GEOWEPP MODEL APPLICATION IN SIMULATING SOIL EROSION IN BAMBOO PLANTED AND CULTIVATED CATCHMENTS

George R. Puno*[1], Rico A. Marin[1], Angela Grace Toledo-Bruno[1]
[1]College of Forestry and Environmental Science, Central Mindanao University, Musuan, Bukidnon, 8710, Philippines
Email: geopuno@yahoo.com

Keywords: GeoWEPP, soil erosion, simulation, WEPP model

Abstract: This study applied the Geospatial Interface for Water Erosion Prediction Project (GeoWEPP) to determine soil erosion and sediment yield in the two catchments with and without bamboo, respectively. The catchments are located within Taganibong Watershed in Bukidnon, Philippines. GeoWEPP simulation requires four main input files corresponding to climate, slope, land management, and soil. Climate input file was processed within the Breakpoint Climate Data Generator (BPCDG) computer program based on the 2014 climate data collected using the automatic weather station. Slope input file was generated from Digital Elevation Model (DEM) derived from Interferometric Synthetic Aperture Radar (IFSAR) data. Soil and management input files were processed from field surveys. Separate database files in text format were also created to link WEPP model with GIS tool. Plant databases for bamboo obtained from various literatures were used to adjust the parameters of plant databases within the WEPP model environment. After series of calibration, soil erosion rate was predicted at an average value of 13.52 and 56.04 $t \cdot h^{-1} y^{-1}$ for catchments with bamboo and without bamboo, respectively. The respective sediment yields of 20.90 and 104.95 $t \cdot h^{-1} y^{-1}$ for site with bamboo and without bamboo were also simulated. Results showed that catchment planted with bamboo has consistently lower erosion and sediment yield values suggesting the capability of bamboo in reducing soil erosion and sedimentation rates. Model validation using observed data for catchment with bamboo showed satisfactory performance with coefficient of determination (R^2), Root mean square errors-observations Standard deviation Ratio (RSR), Nash-Sutcliffe Efficiency (NSE) and percent bias (PBIAS) values of 0.64, 0.62, 0.61, and 44.35, respectively. For cultivated sites or area without bamboo, R^2, RSR, NSE and PBIAS values of 0.85, 0.66, 0.56 and 25.62, respectively, were obtained. Overall, GeoWEPP performed satisfactorily implying applicability of the model in catchments with and without bamboo planted and steeper hillslopes like Taganibong.

1. INTRODUCTION

Denudation in majority of the Philippine uplands is evident due to severe soil erosion. About 80 million tons of soil is lost annually affecting 77% of the country's total land area, with 13 of 73 provinces experiencing moderate to severe erosion (PCARRD, 1999). Soil erosion and sedimentation continually threaten the sustainability of upland farming, the health of downstream ecology, and the quality and quantity of water resource. Like other watersheds in the country, Taganibong is saddled with soil erosion problem. The combined biophysical and anthropogenic factors make it prone to erosion.

The use of process-based model like GeoWEPP that could potentially aid in predicting soil loss has been supported and adopted for several years. After few decades, hundreds of researches were already conducted in line with the application of these models (DeRoo et al., 1996) and the studies became fundamental to the improvement of understanding and quantification of soil erosion and sediment yields (Nearing and Hairsine 2011). Moreover, researchers recognize the importance of erosion models as useful tool for land management, policy and decision making in the protection of soil and water resources (Acharya & Cochrane, 2009; Summer & Walling, 2002). Along with the understanding of relationships between the physical factors fallowing the dynamics of soil erosion is the advancement of computer generated geospatial interface becoming a useful tool of modeling the physical environment into computer simulation programs.

Process-based models are those simulations which maintain both empirical and physical relationships within a physically based structure represented in computer software (Moore et al., 2007). These models usually consider properties and processes at fine spatial and temporal scales to estimate distributions of soil loss and predict sediment yield (Flanagan and Nearing 1995). Moreover, these tools are versatile since it can be tailored and applied to selected locations (Covert et al., 2005) and could project accurate soil loss measurements to ungagged sites (Flanagan and Nearing 1995). If appropriately constructed, a process-based model may have the ability to extrapolate a short record of measured erosion to a longer time frame (Nearing and Hairsine 2011). However they require large number of input parameters (Renschler, 2003; Renschler & Flanagan, 2002).

WEPP was developed by the US Department of Agriculture–Agricultural Research Services in 1985. One of the most well-studied process based model, WEPP is a complex distributed parameter, continuous simulation soil erosion prediction model that incorporates the fundamentals of soil hydrologic and erosion science (Flanagan and Nearing, 1995). It was developed to estimate soil loss and sediment yield based on specific erosion factors including soil type, climate conditions, ground cover percentage, and topographic condition (Flanagan and Livingston, 1995). Along with WEPP is its geospatial interface (GeoWEPP) used as extension of GIS tool (Renschler, 2003). GeoWEPP allows users to access and import available topography, soils, and land cover information to conduct a WEPP model simulation (Flanagan et al., 2011). Outputs are displayed in spatial maps of predicted erosion. A lot of studies had already been conducted using GeoWEPP in many countries like the U.S, Brazil, Turkey, including Philippines. Generally, though challenged by the lack of information in field conditions of soil and values of its properties, still most researchers concluded the better performance of GeoWEPP when compared with other models (Mello et al., 2016). However, there still no application of GeoWEPP with plant database specific to bamboo.

Bamboo is expected to be effective in arresting soil loss under certain environmental conditions. However, literatures regarding the quantification of giant bamboo's capability in soil erosion are very limited. It is in this premise that this study was conducted with the aim of forwarding a recommendation of using giant bamboo as measure for soil and water conservation. The study also aimed at attesting the applicability of GeoWEPP model given the physical characteristics of the sites and the plant database of bamboo using secondary information from various literatures (Virtucio et al., 2003; Schneider at al., 2011; Kleinhenz and Midmore, 2001; Scurlock et al., 2000; Wangchuk at al., 2014; Lobovikov et al., 2009).

GeoWEPP is more suited for this kind of simulation which produces spatial variability map of erosion at specific location. The model was applied to simulate soil loss in the two sites within the Taganibong Watershed. The first site is planted with bamboo while the other one was cultivated for corn production. Clay loam type of soil dominates in the two sites. The model uses four main input files corresponding to climate, soil, slope and management which were prepared based on the condition of the area.

Average soil loss of 13.52 and 56.04 $t \cdot h^{-1}y^{-1}$ and average sediment yield of 20.90 and 104.95 $t \cdot h^{-1}y^{-1}$ were predicted at the two catchments with and without bamboo. The model was validated using observed soil loss data collected from site with bamboo and found acceptable with coefficient of determination (R^2), Root mean square errors-observations Standard deviation Ratio (RSR), Nash-Sutcliffe Efficiency (NSE) and percent bias (PBIAS) values of 0.64, 0.62, 0.61, and 44.35, respectively. Using soil loss data from site with no bamboo, statistics of 0.85, 0.66, 0.56 and 25.62 were calculated for R^2, RMSE, NSE and PBIAS, respectively.

Overall, GeoWEPP performed satisfactorily implying applicability in catchment with intensive cultivation and steeper hillslopes like Taganibong. Under prediction by the model as shown by a consistent positive PBIAS values may be attributed to complex varying factors of the catchment which the model has not accounted for (Liu, et al., 1997). Outputs of this research could potentially be helpful in site specific decision making related to soil and water protection and conservation.

2. METHODOLOGY

2.1. Study Sites

Two soil erosion monitoring sites were established within Taganibong Watershed in Bukidnon, Philippines. The sites were labelled as area with bamboo and without bamboo (Figure 1). The monitoring sites have an average elevation of 390 meters above sea level with an average slope of 12%. Clay loam type of soil dominates the area with approximately 10% rocks. The site with bamboo plantation has an area of 0.86 hectares. It is grown with middle aged culms of giant bamboo (*Dendrocalamus asper)* spaced approximately at 10 by 10 meters. Culm removal and other activities inside the area have been temporarily prohibited to avoid disturbances for research purposes. The site without bamboo has an area of 0.55 hectares which was cultivated for corn production. After harvest of corn, the site was left uncultivated for two years with short grasses and herbs as the dominant land cover.

The sites were monitored for soil erosion from 2013 to 2015 using erosion bar. There were 19 erosion bars installed in area with bamboo while 6 in area without bamboo. Erosion values were measured every rainfall event. An automatic weather station (AWS) was installed near the sites to monitor the different climate parameters such rainfall, temperature, wind speed and wind direction, and relative humidity. In the succeeding year, two weirs were installed at the outlet of each site which were used to measure sediment yield.

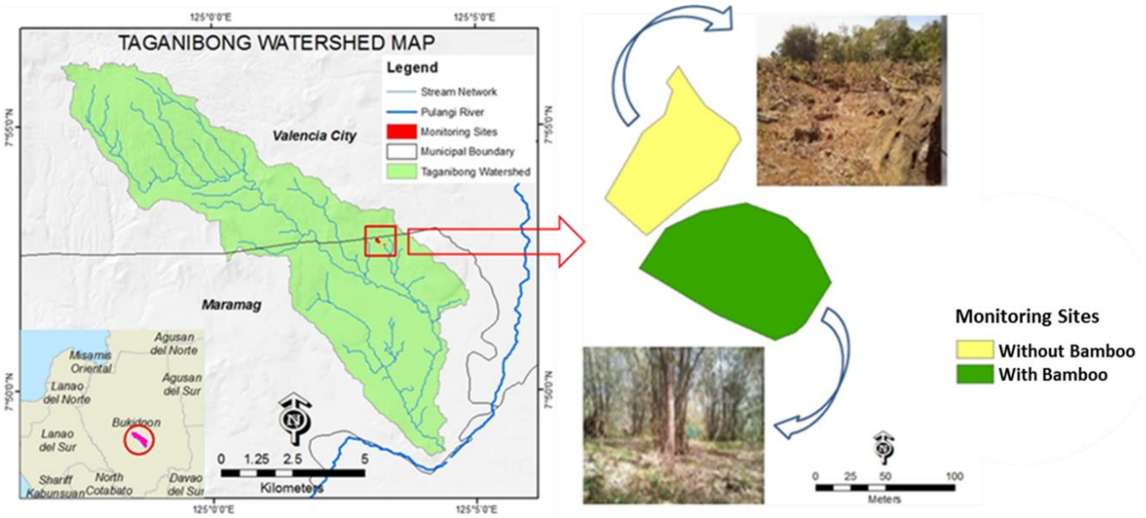


Figure 1: Location of soil loss monitoring sites

2.2. Data Processing for GeoWEPP Simulation

Basically, GeoWEPP modeling requires four major groups of input files corresponding to climate, land cover, soil, and slope data. All input files needed by the model to run were processed and prepared based from the data collected from the sites.

2.2.1. Slope Files Preparation. GeoWEPP utilizes Topographic Parameterization (TOPAZ) tool to automatically generate hillslope profiles from a Digital Elevation Model (DEM) (Yuksel et al., 2008). To create a more accurate DEM, the Geographic Positioning System (GPS) Devise was used to mark the coordinates within the study areas. The collected points were georeferenced and interpolated to generate DEM with higher resolution. GeoWEPP requires DEM data in ASCII) format so that the resulting map layer was saved as dem.asc.

2.2.2. Soil File Preparation. Percentage of sand, silt, clay, and organic matter content of the soil were obtained through soil analysis. Soil samples were collected from the site to represent the first and second layer, respectively. Presence of rocks expressed in percentage was estimated through ocular observation which covers 10% of the area. Data on albedo and cation exchange capacity (CEC) were collected from published literatures. Interrill and rill erodibility, critical shear, and effective hydrologic capability were calculated from the internal capability of WEPP.

Soil map layer was created for the GeoWEPP interface. Initially, a vector polygon map containing soil attributes of the area was created, edited, processed, finalized, and converted into a raster-based data model. The resulting map was converted into ACII and saved as soilsmap.asc file. The procedure by Minkowski (2007) as revised by Puno (2014) was followed in creating the soil map layer.

2.2.3. Management File Preparation. Management files for GeoWEPP model require information of initial condition and plant database. Plant characteristics and information of the site such as tillage and rotation were created using the built-in database of the WEPP with modifications in some of the parameters to fit with the existing conditions. Since WEPP does not have databases for bamboo, a new database for the plant was created. Information on Giant Bamboo was gathered from field observation supported with literatures. Table 1 shows the plant database of bamboo used in the simulation. For the area without bamboo, the built-in databases of WEPP were adjusted to suit with the field conditions. To link management database with GeoWEPP, a land cover/land use map in ASCII format saved as landcov.asc file was also created for the two sites in a manner where soils map layer was created.

2.2.4. Climate Data Processing. GeoWEPP model will run using a climate file for one year. A five-minute interval climate data was collected from automatic weather station installed near the study site for one year (Jan-Dec, 2015). Climate data includes values of precipitation (mm), maximum and minimum air temperature, relative humidity (%), solar radiation (Mj/sq.m.), wind direction, and wind speed (m/s).

Standalone program such as Break Point Climate Data Generator (BPCDG) (Zeleke et al., 1999) was used to generate climate input file for the WEPP model to run the simulation. The detail of the process discussed in Minkowski (2007) was followed in generating the climate input using the BPCDG module. BPCDG helps to create breakpoint climate data for WEPP from standard rain gauge data and other daily weather datasets of any meteorological station. The use of BPCDG was preferred based on its advantages over CLIGEN as identified by Zeleke et al., (1999). Unlike other climate data generator, BPCDG allows direct use of observed storm and other daily standard climate data sets.

Table 1. Bamboo plant database for GeoWEPP simulation

Initial Condition	Input Values	Sources
In-row plant spacing	700 cm	Bareja, 2010
Plant stem diameter at maturity	22 cm	Bareja, 2010
Days of last tillage (approximate)	10,585 days	Interview
Harvest index	53.13%	Kleinhenz and Midmore, 2001
Period over which senescence occurs	2920 days	Lobovikov et al., 2009
Bulk Density after last tillage	0.9 g/cu.cm	Result from laboratory analysis
Biomass energy ratio	28.7 kg.MJ	Schneider et al., 2011
Maximum leaf area index	11.6	Scurlock et al., 2000
Growing degree days of emergence	14	Virtucio and Roxas, 2003
Height of Post-harvest standing residue	2000 cm	Virtucio and Roxas, 2003
Optimal temperature for plant growth	22.5^0	Virtucio and Roxas, 2003
Maximum temperature that stops growth	36^0	Virtucio and Roxas, 2003
Maximum canopy height	3000 cm	Virtucio and Roxas, 2003
Maximum root depth	100 cm	Virtucio and Roxas, 2003

2.3. Model Simulation Run

Prior to the actual simulation run, channel network and catchment boundary was delineated within GeoWEPP using the files created such as dem.asc, landcov.asc, and soilsmap.asc using the concept of a critical source area (CSA) and minimum source channel length (MSCL). CSA and MSCL were set to determine the desired density of channel network and number of hillslope for the catchment.

2.4. Model Evaluation

Model performance to predict was evaluated by calculating the coefficient of determination (R^2) RMSE, NSE and PBIAS values. The RMSE-observations standard deviation ratio (RSR) standardizes RMSE using the observations standard deviation and incorporates the benefits of error index statistics and includes a scaling/normalization factor (Legates and McCabe, 1999). It ranges from the optimal value of 0 which indicates a perfect prediction or zero RMSE to large positive value. It follows the lower RSR, the lower the RMSE, and the better the model simulation performance (Moriasi et al., 2007). RSR is calculated as the ratio of the RMSE and standard deviation shown in the below equation,

$$RSR = \frac{RMSE}{STDEV_o} = \frac{\left[\sqrt{\sum_{i=0}^{n}(Y_i^o - Y_i^s)^2}\right]}{\left[\sqrt{\sum_{i=0}^{n}(Y_i^o - Y_i^m)^2}\right]}$$

where Y_i^o is the i^{th} observation for the constituent being evaluated, Y_i^s is the i^{th} simulated value for the constituent being evaluated, Y_i^m is the mean of observed data for the constituent being evaluated, and n is the total number of observations.

Percent bias (PBIAS) assesses the average tendency of the predicted results to overestimate or underestimate the field observed data (Gupta et al., 1999). A PBIAS of 0.0 indicates an accurate model performance. Positive value on the other hand indicates 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). PBIAS is calculated with the equation below,

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Y_i^o - Y_i^s)100}{\sum_{i=1}^{n}Y_i^o}\right]$$

where symbols are as stated from previous equation.

NSE is another test of model performance which indicates how well the plot of observed versus simulated data fits the 1:1 line. Using the symbol from the previous equations, NSE is computed as shown below,

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^o - Y_i^s)^2}{\sum_{i=0}^{n}(Y_i^o - Y_i^m)^2}\right]$$

NSE ranges between -∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance (Moriasi, 2007).

3. RESULTS AND DISCUSSION

3.1. Model Simulation

GeoWEPP simulation for soil loss and sediment yield was set at tolerable limit of 10 t^{-1} $ha^{-1}yr^{-1}$. Tolerable limit refers to the degree of soil loss which can be accepted as normal. This considers significant factors as enumerated by Mannering (1981) which includes the anticipated rate at which soil renewal may occur, by in situ formation or imported deposits as a result of prevailing weathering processes; the effect of soil removal on soil productivity; and the impact of delivered sediments on the environmental quality of waterways or other destination points. The tolerable value set for this study was within the normal range suggested in several literatures (El-Swaify et al., 1982; Morgan, 1995; Troeh and Hobbs, 1999; Puno 2014).

A 0.01 hectare for Critical Source Area (CSA) and 20 meters for the Minimum Source Channel Length (MSCL) was set before simulation was conducted. CSA and MSCL are input parameters in GeoWEPP which are important for hydrographic landscape segmentation and channel network generation (Puno, 2014). As the value of CSA increases, generated network of drainage density decreases while increasing the value of MSCL removes the shorter channels.

Model results showed predicted soil loss of 13.52 and 56.04 $t{\cdot}ha^{-1}yr^{-1}$ for sites with bamboo and without bamboo, respectively. Coded with different colors, variability of erosion values for the two sites is shown in Figure 2.

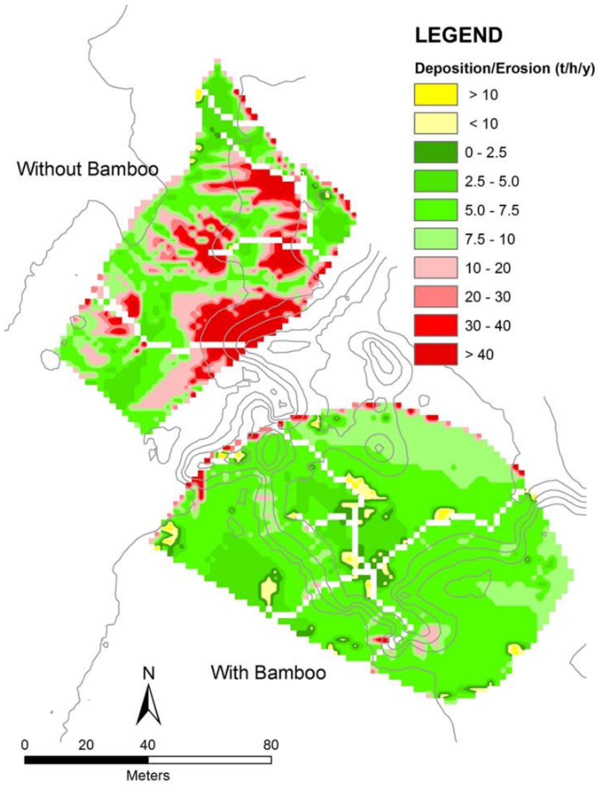


Figure 2. Annual soil loss map of the two sites

3.2. Model Evaluation

The predicted soil erosion of the two sites were compared with observed data to test model performance. Results (Table 2) show close fitting between observed and predicted erosion values in both areas. R^2 of these ranges were also observed in several studies (Kirnak, 2002; Pandey, 2007; Yuksel, 2008; Alibuyog, 2009; Yesuf et al., 2015) implying that the model is a good predictor of erosional processes at an acceptable parametric calibration under similar conditions.

Table 2. Model evaluation statistics using average erosion values.

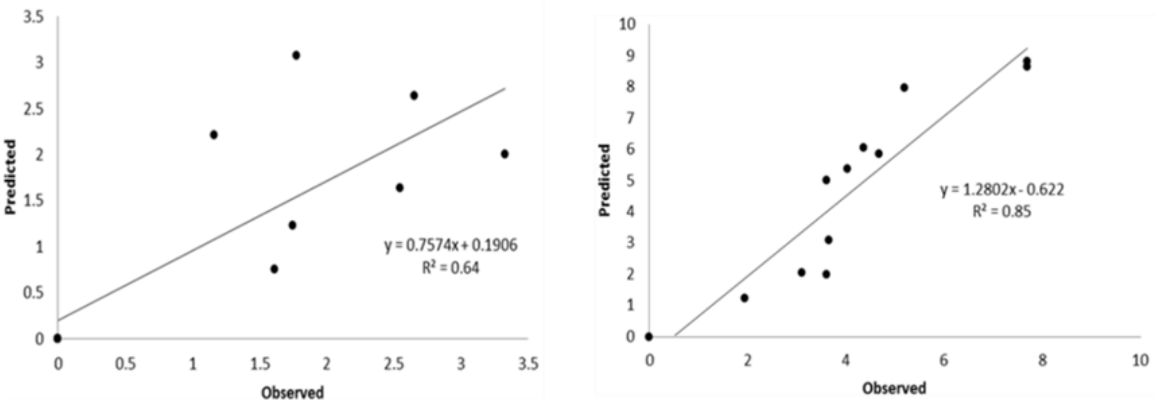
Site	Observed ($t \cdot h^{-1} y^{-1}$)	Predicted ($t \cdot h^{-1} y^{-1}$)	Evaluation Parameters			
			R^2	RSR	NSE	PBIAS
With bamboo	25.31	13.52	0.64	0.62	0.61	44.35
Without bamboo	49.60	56.04	0.85	0.66	0.56	25.62

Acceptable range of model performance ratings based on recommended statistics (Table 2) showed that the model generally performed satisfactorily. A value of RSR closer to 0 means increasing model prediction accuracy with good performance rating (Moriasi et al., 2007). Model evaluation on GeoWEPP researches had also performed similar satisfactory rates. Yesuf et al. (2015) acquired the values of 0.67 and 0.69 RSR in predicting sediment yield in Maybar gauged watershed in Northeast Ethiopia. Similar study conducted by Fukunaga et al. (2015) on the hydrologic modeling to a tropical watershed at Brazil where RSR values of 0.57 was acquired.

The model has the tendency to underestimate soil erosion values as shown by consistent positive PBIAS values for the three sites. Values of PBIAS on the results of simulation using GeoWEPP model are generally acceptable based on the report of Moriasi et al. (2007) where PBIAS of $\pm$55% for sediment is already satisfactory. Under 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 factors (Liu et al., 1997).

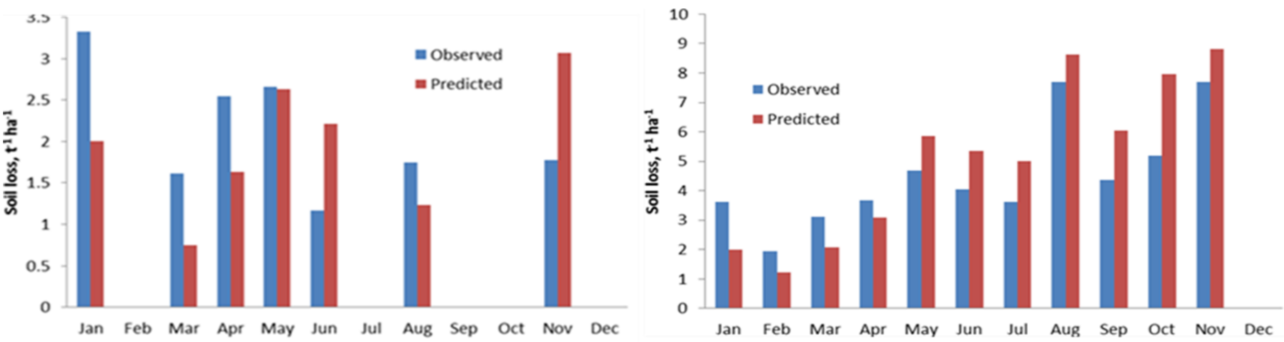
Highest variability of soil erosion from low to severe up to more than 40 $t \cdot h^{-1} y^{-1}$ in some locations were predicted in the two fallow sites. High soil losses in these sites indicate that short grasses and herbs are not as effective in arresting soil loss as compared with bamboo plant.

Figure 3 presents the linear analysis between observed and predicted soil erosion for the two sites. Similarly, Figure 4 shows the graphical comparison of the considered parameters based on monthly average values.



a) b)

Figure 3. Observed and predicted erosion values; a) with bamboo, b) without bamboo



a) b)

Figure 4. Observed and predicted soil erosion; a) giant bamboo, b) without bamboo

4. CONCLUSION

GeoWEPP was successfully applied to predict soil erosion on land cover-specific areas. Two study sites within Taganibong Watershed were selected corresponding to giant bamboo plantation and without bamboo. For the GeoWEPP simulation, digital files of soil, land cover and DEM all in ACII format were prepared using GIS processing tools. Database files for management and soil information were also created within the WEPP model interface. Climate file was processed using the BPCDG standalone module. Results showed a predicted soil loss of 13.52 and 56.04 $t{\cdot}h^{-1}y^{-1}$ and sediment yield of 20.90 and 104.95 $t{\cdot}h^{-1}y^{-1}$ for areas with and without bamboo, respectively. The predicted soil loss was consistent with observed data where highest value occurred in the area without bamboo. This indicates the short grasses and herbs are not as effective as compared with bamboo plant in arresting soil erosion considering all other factors held the same.

Model performance was evaluated by comparing the predicted soil loss values with the observed data from each land cover type. Overall, using the recommended model performance evaluation statistics (R^2 = 0.64, RSR = 0.62, NSE = 0.61 and PBIAS = 44.35) for bamboo site, (R^2 = 0.85, RSR = 0.66, NSE = 0.56 and PBIAS = 25.62) for area without bamboo, respectively. This indicates that the model performed satisfactorily in predicting hydrologic variables like soil loss and sediment yield at certain level of accuracy.

GeoWEPP underestimated the soil erosion of about 44.35% and 25.62% in areas with bamboo and without bamboo, respectively, as consistently indicated with positive PBIAS values. Under prediction however does not necessarily mean poor performance by the model but rather an indication that modeling is subject to complex varying environmental factors which may not be captured during the entire simulation exercise. In so doing, model performance was satisfactory being consistent with the $\pm$55% acceptable PBIAS rate for sediment yield modeling (Moriasi et al., 2007).

5. ACKNOWLEDGEMENTS

This paper is part of the project funded by the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD) of the Department of Science and Technology (DOST). The author is grateful to the Central Mindanao University administration for its support.

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