and deposit it elsewhere.

Soil erosion is one of the key processes underlying land degradation and desertification. Erosion affects nutrient cycling and reduces the fertility of the soil through a reduction in the pool of available nutrients. Soil erosion thins the soil solum (topsoil), which reduces the soil's ability to hold nutrients and water, making the soil unproductive in the long run. An eroded soil loses its capacity to store nutrients and water needed to sustain plant growth. Such a condition leads to a perpetual cycle of crop failure, hunger, and eventually poverty. Research reveals strong links between economic status and soil quality (*Barrett and Bevis 2015*).

With the threat of climate change, the occurrence of soil erosion is expected to increase in frequency and in magnitude. A close link between climate change and soil erosion and many studies suggest that rainfall is the most direct influencing factor (*Li and Fang 2016*). Rainfall impacts the soil causing soil particles to get dislodged from their aggregated state. Steep slopes increase surface runoff velocity and scouring power. Increasing slopes and annual precipitation increases soil erosion rates (*García-Ruiz et al. 2016*). Sheet erosion rate was found to be more sensitive to rainfall intensity than to slope gradient (*Wu et al. 2017*).

In a tropical watershed, factors that enhance soil erosion are present: steep slopes and high rainfall erosivity, exacerbated by anthropogenic activities. Soil erosion must be minimized for a watershed to continuously provide ecosystem services to the community. The amount of eroded soil and runoff is a function of human activities, land use, and the amount of rainfall. Human activity and related land use change are the primary cause of accelerated soil erosion (*Borrelli et al. 2017*). The anthropogenic disturbance of the soil and landscape is inevitable with increasing population, which puts pressure on soil resources resulting to an increase in the occurrence and severity of soil erosion.

Labrière et al. (*2015*) made a systematic quantitative review of soil erosion research made in the humid tropics. Soil erosion appears more concentrated in space and time in the humid tropics than elsewhere. Magat Watershed, being situated in the tropical Philippines, where an active interplay between climate and multiple land uses, had been the subject of numerous researches related to land use and soil erosion. *Latap* (*2014*), used the Universal Soil Loss Equation (USLE) and estimated that a continuous, silvipastoral system in the Magat Watershed resulted to a higher soil erosion rate of 128,700 kg ha^{-1} yr^{-1}, as compared with lower erosion rate of 40,680 kg ha^{-1} yr^{-1} for the continuous, regular/conventional grazing farms. A soil erosion index using GIS to determine soil erosion potential generated a score of 1.68 for Magat Watershed, with a recommendation of utilizing only 41% of the watershed's land area for agriculture and the remaining 58% for strict protection (*Combalicer 2000*).

Remote sensing (RS) and GIS techniques have been used by researchers to study land use, streamflow, and soil erosion of Magat Watershed. *Sarmiento et al.* (*2012*) utilized RS techniques to study the inflow and outflow of water in Magat Reservoir. *Tattao* (*2010*) utilized RS and GIS to analyze land cover and perform soil erosion modelling. A multi-temporal land cover/land use change study of the Upper Magat Watershed listed the following factors affecting land use change: climatic conditions; human activities through agriculture, deforestation, and reforestation; and natural disasters like earthquakes that promote soil erosion (*Bato 2000*).

Massive erosion occurred in the Magat Watershed as caused by landslides that occurred during the 1990 earthquake (*Ortiz 2006, as cited in Tattao 2010*). The earthquake, which struck the island of Luzon with a magnitude of 7.7, resulted to numerous mass movements in Ifugao Province and its vicinity. Mass movement or mass wasting is defined as the gravity-driven movement of regolith down a slope (*Millar 2013*). The mass movement of soil and rocks resulted to the increase in the volume of sediments entering the Magat Reservoir from 7,400,000 m3 to 213,000,000 m^3 from 1982 to 2000. However, there was a sudden decrease in the volume of sediments entering Magat Reservoir from 21,700,000 m^3 in 1995 to 6,700,000 m^3 in 2000 (*Elazegui and Combalicer 2004*). This decrease in the amount of sediment volume, to a value close to that of the sediment volume prior to the 1990 earthquake, only means that the slopes and soils have already stabilized.

The unabated occurrence of soil erosion due to anthropogenic activities or natural calamities warrant the continued study of soil erosion in Magat Watershed. Quantifying soil erosion on-site is exceptionally challenging considering the complex interplay of physical, topographic, geological, hydrologic, and soil processes and characteristics (*Sobral et al. 2015*). At a watershed scale, the different land uses adds complexity to the process of determining soil erosion rates. Tools to help determine the effects of land use on soil erosion are needed for decision makers to properly manage watershed resources and address current soil erosion problems. Soil erosion models are such tools, but soil erosion models developed in temperate regions should not be directly applied in the humid tropics, like Magat Watershed, where different climatic and land use conditions exists. A more appropriate erosion model to be used for erosion research in a tropical setting like the Philippines should be based on the prevailing local conditions. Physical concepts and laws that govern the movement of matter (water and sediments) and energy (fluxes) should be utilized in the model as these are universal and not location specific. If these physical concepts and laws are taken into consideration in the modelling process, they will serve as a solid theoretical foundation for a functional erosion model. To estimate soil erosion and to establish soil erosion management plans, computer models are needed, employing RS and GIS techniques (*Devatha et al. 2015*).

The objective of this study was to build a dynamic, physical model that can predict soil erosion during rainstorm events using GIS, remote sensing, and environmental sensing technologies. The governing equations for this model includes Manning's Equation for streamflow simulation and Rose' and Freebairn's Equation for sediment concentration.

MATERIALS AND METHODS

Study Area

The Lagawe River Sub-watershed, located in Ifugao Province, Philippines is a sub-watershed of Magat River Watershed within the geographic extents of 121°3'E-121°11'E Longitude and 16°48'N–16°54'N Latitude (**Figure 1**). The sub-watershed has an approximate area of 7,392 ha and is classified as a small watershed by the Forest Management Bureau (*Forest Management Bureau n.d.*). Lagawe River Sub-watershed site falls within the Municipal Boundaries of Lagawe, Hingyon, and Banaue of Ifugao Province.

Rainfall and Water-level Data

Event-based rainfall data were gathered by installing a tipping-bucket rain gauge. Every tip of the bucket in the rain gauge, equivalent to 0.22 mm of rainfall, is recorded on the data logger, together with the date and time stamp. The rain gauge is located at 121°5' 56.46" E Longitude, 16°51' 8.66" N Latitude. A water-level recorder was also installed on a straight section of the lower segment of Lagawe River. The water-level recorder is located at 121° 8' 0.00" E Longitude, 16° 48' 32.03" N Latitude. Both instruments (tipping-bucket rain gauge and water-level recorder) recorded data at a ten-minute interval. A computer program was created to synchronize the time step of the rainfall data and water-level data, a procedure required by the model. Data gathering started April 4, 2015 and ended December 17, 2015.

Water and Sediment Sampling

Water samples were taken at the center of the river during perceived erosive rainfall events. Sampling was done by collecting water using a pail, tied to a rope, and tossing the pail onto the center of the river. A 350 mL plastic bottle was filled with water sample from the bucket. Sample bottles were labeled with the date and time of sampling. The water samples were brought to the University of the Philippines Los Baños Soil Physics Laboratory for oven-drying and determination of dry mass of soil solids. Sediment concentration of the water samples were used to calculate the amount of sediment lost in rainstorm events (**Table 1**).

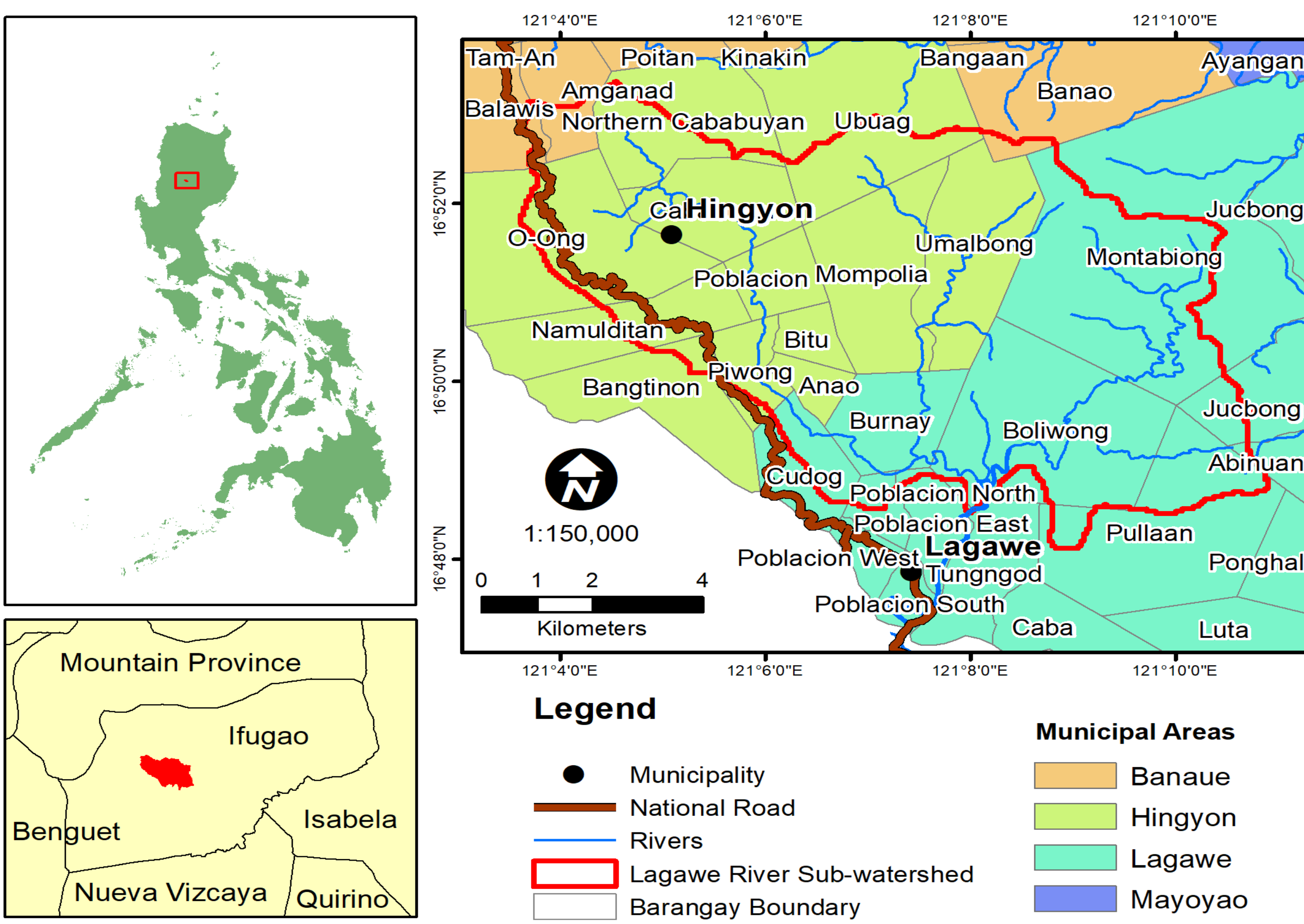

Figure 1. Location of Lagawe River Sub-watershed, Ifugao Province, Philippines.

Table 1. Sediment concentration and sampling date and time of water samples gathered from Lagawe River during rainstorm events.

Sample Number	Sample Date	Sample Time	Sediment Concentration ($g\ L^{-1}$)
1	12-May-15	6:33 pm	2.43
2	12-May-15	7:03 pm	2.83
3	12-May-15	8:00 pm	1.86
4	May 29, 2015	5:00 pm	0.40
5	May 29, 2015	5:37 pm	1.31
6	May 30, 2015	5:37 pm	0.84
7	August 18, 2015	5:20 pm	3.5
8	August 18, 2015	5:50 pm	3.64
9	August 18, 2015	8:20 pm	0.99
10	August 31, 2015	3:49 pm	0.92
11	September 10, 2015	5:20 pm	0.09
12	September 10, 2015	6:15 pm	0.61
13	October 2, 2015	11:25 am	0.16
14	December 16, 2015	2:05 pm	0.25
15	December 16, 2015	2:26 pm	0.25

Spatial Data Processing and Modelling

Digital elevation model (DEM) is needed for computing the LDD (local drainage direction) and slope maps. The DEM (**Figure 2**) used was the ASTERGDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) data which was downloaded from https://asterweb.jpl.nasa.gov/gdem.asp. The slope and LDD maps were calculated from the DEM using the pcrcalc.exe module. The LDD (**Figure 3**) map was needed by the model in order to route materials (surface runoff and sediments). Material movement followed the LDD from an area (pixel) of higher elevation to an area (pixel) of lower elevation, until the common outlet is reached where the water-level recorder is located.

The model utilized a Manning's n map to represent the roughness coefficient of each land use/ land cover (**Table 2**). The land use map was a product of digital image classification of cloud-free Landsat Data (**Figure 4**). The classification accuracy was further improved by incorporating locations of rice terraces identified using Google Maps and the conduct of several field verification surveys. The Manning's n values are based on *Paningbatan* (*2001*) and *Chow* (*Chow 1959 as cited in Hameed and Ali 2013*), with slight adjustments to the values to fit the model's needs. Vegetation played a crucial role in the resulting surface roughness. High hydraulic roughness values reduces flow velocity and increases flood depth (*Mtamba et al. 2015*).

The model also utilized a saturated hydraulic conductivity map (**Table 2**) whose values were dictated by land use and land cover and are based on a previous study

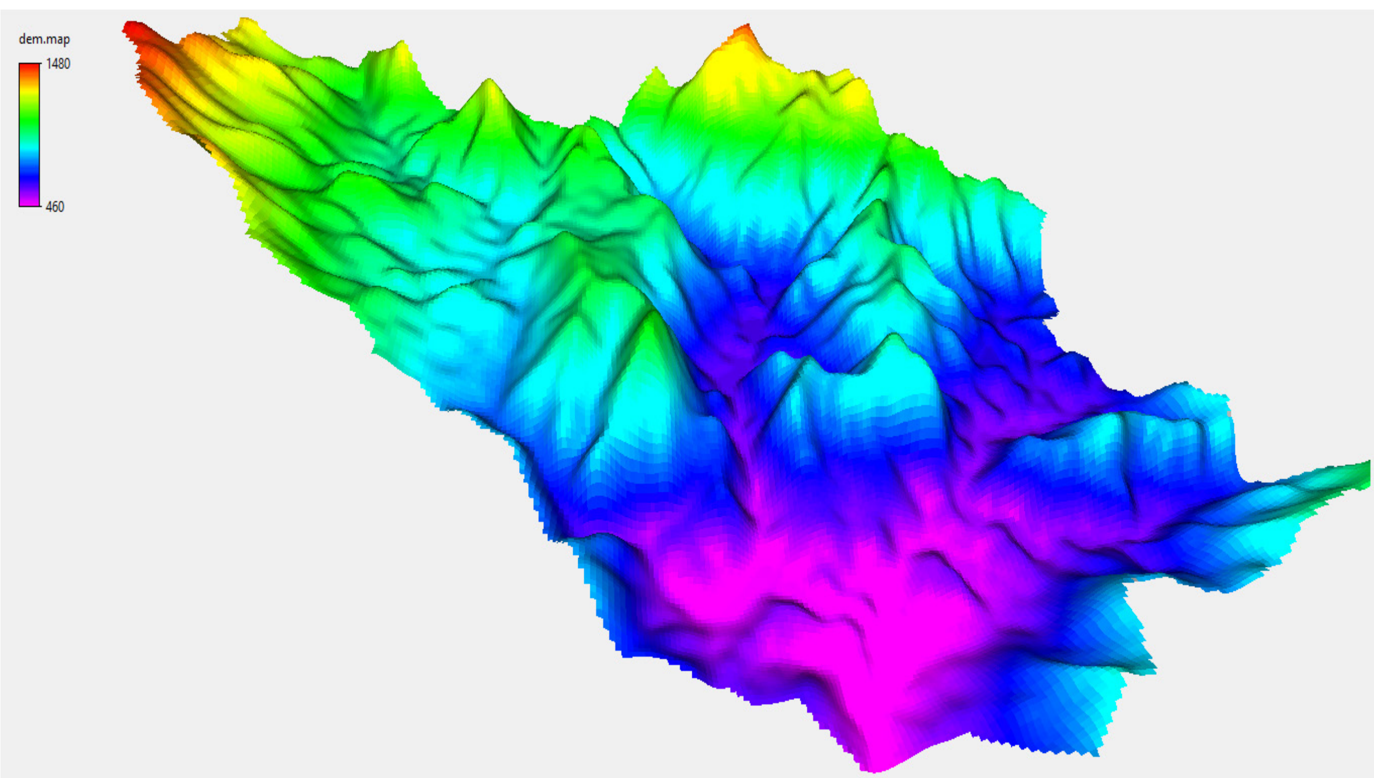

Figure 2. Three-dimensional image of Lagawe River Sub-watershed displayed using Aguila module of PCRASTER.

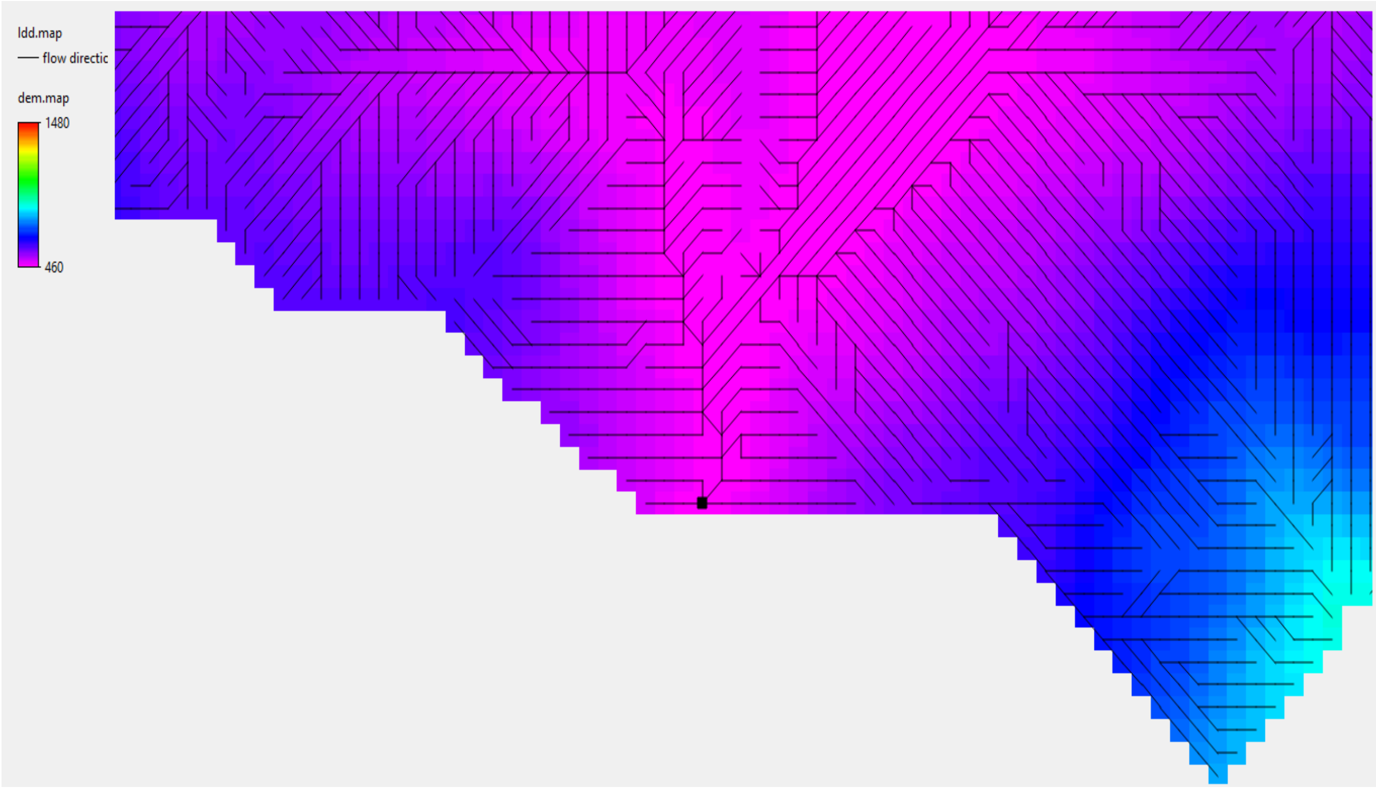

Figure 3. Local drainage direction (LDD) map of Lagawe River Sub-watershed showing the pit (common drainage) as a black dot.

of the author. Saturated hydraulic conductivity is higher where vegetation density is high and soil organic matter is high. Arable agricultural lands have lower saturated hydraulic conductivity values than natural vegetation, forests, and perennial agriculture (*Jarvis et al. 2013*). Saturated hydraulic conductivity is the maximum rate of flow that can take place through a soil profile at saturated moisture conditions (*Shukla 2014*; *Islam et al. 2018*).

Rainfall-Runoff Analysis

The ten-minute interval rainfall data were processed in a spreadsheet to derive rainfall intensity (**Figure 5**).

Table 2. Saturated hydraulic conductivity and Manning's n values for various landuse used for modelling soil erosion in Lagawe River Sub-watershed.

Land Use	Saturated Hydraulic Conductivity (mm hr^{-1})	Manning's n
Forest	100.8	0.1
Brush	42.0	0.12
Grass	100.8	0.035
Very Thin Grass	33.0	0.03
Bare	0.6	0.025
River	0.0	0.04
Terrace	6.0	0.06
Trail	0.6	0.025
Urban	0.6	0.02

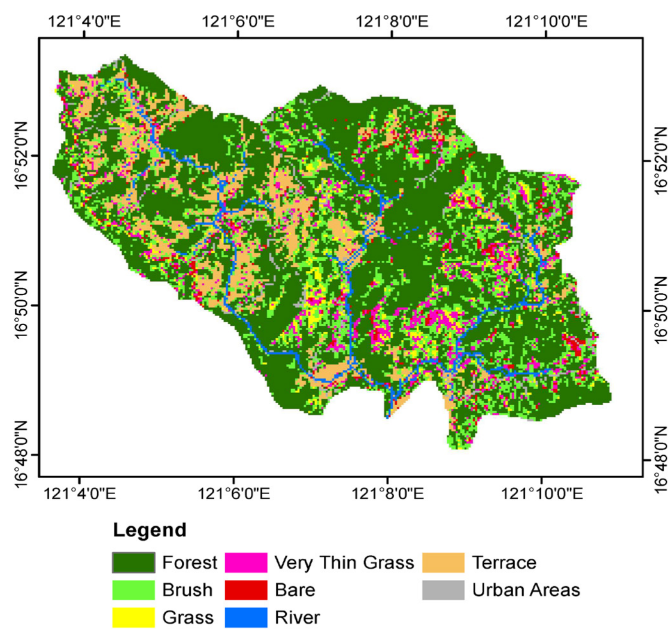

Figure 4. Land use map of Lagawe River Sub-watershed, Ifugao, Philippines.

Cumulative rainfall (**Figure 5**) was computed by adding rainfall depths of successive rain gauge bucket tips with a criteria of at most a ten-minute gap with no recorded rainfall. The rainfall event with the highest cumulative value, duration, and intensity was considered for the modelling process.

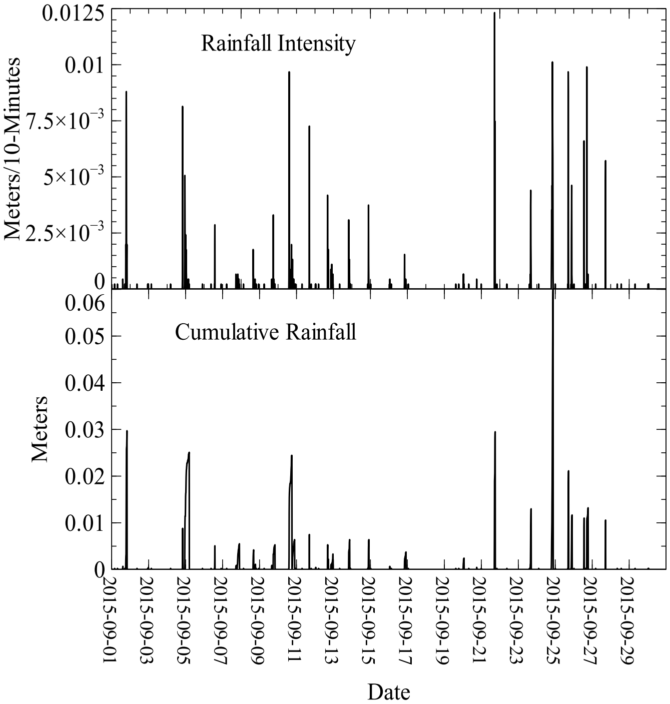

Figure 5. Rainfall intensity and cumulative rainfall for September 1, 2015 – September 30, 2015, Barangay Poblacion, Municipality of Hingyon, Province of Ifugao, Philippines.

The ten-minute interval water level data (**Figure 6**) was time-synchronized with the rainfall data using a customized computer program. Time synchronization is an important step in the conduct of time-dependent (time series) modeling. The graph was a subset of the ten-minute interval water-level data gathered in this research (**Figure 6**).

Modeling Process

The overview of the soil erosion modeling process, including the governing equations used, input data and maps, calibration process, and output products is illustrated in a flow chart (**Figure 7**).

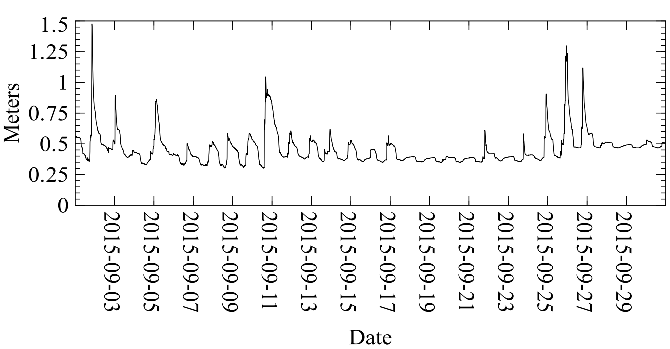

Figure 6. Water level at gauging station of Lagawe River for September 1, 2015 – September 30, 2015, Barangay Boliwong, Municipality of Lagawe, Province of Ifugao.

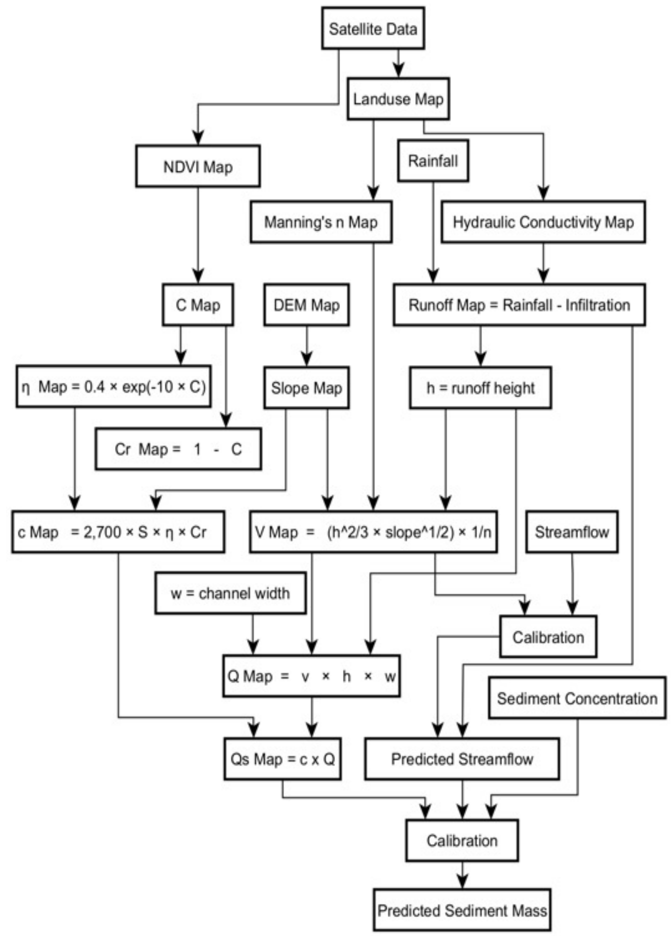

Figure 7. Flow chart of the soil erosion modeling process.

The sediment loss per unit plane (pixel), Q_s ($kg\ sec^{-1}$), is a product of sediment concentration and surface runoff (Equation 1).

$$Q_s = c \times Q \quad (1)$$

Where: c is sediment concentration, $kg\ m^{-3}$
Q is surface runoff discharge, $m^3\ sec^{-1}$

Surface runoff discharge rate, Q, was computed using Equation 2. This equation assumes that the channel is rectangular in shape, an assumption used in the model.

$$Q = v \times h \times w \quad (2)$$

Where: Q is surface runoff discharge, $m^3\ sec^{-1}$
v is velocity of flow, $m\ sec^{-1}$
h is height of flow, m
w is width of flow, m

During an erosive rainfall event, soil material and water normally flows from an area of higher elevation to an area of lower elevation, moving along the soil surface as sheet erosion or through channels like rills and gullies. The *Soil Science Society of America* (*2020*) defines rills as small, intermittent water courses with steep sides, usually only several centimeters deep. Gullies, on the other hand, are channels resulting from erosion and caused by the concentrated but intermittent flow of water usually during and immediately following heavy rains. Both rills and gullies convey surface runoff and sediments downslope at a certain velocity. The creation of rills and gullies is a product of the entrainment process and the scouring effect of surface runoff. The velocity of surface runoff along these channels can be estimated using Manning's Equation (Equation 3).

$$V = (r^{2/3} \times \alpha^{1/2}) \times 1/n \quad (3)$$

Where: V is velocity, $m\ sec^{-1}$
r is the hydraulic radius, m
α is the slope, $m\ m^{-1}$
n is Manning's surface roughness index

Manning's n was generated by recoding the land use map to create a Manning's Roughness Index Map. The hydraulic radius was the ratio of the cross-sectional area of flow to the wetted perimeter (Equation 4). The model assumed the channels to be rectangular in shape throughout the watershed for the sake of simplicity.

$$r = (h \times w) / (w + (2 \times h)) \quad (4)$$

Where: r is the hydraulic radius, m
h is the height of flow, m
w is the width of flow, m

Surface runoff travels down the slope at a certain velocity: increasing, as the height of the surface runoff increases, and decreasing, as the surface roughness increases. In the model, a uniform sloping surface in a landscape was assumed as a very wide channel with negligible sides. In such a case, the hydraulic radius, r, becomes the height of flow, h, (*Hillel 2004*). Thus Equation 3 becomes:

$$V = (h^{2/3} \times \alpha^{1/2}) \times 1/n \quad (5)$$

Where: V is velocity, $m\ sec^{-1}$
h is the height of flow, m
α is the slope, $m\ m^{-1}$
n is Manning's surface roughness index

Based on Rose's and Freebairn's Equation, sediment concentration, c, (Equation 6) is a function of the slope of the landscape, amount of vegetation cover, and efficiency of sediment entrainment.

$$c = 2{,}700 \times S \times \eta \times C_r \quad (6)$$

Where: c is sediment concentration, $kg\ m^{-3}$
S is slope angle, $m\ m^{-1}$
η is efficiency of sediment entrainment
Cr is fraction of soil uncovered by vegetation

Entrainment efficiency, η, can be evaluated from Equation 7.

$$\eta = 0.4 \times exp(-10 \times C) \quad (7)$$

Where: η is efficiency of sediment entrainment
C is surface cover fraction

The quantity C is the contact cover. The fraction of the soil uncovered by vegetation, Cr, was computed from Equation 8.

$$Cr = 1 - C \quad (8)$$

Where: Cr is fraction of the soil uncovered by vegetation
C is surface cover fraction

Model Performance Evaluation

To assess the performance of the model in predicting streamflow and soil erosion, correlation analysis between the measured and predicted values was performed. Likewise, the Welch's t-test was used in order to determine if the difference between the measured and predicted values were significant or not. A high correlation between the measured and predicted values indicated that the model performs well in predicting streamflow and soil erosion (**Figure 8**).

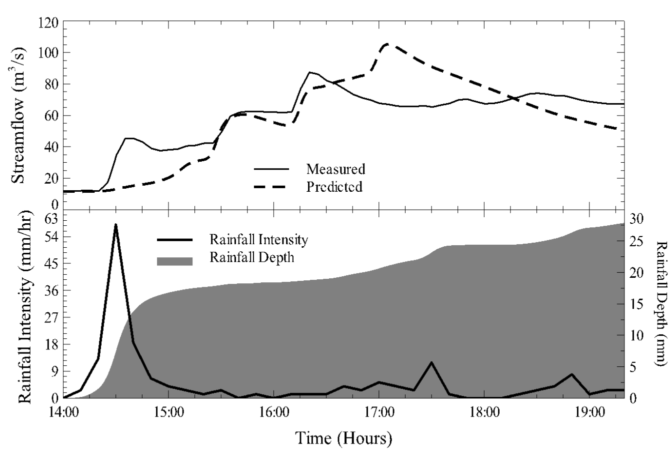

Figure 8. Measured and predicted streamflow of Lower Lagawe River and rainfall intensity and depth, September 10, 2015.

RESULTS AND DISCUSSIONS

To assess how well the model predicts soil erosion, there should be a good correlation between the measured and predicted values. The graph showed a positively linear correlation between measured sediment mass and predicted sediment mass with an R^2 of 0.74 (**Figure 9**). The Welch Two Sample t-test has a t-value of -0.25 and a p-value of 0.81. Because the p-value is greater than 0.05, there is no significant difference between the measured and predicted sediment mass. The physical, dynamic model is, therefore, able to predict soil erosion quite well.

The outlier point (**Figure 9**), where the measured sediment mass was 4,455 kg and the predicted sediment mass is 15,389 kg, was due to an error that occurred in the sampling of river water. While every effort was made to gather samples accurately, the difficulty and risk in getting water samples from the middle of the river, during the height of a rainstorm, when streamflow is high and turbulent, could have contributed to this error.

Most noteworthy among the water samples were those taken on May 12, 19:03 hours and August 18, 17:20 hours. The former reached a water level of 1.5 m (150 m^3 s^{-1} discharge), during the time of sampling, with a sediment mass in runoff of 4,327 kg. The latter had a water level of 1.2 m (130 m^3 s^{-1} discharge), during the time of sampling, and a sediment mass in runoff of 4,078 kg (**Table 3**). As streamflow increases, the amount of eroded sediments carried by runoff also increases. The estimated total surface runoff volume and estimated total eroded sediments are for the duration of each rainstorm event (**Table 4**). The peak water level of

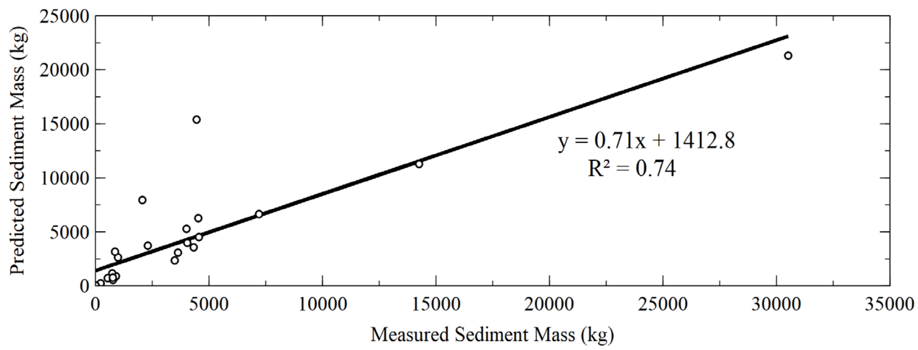

Figure 9. Correlation analysis of measured (actual field samples) and predicted (estimates by soil erosion model) for Lagawe River Sub-watershed.

Table 3. Sediment concentration from water samples of Lagawe River under various rainfall events utilized for calibrating model results*.

Event No.	Date Time	Sediment Concentration (g L^{-1})	Water Depth (m)	Runoff Volume (m^3)	Sediment Mass in Runoff (kg)
1B	May 12, 2015				
	18:33	2.43	1.4	1,440	3,492
	19:03	2.83	1.5	1,529	4,327
	20:00	1.86	1.2	1,241	2,305
2B	May 30, 2015				
	17:37	0.84	1.1	1,072	901
3B	August 18,2015				
	17:20	3.50	1.2	1,155	4,045
	17:50	3.64	1.0	999	3,635
	19:10	0.99	0.9	873	860
	20:20	0.92	0.8	801	738
4B	September10, 2015				
	17:20	0.61	0.9	875	537
	18:15	0.84	0.9	914	770
5B	October 19, 2015				
	17:20	1.34	0.6	569	764
6B	December 16, 2015				
	14:05	0.25	0.9	911	231
	14:26	0.25	0.9	921	227

*Samples were taken from the gauging station of Lagawe River in Barangay Boliwong, Lagawe Municipality rainstorm event 3B was around 1.7 m (180 m^3 s^{-1} discharge) and 2.1 m (160 m^3 s^{-1} discharge) for event 5B (Typhoon Koppu). For event 3B, the predicted total eroded sediments is about 12,262,000 kg. The service area of the gauging station is 7,391.5 ha. The rate of soil loss for the duration of the rainstorm event is about 1,659 kg ha^{-1}. For event 5B, the predicted total eroded sediments for the rainfall event is about 57,905,000 kg, which translates to a soil loss rate of about 7,834 kg ha^{-1}. Both these values exceeded the 2,200 kg ha^{-1} yr^{-1} (*Montgomery 2007, as cited in Pennock 2019*) tolerable value for soil erosion for a year and these are just rainstorm events that lasted for a day or two.

The mass of sediments increases with increasing streamflow. Sediment discharge only occurs once the water level in the river exceeded the base level, which only happens during rainstorm events (**Figures 10 and 11**).

The total rainfall volume and estimated total surface runoff volume are different for every rainfall event as the various rainfall events vary in their cumulative values. The total rainfall volume was computed based on the rainfall data gathered by the rain gauge, multiplying by the total area of the sub-watershed. The estimated total surface runoff is based on measurements at the gauging station for the duration of the rainstorm and would vary as different antecedent moisture contents exists in the soil depending on the weather. Antecedent moisture contents will initially affect the amount of rainfall that infiltrates the soil.

Table 3. Sediment concentration from water samples of Lagawe River under various rainfall events utilized for calibrating model results*.

Event No.	Date	Rainfall Depth (mm)	Total Rainfall Volume (m^3)	Estimated Total Surface Runoff Volume (m^3)	Estimated Total Eroded Sediments (kg)
1B	May 12-13, 2015	37	2,756,000	122,000	12,893,000
2B	May 30, 2015	18	1,330,000	50,000	1,750,000
3B	August 18, 2015	31	2,309,000	95,000	12,262,000
4B	September 10, 2015	28	2,065,000	60,000	1,623,000
5B*	October 18-19, 2015	68	5,041,000	422,000	57,905,000
6B	December 16, 2015	75	5,578,000	381,000	2,738,000
				Total	89,171,000

*Samples were taken from the gauging station of Lagawe River in Barangay Boliwong, Lagawe Municipality

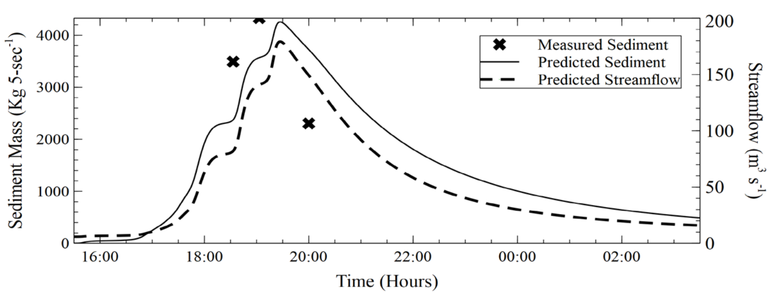

Figure 10. Sediment mass and predicted streamflow of Lower Lagawe River, May 12, 2015, Barangay Boliwong, Lagawe Municipality, Philippines.

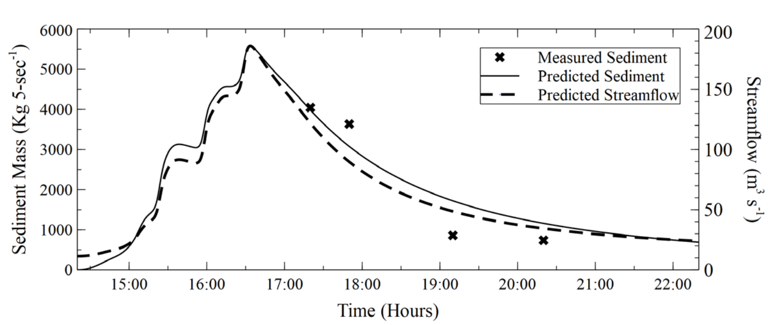

Figure 11. Sediment mass and predicted streamflow of Lower Lagawe River, August 18, 2015, Barangay Boliwong, Lagawe Municipality, Philippines.

CONCLUSIONS AND RECOMMENDATIONS

The procedure and the model developed in this research can be used to predict the possible effects of land use change in a watershed. The presence of soil erosion is an indicator of inappropriate land use and absence of soil conservation measures. Given three scenarios: reforestation, low deforestation, and high deforestation, assuming a rainfall condition similar to that of Typhoon Koppu, the predicted surface runoff and eroded soil were calculated using the model. Reforestation in the sub-watershed will significantly decrease the surface runoff and eroded soil to 38,100 m^3 and 57,905,000 kg, respectively. If low deforestation occurs, surface runoff and eroded soil will increase to 435,000 m3 and 58,735,000 kg, only by small amount from the current figures. If high deforestation occurs in the sub-watershed, surface runoff and eroded soil is predicted to significantly increase to 661,000 m^3 and 129,878,000 kg, respectively. Urban and land use planning should include appropriate measures to conserve the soil and the forests to ensure available clean water and minimize, if not entirely eliminate, the occurrence of landslide and mass movement of soil and rocks, especially in mountainous areas. The occurrence of super typhoons and extreme rainfall events cannot be prevented. But Philippine watersheds can better withstand these events if they are full of vegetative cover. To continue the provision of ecosystem services of Lagawe sub-watershed and to prevent its degradation, reforestation and/or planting of green vegetation in areas susceptible to soil erosion is recommended..

For the study and quantification of soil erosion and management of natural resources,changes in the way rainfall data is gathered, processed, archived, and distributed by the local weather bureau is recommended.. The weather bureau should preserve and make available to researchers and scientists the high temporal resolution rainfall data from tipping-bucket rain gauges gathered from weather stations. Soil erosion occurs during high intensity and duration rainfall. Soil erosion can only be accurately quantified if such rainfall properties are reflected in the rainfall dataset. Rainfall intensity and duration is captured using high-temporal resolution rainfall data recorded using a tipping-bucket rain gauge that records bucket tips at most every ten minutes. Daily rainfall statistics, as recorded by most weather bureau, fails to capture rainfall intensity and duration and is not suitable for use in soil erosion modelling and quantification.

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