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Geographic information system and process-based modeling of soil erosion and sediment yield in agricultural watershed

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ABSTRACT

BACKGROUND AND OBJECTIVES: The study explored the capability of the geographic information system interface for the water erosion prediction project, a process-based model, to predict and visualize the specific location of soil erosion and sediment yield from the agricultural watershed of Taganibong.

METHODS: The method involved the preparation of the four input files corresponding to climate, slope, land management, and soil properties. Climate file processing was through the use of a breakpoint climate data generator. The team had calibrated and validated the model using the observed data from the three monitoring sites.

FINDINGS: Model evaluation showed a statistically acceptable performance with coefficient of determination values of 0.64 (probability value = 0.042), 0.85 (probability value = 0.000), and 0.69 (probability value = 0.001) at 95% level, for monitoring sites 1, 2, and 3, respectively. A further test revealed a statistically satisfactory model performance with root mean square error-observations standard deviation ratio, Nash-Sutcliffe efficiency, and percent bias of 0.62, 0.61, and 44.30, respectively, for monitoring site 1; 0.65, 0.56, and 25.60, respectively, for monitoring site 2; and 0.60, 0.65, and 27.90, respectively, for monitoring site 3. At a watershed scale, the model predicted the erosion and sediment yield at 89 tons per hectare per year and 22 tons per hectare per year, respectively, which are far beyond the erosion tolerance of 10 tons per hectare per year. The sediment delivery ratio of 0.20 accounts for a total of 126,390 tons of sediments that accumulated downstream in a year.

CONCLUSION: The model generated maps that visualize a site-specific hillslope, which is the source of erosion and sedimentation. The study enables the researchers to provide information helpful in the formulation of a sound policy statement for sustainable soil management in the agricultural watershed of Taganibong.

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INTRODUCTION

Accelerated soil erosion is the primary issue of the declining trend of soil fertility and the overall degradation of agricultural lands which in turn threatens the global socio-economic and environmental conditions (Van Leeuwen *et al*., 2019; Ghafari *et al*., 2017). Common to the other regions of the developing world, soil erosion poses a serious threat to soil sustainability and degradation of the entire agricultural systems (Zhang *et al*., 2019; Olabisi, 2012). The report shows that degraded 44% of the total land area due to soil erosion in the Philippines is affecting 33 million Filipinos (Dar, 2017). To address land degradation issues, quantification of soil erosion rate from a particular agricultural watershed is necessary. Quantification of soil erosion by water offers a variety of procedures ranging from actual field data collection to computer simulation using geographic information system (GIS) tools coupled with the standalone and process-based models (Diwediga *et al*., 2018; Brooks *et al*., 2016). The current trend of soil erosion research recognizes extensively the use of prediction models, as the measurement of soil erosion rates from large watersheds is impractical due to complex hydrologic processes under varying conditions such as climate, soils, slope, vegetation and tillage (Pijl *et al*., 2020; Zheng *et al*., 2020). Over the few decades, the experts were focusing on the development of various modeling techniques to assess soil erosion in agricultural watersheds where the Water Erosion Prediction Project (WEPP) is among of the widely applied models as identified by most works of literature (Xiong *et al*., 2019; Pandy *et al*., 2016). In as much as the development of reasonable and scientific control measures depends on reliable data and information, the selection of an effective prediction model is critical (Han *et al*., 2016). Thus, a review of fifty erosion and sediment models in terms of worldwide applicability for best management practices implementation was conducted (Pandy *et al*. 2016). The findings revealed that only five to be the most promising, including the Soil and Water Assessment Tool (SWAT) and WEPP. Further comparison between the two models reported by Shen (2009) showed that the later had provided better results over the former for both runoff and sediment yield. WEPP is standalone software, a process-based, and a continuous soil erosion model that predicts the spatial and temporal distribution of soil loss and deposition due to surface runoff on the small agricultural watershed (Flanagan *et al*., 2001). In August 1985, the United States Department of Agriculture-Agricultural-Research Service (USDA-ARS) has initially developed the software (Flanagan *et al*., 2007). The detailed descriptions of WEPP in terms of model components, processes, and input files requirements are presented in the works of Meghdadi (2013) and Gonzàlez-Arqueros *et al*. (2016). The advancement of computer technology allows the model to enhance its capabilities through the geospatial interface known as GeoWEPP (Renschler and Zhang, 2020). The interface, therefore, is enriched with the excellent characteristics of GIS such as the processing and creation of digital data at a watershed scale (Gonzàlez-Arqueros *et al*., 2016; Flanagan *et al*., 2013). The application of GeoWEPP model is now model worldwide to assess its predictive capability under varying factors of erosion processes that are unique to a specific watershed such as climate, soil, slope, and land management (Han *et al*., 2016). The following discussions are some of the works on the application of GeoWEPP outside the USA. In Iran, the GeoWEPP model was used to identify the type of land uses and management scenarios effective to reduce runoff, soil erosion, and sediment yield (Mirakhorlo and Rahimzadegan, 2019; Narimani *et al*., 2017). The findings of several GeoWEPP modeling studies in that country enable the researchers to identify the best management practices suitable for agricultural and critical watersheds (Meghdadi, 2013). The model was also explored in Japan to assess the potential disaster caused by sediment discharge from the mountainous watershed (Amaru and Hotta, 2018). GeoWEPP was also used in Central Mexico to account for the impact of the human via land-use changes on soil erosion trends covering almost 2000 years from pre-Hispanic period to modern times (Gonzàlez-Arqueros *et al*., 2016). The model also performed satisfactorily in predicting daily runoff and sediment yield in the highlands of Northern Ethiopia. The results served as bases to assess the impact of soil and water conservation structures to prevent land degradation (Melaku *et al*., 2018). In Malaysia, GeoWEPP has accurately predicted runoff although over calculation of sediment load was observed due to steeper slopes of the study site (Ebrahimpour *et al*., 2011). Satisfactory performance of GeoWEPP in simulating streamflow and sediment yield under the prevailing environmental condition of the heterogeneous catchment in Italy was also

reported (Peiri *et al*., 2014). In China, the model was used to account for the effect of slope gradients, and land uses on soil erosion intending to provide scientific evidence for a sound land use plan in the watershed (Zhang *et al*., 2015). Locally, the model was successfully applied to assess soil sustainability in the agriculturally active watershed of the Philippines (Puno, 2014). Oftentimes, model evaluation is necessary to test how results will aid as a guide to local land management in providing science-based policy implications and guidelines relative to soil conservation for sustainable agriculture. (Renschler and Zhang, 2020; Panagos and Katsoyiannis, 2019; Prasuhn *et al*., 2013). Like any other impaired watersheds in the country, Taganibong is an agricultural watershed that suffers erosional problems due to rapid land conversion and uncontrolled land tilling along steeper hillslopes, which may result in a poor soil condition when remains unabated. Site-specific information on erosion in the area to support the advocacy of sustainable soil management in the agricultural watershed of Taganibong is sought. Acquiring this kind of information needs a GIS and a process-based model like GeoWEPP, as the measurement of erosion and sediment yield at a watershed scale is almost impossible considering the complexity of the interacting environmental factors (Liu *et al*., 1997). This academic exercise aimed to explore the applicability of GeoWEPP model to predict soil erosion and sedimentation rates in the study area. This study anticipates providing preliminary information helpful in evaluating the soil condition of the watershed. The research team chose the model as it works as an extension tool of the leading GIS software, and is extensively applied worldwide. Further, only the GeoWEPP model can predict erosion distribution along hillslope on a per-event basis (Flanagan *et al*., 2001). The study was carried out for about two years from 2013 to 2015 within the watershed of Taganibong, Mindanao, Philippines.

MATERIALS AND METHODS

Study area

The study location was at the watershed of Taganibong, Mindanao, Philippines (Fig. 1). Geographically, the watershed lies between 124°56' to 125°4' east and 7°48' to 7°56' north with a total land area of 5,853 ha. The terrain is mostly undulating to rolling with 11.6% average slope and 121% as the steepest, particularly along channel and mountainside hillslopes. The area has an elevation of 284 to 1,334 meters above sea level (masl) with 595 masl on the average. The site has a heavy-textured brown clay dominated by a silt loam and a sandy clay loam type of soil texture. The area receives an average annual rainfall of 2,587 mm with a mean annual temperature of 25°C. There is no very pronounced dry season, although dry periods are experienced from November to April while the rest of the year

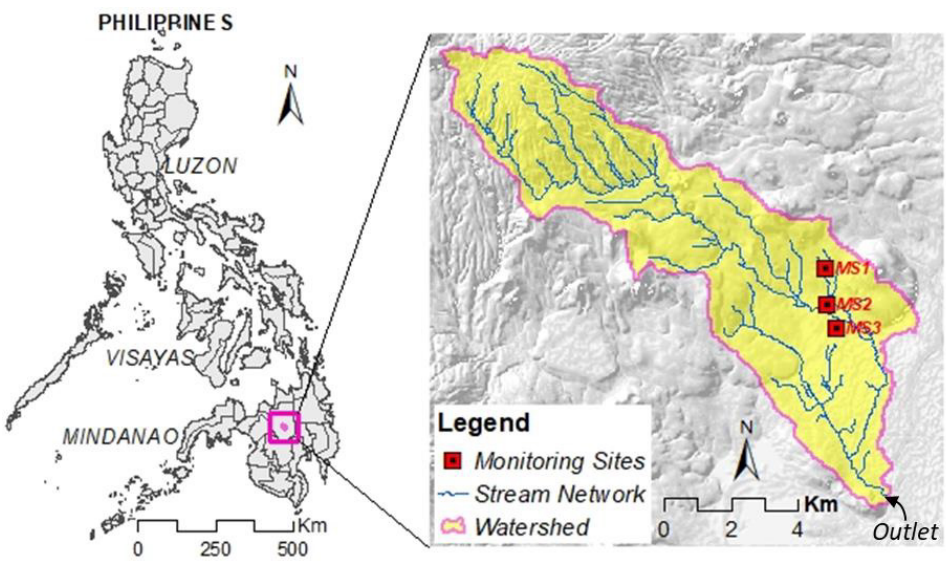

Fig. 1: Geographic location of the study area in Taganibong Watershed, Philippines

is wet. Generally, cultivation for agricultural crop production is among of the land-use practices in the watershed with the presence of some growing built-ups. The research team established three monitoring sites (M1, M2, and M3) within the watershed for the collection of soil erosion data.

The GeoWEPP Model

GeoWEPP is the interface of the WEPP model and GIS that uses the topography parameterization (TOPAZ) algorithm with ArcGIS software as a working platform. A standalone WEPP model is a daily continuous, physically, and process-based model that describes hillslope, channel, and impoundment and simulates hydrologic variables such as erosion, sediment, runoff, and deposition on a temporal and spatial base (Ebrahimpour *et al*., 2011). As a plugin in the ArcGIS software, GeoWEPP allows two simulation options, the onsite or flowpath method for the onsite assessment of erosion, and the offsite or the watershed method for the assessment of sediment yield based on a single hillslope and channel (Amaru *et al*., 2018). The TOPAZ tool allows GeoWEPP to delineate watershed boundary and generate hillslopes or subwatershed profiles using a digital elevation model. (Maalim *et al*., 2013). A detailed description of the GeoWEPP model discussing how the model runs and produces textual and spatial databases is presented in the work of Flanagan *et al*., (2013).

Data collection for model simulation

Modeling with GeoWEPP requires four significant data groups corresponding to the slope, landcover, soil, and climate (Table 1). The preparation of the slope input file needs the synthetic aperture radar-digital elevation model (SAR-DEM) availed from the University of the Philippines Diliman (UPD), Quezon City, through its Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program. The slope was classified following the recommendation from the Bureau of Soil and Water Management (BSWM) that includes six categories described as flat (0-3%), undulating (3.01-8%), undulating to rolling (8.01-18), rolling (18.01-30%), step (30.01-50%), and very steep (>50%) (Fig. 2). Landcover data (Fig. 3) was collected by digitizing an image from the Google Earth tool and was

Table 1: Data for GeoWEPP simulation

Type of data	Methods of data acquisition
Slope	SAR-DEM, UPD-DREAM
Landcover	Google Earth, field survey
Soils (NPK, OM, CEC, albedo, texture, rock)	Field survey, laboratory analysis, literature
Climate (rainfall, RH, max and min temperature, solar radiation, wind speed, and direction)	Automatic Weather Station

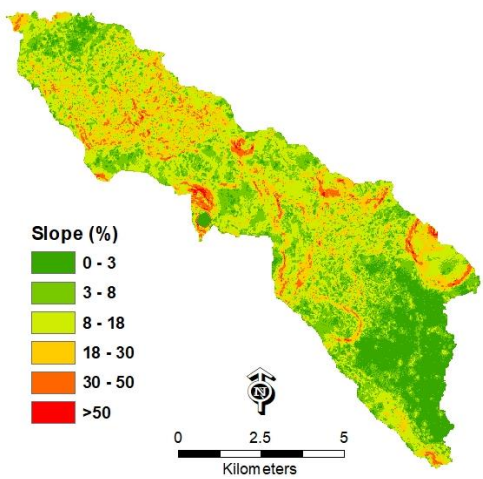

Fig. 2: Slope map of the Taganibong watershed

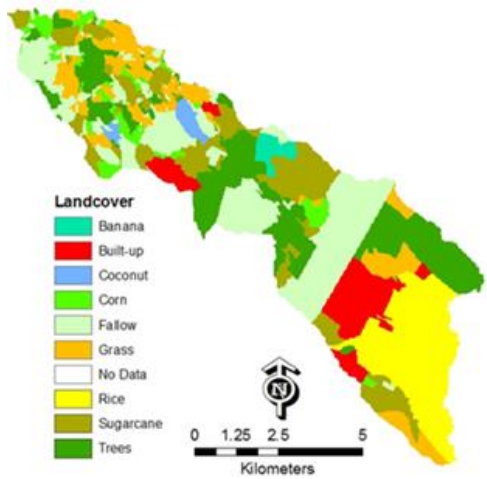

Fig. 3: Landcover map of the Taganibong watershed (2015)

Table 2. Landcover or land use of the Taganibong watershed

Landcover	Area (ha)	%
Banana	84.5	1.4
Built-up	487.0	8.3
Coconut	258.6	4.4
Corn	85.2	1.5
Fallow	1,168.8	20.0
Grass	659.0	11.3
Rice	947.5	16.2
Sugarcane	928.7	15.9
Trees	1,233.7	21.1
Total	5,853.0	100.0

validated on the ground. Crops like corn, sugarcane, banana, among others, with patches of grasslands and fallow areas were the typical landcover or land uses (Table 2). The Central Mindanao University manages both the patches of natural and mixed plantation forests at the rolling lower portion of the watershed and the rice fields at the floodplain areas. The straight line formed in the landcover reflects the real situation on the ground where the power transmission lines traverse the area, restricting the site from being grown or planted with taller perennial vegetation. Soil parameters such as nitrogen (N), phosphorus (P), potassium (K), organic matter (OM), texture (silt, loam, clay, and sand) were derived from the collected samples, which were analyzed at the laboratory. The albedo of the ground surface was availed from literature, while the cation exchange capacity (CEC) was based on the built-in database of the software. The rock information expressed in percent of the total area was obtained via an ocular survey. Fig. 4 shows the spatial distribution of the soil textural properties in the area. Climate variables comprising of the rainfall amount, relative humidity (RH), maximum and minimum temperature, solar radiation, wind speed, and direction were collected through the automatic weather station installed near the three monitoring sites within the watershed.

Map Layer and database requirements

The initial step of setting up the GeoWEPP model before the actual simulation run requires two groups of input files. The first group includes the grid-based map layers written in the American Standard Code for Information Interchange (ASCII) format comprising of dem.asc, landcov.asc, and soilsmap.asc layers. The second group includes the database files in text format corresponding to landcov.txt, soilsmap.txt, landusedb.txt, and soilsdb.txt. The first group of data was processed and prepared using the ArcGIS version 10.2.2 software of the Environmental Systems Research Institute Inc. The step by step procedure of making the above data is presented in the work of (Minkowski and Renschler, 2008).

Slope grid file preparation

The slope grid layer was derived from a 10-meter resolution SAR-DEM. As mentioned, GeoWEPP accepts the grid input file in ASCII format. Thus, the input slope map layer was saved as dem.asc.

Landcover and soil grid files preparation

The landcover in a shapefile format of the watershed was created through digitizing an image

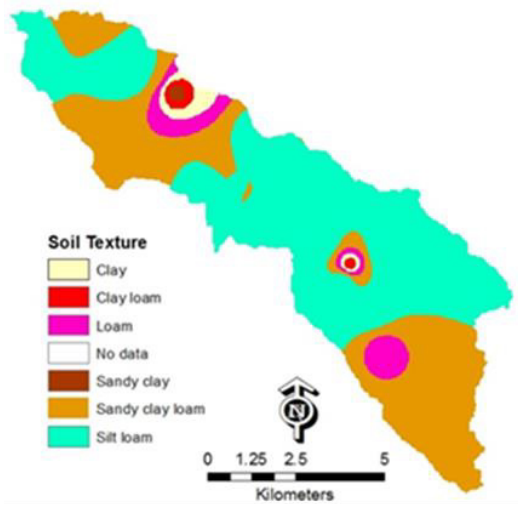

Fig. 4: Soil map of the Taganibong watershed

from the internet with the Google Earth application tool. The resulting shapefile layer was converted into a raster layer file and saved as landcov.asc. Similarly, the soil map layer in the raster format was prepared as the landcover map layer with a slight difference at the initial step. The shapefile containing all the descriptions of the soil samples was created using the coordinates of the sample pits randomly distributed in the watershed. The soil map layer in the raster format was finalized to satisfy the requirement of GeoWEPP using the ArcGIS tool capabilities.

Landcover and soil database files preparation

When using a landcover layer in ASCII format, the program will not proceed if the landcover in the text file format (landcov.txt) is missing. In the same manner, the program also fails to run if the soil in text file format (soil.txt) is missing. Finally, the created database files were saved with an extension file names of .txt corresponding to landcov.txt, landusedb.txt, soilsmap.txt, and soilsdb.txt. The landcov.txt and soilsmap.txt files were used by the GeoWEPP and WEPP/TOPAZ translator (WEPP Management and Soil Lookup) to determine the description that corresponds to the landcov.asc, and soilsmap.asc layers, respectively. Likewise, landusedb.txt and soilsdb.txt files were georeferenced in a similar manner as landcov.txt and soilsmap.txt files. The detailed procedure in making the landcover and soil database input files followed the procedure in the work of Minkowski and Renschler (2008).

Climate input file preparation

The model will run using a climate input file generated using either a climate generator (CLIGEN) or the BPCDG module. CLIGEN is the built-in capability of the WEPP model to make the required data using long historical climate data. The BPCDG, on the other hand, is a standalone software module that processes a single year observed climate datasets. This study used the module to process the climate input file for the GeoWEPP simulation. The climate parameters required by the BPCDG involve five-minute interval climate datasets comprising rainfall, minimum and maximum temperature, relative humidity, solar radiation, wind speed, and direction, which were collected using an automatic weather station installed in the site. The use of BPCDG was preferred based on its advantages over CLIGEN as it allows direct use of observed storm and other daily standard climate data sets (Zeleke, 1999).

Channel network and catchment delineation

GeoWEPP model allows automatic delineation of channel network and catchment boundary through the topographic parameterization (TOPAZ) tool following the concept of a critical source area (CSA) and minimum source channel length (MSCL) (Renschler and Zhang, 2020; Amaru *et al*., 2018). The process involved the arbitrary setting of the CSA and MSCL values to determine the desired density of the channel network and the number of hillslopes within the watershed.

Model calibration and validation

Calibration was conducted manually following the procedures from the previous study, as discussed (Ramos, 2016). The parameters adjusted in the calibration process included the soil erodibility, critical shear, and effective hydraulic conductivity factors. Other parameters like the channel width, presence or absence of rocks in the river bed, type of vegetation, mode of tillage, among others, were manually adjusted until best fit between the first set of observed data and the simulated values. Validation was carried out after a thorough calibration and series of simulation trials by comparing the simulated results of the calibrated model with the second set of observed erosion data.

Model performance evaluation

The process of performance evaluation involved the use of soil erosion data collected from the three monitoring sites (MS1, MS2, and MS3) to assess the predictive capacity of the model. The data collection activity for this purpose applied the modified erosion bar instrument to measure soil erosion values for every rainfall event (Marin and Casas, 2017). The calculated values of the coefficient of determination (R^2), root mean square error (RMSE)-observations standard deviation ratio (RSR), Nash-Sutcliffe efficiency (NSE), and percent bias ratio (PBIAS) were the basis to evaluate the performance of the model. The RSR ranges from zero to a large positive number with 0 and 0.7 indicating a perfect prediction and unsatisfactory values, respectively. NSE ranges between $-\infty$ and 1, with 1 and <0.5 being the optimal and unsatisfactory values, respectively.

Values between 0 and 1 are generally viewed as acceptable levels of performance, whereas values <0 indicates unacceptable performance (Moriasi *et al*., 2007). PBIAS assesses the average tendency of the predicted results to overestimate or underestimate the observed data (Gupta *et al*., 1999). A PBIAS of 0 indicates an accurate model performance. A positive value, on the other hand, suggests underestimation, and overestimation if negative values (Gupta *et al*., 1999). PBIAS of 55% for sediment modeling is already a satisfactory result (Moriasi *et al*., 2007). These statistical criteria are mostly applied to hydrologic modeling studies like GeoWEPP to validate model performance (Ricci *et al*., 2020; Narimani *et al*., 2017; Ramos, 2016).

GeoWEPP simulation

The calibrated and validated GeoWEPP model was then applied for the simulation of erosion and sediment yield at a watershed scale. The simulation involved two assessment methods, namely offsite or watershed method, and onsite or flow path process. The offsite determines a representative profile for the hillslope and assigned one soil and one land use to it (Amaru, 2018). This method predicts the amount of sediment, leaving each hillslope evaluated at the outlet. The onsite process helps the user identifies which hillslopes are the problem areas. This method shows which portions of a particular hillslope are the main contributors to such erosion problems considering the diversity and distribution of the soil and land use types (Minkowski and Renschler, 2008).

Soil sustainability assessment

The concept of soil erosion tolerance or threshold was used as the criteria to assess the sustainability of soil in the watershed. As defined, soil tolerance is the maximum rate of erosion to occur while permitting sustainable and high-level of crop productivity (Lenka *et al*., 2014). The soil is assessed as sustainable when the rate of erosion is not exceeding the allowable soil tolerance. For convenience, a tolerable limit of 10 t/h/y as used in the work of Melaku *et al*. (2018) was also applied in this study because the Philippines is a tropical country where the acceptable soil loss ranges from 10 to 12 t/h/y (Tacio, 2011).

RESULTS AND DISCUSSION

Predicted and observed soil erosion

The predicted soil erosion values were compared with the amount of erosion observed from the three monitoring sites. Figs. 5, 6, and 7 show the graphical representation of the compared values. The graphs show that there is a close relationship between the predicted and observed erosion rates. The result of the t-test revealed that the two sets of erosion values are not statistically different with p-values of 0.28, 0.29, and 0.29 at 0.05 level of significance for MS1, MS2, and MS3, respectively. A similar study reported comparable results where the GeoWEPP model simulated hydrologic variables closer to the measured values (Yuksel, 2008). This indicates that the model is a good predictor of soil erosion and sediment yield in the Taganibong watershed.

Model evaluation results

Table 3 summarizes the statistics of model evaluation results. Results show the linear fitting between observed and predicted erosion values in

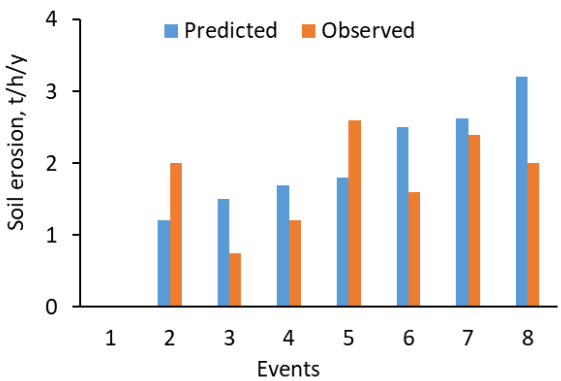

Fig. 5: Comparison of predicted and observed erosion from MS1

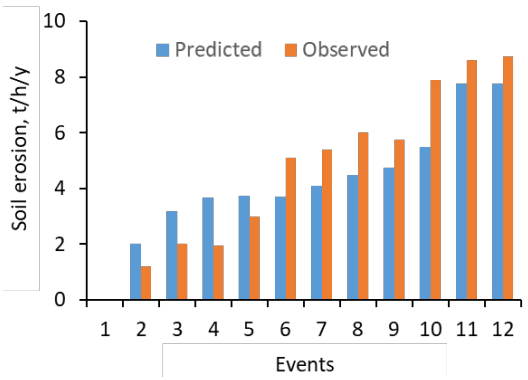

Fig. 6: Comparison of predicted and observed erosion from MS2

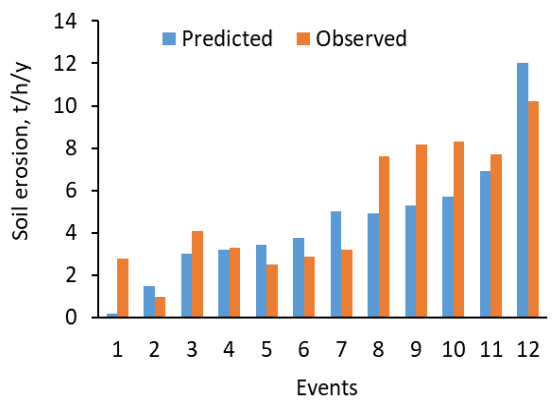

Fig. 7: Comparison of predicted and observed erosion from MS3

the three monitoring sites. Figs. 8, 9, and 10 show the direct relationship between the observed and predicted values with the coefficient of determination (R^2) of 0.64 (p=0.042), 0.85 (p=0.000), and 0.69 (p=0.001) at 95% level for MS1, MS2, and MS3, respectively. Several studies also showed R^2 of these ranges implying that the model is a good predictor of erosional processes at an acceptable parametric calibration under similar conditions (Maghdadi, 2013; Ebrahimpour *et al*., 2011; Alibuyog, 2009; Pandey, 2007). Generally, the results on model performance evaluation following the suggested statistical criteria show closer values reported in previous studies on the application of GeoWEPP and other related hydrologic models (Melaku *et al*., 2018; Fukunaga *et al*., 2015). Using RSR, NSE, and PBIAS statistical tests revealed that the model performance is satisfactory (Table 3). However, the model tends to underestimate soil loss, as shown by consistent large positive PBIAS values for the three sites. Nevertheless, Moriasi *et al*. (2007) reported that PBIAS of ±55% for sediment yield modeling is already satisfactory. Under and over prediction of the model, however, does not necessarily suggest that GeoWEPP performed poorly but rather a manifestation that erosion prediction, in general, contains large factors of error due to the interacting complex and varying environmental conditions (Liu *et al*., 1997).

Watershed scale GeoWEPP simulation

Using the main input files prepared for the model, the calibrated GeoWEPP was applied in a broader scale of Taganibong watershed with the soil tolerance or threshold set at 10 t/h/y. A total of 177 sub-catchments or hillslopes assigned with unique soil and land management type were created based

Table 3: Statistics of model evaluation

Criteria	MS1	MS2	MS3
R^2 (95%)	0.64 (*p=0.042*)	0.85 *(p=0.000)*	0.69 *(p=0.001)*
RSR	0.62	0.65	0.60
NSE	0.61	0.56	0.65
PBIAS	44.30	25.60	27.90

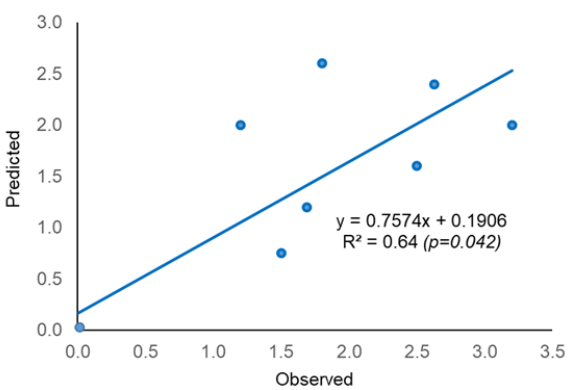

Fig. 8: Regression between predicted and observed erosion from MS1

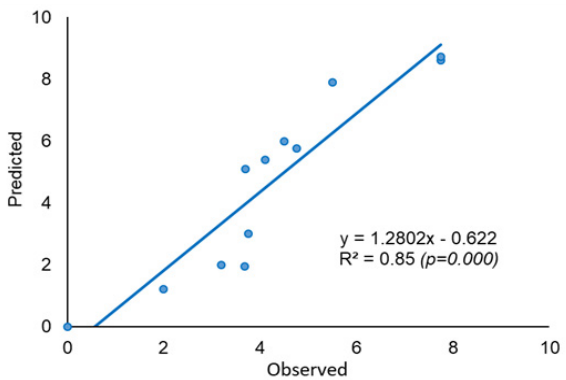

Fig. 9: Regression between predicted and observed erosion from MS2

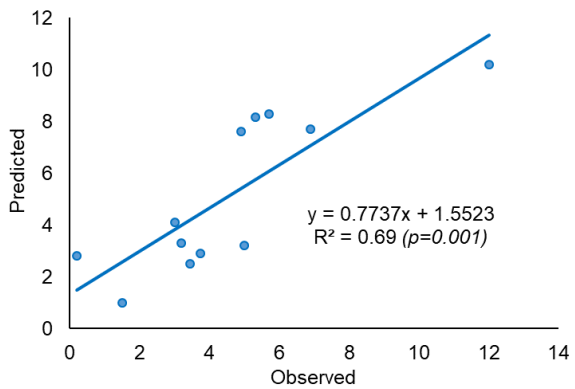

Fig. 10: Regression between predicted and observed erosion from MS3

on the CSA and MSCL values set at 50 hectares and 200 meters, respectively. The model generated two raster map layers as a result of the offsite (watershed) and onsite (flowpath) methods. The offsite method produced the sediment yield map that determines the amount of soil removed and accounted at the outlet of a particular hillslope or subcatchment with homogeneous soil and landcover assigned by the model. The runoff discharges mainly influenced it from the hillslopes and channel and determined the same at the outlet point of the modeled watershed (Maalim and Melesse, 2013).

Sediment yield assessment

The model accounted for a total of 46 out of 177 hillslopes with sediment yield beyond the threshold and 131 with sediment yield lower than the limit, depicted in Fig. 11 with shades of red and green, respectively. The hillslopes with sedimentation rate beyond the threshold are entirely shaded with red because the offsite method assumes entirely those areas as the sources of sediments and does account for the specific location where the origin

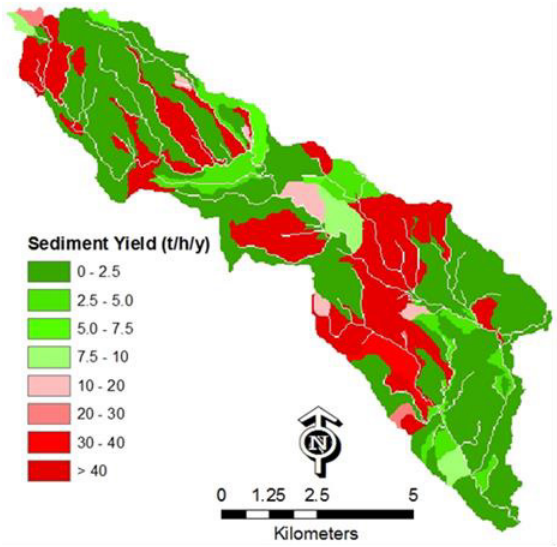

Fig. 11: Sediment yield map of the Taganibong watershed

of sedimentation has occurred. The total land area of the hillslopes with sediment yield beyond the threshold is around 26% of the watershed total area. On average, the model predicted sediment yield at the rate of 22 t/h/y for the whole watershed (Table 4).

Soil erosion assessment

The onsite method identifies the specific location of the area within the watershed where the problem of erosion has occurred (Maalim *et al*., 2013). Through this method, the model generated a more detailed soil erosion map that shows the spatial distribution of the eroded material along the hillslopes. As a result, some of the hillslopes predicted under the offsite method with sediment yields beyond threshold were further subdivided into shades of green, red,

Table 4: Predicted hydrologic values for the Taganibong watershed

Hydrologic parameters	Predicted values
Total area of watershed	5,853 ha
Precipitation volume	124,239,285 m^3/y
Water discharge	6,349,328 m^3/y
Total hillslope soil erosion	523,522 t/y
Total channel soil erosion	124,927 t/y
Sediment discharge from outlet	126,390 t/y
Soil erosion per unit area	89 t/h/y
Sediment yield per unit area	22 t/h/y
Sediment delivery ratio	0.20

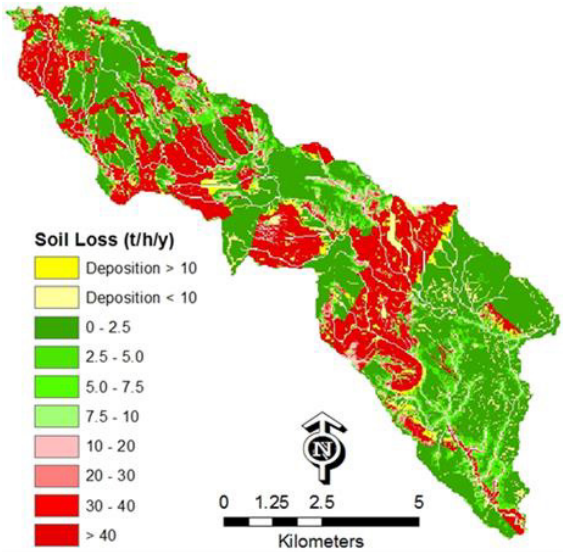

Fig. 12: Soil erosion map of the Taganibong watershed

and yellow, for areas within the threshold, beyond the threshold, and deposition respectively (Fig. 12). The red portion of the hillslope, therefore, is the area where the problem of erosion has specifically occurred. By default, the model generated the soil erosion map with a value code up to >40 for hillslopes with erosion beyond the threshold (Fig. 12). This means that the model can report the hillslopes with large erosion values. The model predicted an amount of 89 t/h/y for the whole area which is very far from the threshold of 10 t/h/y. Table 4 shows the details of the predicted hydrologic parameters for the whole watershed of Taganibong.

The predicted average erosion rate of 89 t/h/y is closed to the national average erosion rate of 80 t/h/y (Asio *et al.*, 2009). The likelihood of higher values beyond erosion tolerance is explained by the steeper and tilled hillslope with a silt loam type of soil texture (Obalum *et al.*, 2019). With some limitations, the model has successfully generated information on the onsite erosion and deposition variables due to the combined effect of climate, soil texture, landcover, and slope factors. Overlaying the predicted soil erosion map (Fig. 12) with the landcover input file map (Fig. 3), revealed that the erosion, depicted with shades of red in the erosion map (Fig. 12), has generally occurred in the areas with built-ups and fewer trees. On the other hand, areas with lesser erosion values, coded with shades of green in the map, are generally covered with trees. This indicates that vegetative landcover is helping to arrest soil erosion in that particular site. However, observation should take into account the combined effect of the slope. As illustrated in the erosion map, and with reference to the slope map, some areas in the watershed without trees have lesser predicted erosion values due to their flat ground surfaces. The results confirmed with the findings from the previous modeling studies, pointing out that the removal of permanent landcover, and tilling in some steeper slopes are the primary factors to accelerate soil erosion rates (Narimani *et al.*, 2017). Tilling in steeper slope for short term crops and the occasional presence of some built-ups are evident in the site. Many studies reported that increased soil erosion and sediment yield is due to changes in land management from vegetated to open areas (Pieri *et al.*, 2014; Alibuyog *et al.*, 2009). More studies also show that tilling in steeper hillslopes resulting in excessive erosion is likely the major contributing factor to the process (Amaru and Hotta, 2018; Zhang *et al.*, 2015). An increase in erosion rates attributed to the absence of forest and other permanent vegetation is further explained by less water infiltration, increased runoff velocity, and proneness to erodibility (Zheng *et al.*, 2020). Steeper slope, however, with trees and perennial plant cover was predicted to have lesser erosion values below the erosion tolerance indicating sustainable soil in the area. Lower soil loss in forested areas was mainly due to the constant ground cover throughout the year, resulting in a minimal runoff and high permeability of the forest soil (Ricci *et al.*, 2020; Amaru and Hotta, 2018). The predicted erosion rates in areas planted with rice located at the southeastern portion of the watershed were below the threshold as indicated with the shade of green in the soil erosion map (Fig. 12). Soil erosion in the irrigated plain and terraced paddy field for rice production was reported to have 0.77 t/h/y (Chen *et al.*, 2012). The model accounted for a difference in the erosion values between the offsite and onsite method despite the same source of contributing hillslope. The concept of the sediment delivery ratio explains the expected difference between the two processes. As defined, sediment delivery ratio is a measure of sediment transport efficiency expressed as the fraction of the gross erosion and deposition from a

given area with a value being inversely proportional to the size of the watershed (Dong *et al*., 2013). The lower predicted sediment delivery ratio indicates a relatively smaller volume of sediment deposited downstream. The sediment delivery ratio of 0.20 indicates about 80% of sediment were deposited or trapped within the watershed due to vegetation, size of the watershed, and slope gradient of the mainstream channel, that control the soil particles to reach the lowest point of the watershed (Nguyen and Chen, 2018). With the prevailing sediment delivery ratio, the model accounted for a total of 126,390 tons of sediments that had accumulated at the low-lying bodies of water in just one year. To some extent, the model predicted soil erosion and sediment yield with some degree of variability. As evaluated, however, the model is statistically acceptable with a satisfactory performance with the predicted hydrologic variables closed to the results of the previous studies. Nevertheless, the variability of the predicted results suggests for future modeling study based on challenging quantitative field data measurements sufficient for model calibration and validation to improve the predictive performance of the model.

Assessment of soil sustainability

The excessive predicted soil erosion and sediment yield values of 89 t/h/y and 22 t/h/y, respectively, are excessively far from the erosion tolerance of 10 t/h/y. This indicates that the soil in some hillslopes of the watershed is unsustainable. This is probably due to the uncontrolled land cultivation for crops production. Open land tilling for sugarcane, corn, banana, among others growing at steeper slopes and elevated areas, has a greater tendency to cause accelerated soil erosion. Further, silt soil being a loose-type of ground quickly releasing particles covers 55% of the total watershed land area. The presence of a dominant silt loam type of soil may have contributed to a higher rate of soil loss (Obalum *et al*., 2019). Site-specific land-use planning is encouraged for hillslopes with erosion and sedimentation rates beyond the threshold, using the type of crop suited for a certain percent of a slope category as suggested by the BSWM. Further, it is important to integrate conservation measures such as alley cropping and contour hedgerows in the sloping areas that exhibited high erosion rates to prevent accelerated erosion.

CONCLUSION

GeoWEPP was successfully applied and validated with statistically acceptable performance to predict soil erosion and sediment yield in Taganibong watershed. GeoWEPP simulation used digital files of soil, landcover, and elevation all in ASCII format prepared using the GIS tool capabilities. The use of the WEPP model interface enabled the research team to create the database files for management and soil information. The climate file was processed using the BPCDG standalone software. The modeling process involved a rigorous calibration of various parameters to fit the existing condition of the watershed and the series of model simulation trials. The model was validated by comparing the predicted with the observed soil erosion values from the three monitoring sites (MS1, MS2, and MS3), and revealed to be statistically satisfactory with R^2 values of 0.64 (p=0.042), 0.85 (p=0.000), and 0.69 (p=0.001), respectively, at 95% level. A further statistical test proved the acceptability of model performance with RSR, NSE, and PBIAS of 0.62, 0.61, and 44.30, respectively, for MS1; 0.65, 0.56, and 25.60, respectively, for MS2; and 0.60, 0.65, and 27.90, respectively, for MS3. At a watershed scale of Taganibong, the calibrated model had predicted the average soil erosion and sediment yield at 89 t/h/y and 22 t/h/y, respectively. These values are far from the erosion tolerance of 10 t/h/y indicating unsustainable soil particularly in some hillslopes of the watershed. The sediment yield and erosion maps generated by the model revealed the specific hillslopes in the watershed where the problem of erosion has occurred, coded with red color in the respective map layers. The sediment delivery ratio of 0.20 indicates that around 20% of the sediments amounting to 126,390 tons had accumulated at the downstream areas of the watershed. The remaining 80% of sediments were deposited elsewhere within the watershed. Similar to other modeling studies, GeoWEPP showed under and over prediction as indicated by consistent higher positive PBIAS values for the three monitoring sites. This observation, however, does not necessarily mean poor performance by the model but rather a manifestation that erosion modeling is subject to varying environmental factors, where the process had unintentionally missed to capture. Subject to some limitations, the overall result of this modeling exercise illustrated the applicability of GeoWEPP to predict soil erosion and sediment yield under a similar

condition like the Taganibong watershed. The result offers an insight into identifying a specific location in the watershed with excessive soil erosion beyond the threshold. This study enables the research team to fill the gaps of information needed in the formulation of a site-specific policy recommendation for sustainable soil management in the agricultural watershed of Taganibong.

AUTHOR CONTRIBUTIONS

G.R. Puno performed the manuscript writing, prepared the GIS databases, thematic map layers, layout design, and graphs. R.A. Marin managed the operation of the project, collated, and analyzed the field data. R.C.C. Puno updated the landcover map using satellite images and edited the manuscript. A.G. Toledo-Bruno acted as project staff and edited the manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. Also, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

ArcGIS	Geographic Information System software product
ASCII	American Standard Code for Information Interchange
BPCDG	Breakpoint Climate Data Generator
BSWM	Bureau of Soil and Water Management
CEC	Cat-ion Exchange Capacity
CSA	Critical Source Area
DEM	Digital Elevation Model
dem.asc	Digital elevation map layer saved as ASCII format
DREAM	Disaster Risk and Exposure Assessment for Mitigation
GeoWEPP	Geospatial Interface for Water Erosion Prediction Project
GIS	Geographic Information System
ha	Hectare
Landcov.asc	Landcover map layer saved as ASCII format
Landcov.txt	Landcover map layer saved as text format
Landusedb.txt	Land use database saved as text format
masl	Meters above sea level
mm	Millimeters
m^3/y	Cubic meter per year
MS1	Monitoring Site 1
MS2	Monitoring Site 2
MS3	Monitoring Site 3
MSCL	Minimum Source Channel Length
NPK	Nitrogen, Phosphorus and Potassium
NSE	Nash-Sutcliffe Equation
OM	Organic Matter
PBIAS	Percent bias
R^2	Coefficient of determination
RMSE	Root mean square error
RSR	RMSE-observation Standard Deviation Ratio
SAR-DEM	Synthetic Aperture Radar-Digital Elevation Model
Soilsdb.txt	Soil database saved as text format
Soilmap.asc	Soil map layer saved as ASCII format
Soilmap.txt	Soil map layer saved as text format
SWAT	Soil and Water Assessment Tool
t/h/y	Tons per hectare per year
TOPAZ	Topographic Parameterization
UPD	University of the Philippines Diliman
USA	United State of America

USDA-ARS	United State Department of Agriculture-Agricultural-Research Service
WEPP	Water Erosion Prediction Project

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