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Validation and Sensitivity Analysis of Catchment Runoff and Erosion Simulation Technology (CREST): A GIS-assisted Soil Erosion Model at Watershed Level

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Abstract

Most erosion models have been developed based on a plot scale and have limited application to a watershed due to the differences in scale. In order to address this limitation, a GIS-assisted methodology for modeling soil erosion was developed using PCRaster to predict the rate of soil erosion at watershed level and identify the location of erosion prone areas. The GIS-assisted hydrology and erosion models were validated at Tanghaga Watershed using the observed values from previous experiment. The predicted peak rates, Q_p, showed a highly significant relationship with the observed Q_p, with an r^2 value of 0.75. For soil loss prediction, a significant relationship was also noted with an r^2 value of 0.74. Sensitivity analysis using four parameters was done. The model response was most sensitive to Manning's roughness coefficient (n) for Q_p. An increase in n value from 0.02 to 0.13 resulted in a decrease of 546% in the predicted Q_p. On the other hand, the predicted soil loss was most sensitive to the vegetative cover. Increasing the value of vegetative cover form 0.20 to 0.95 resulted in decrease of about 1,567%. The location of erosion hotspots was predicted within and along the tributary channels as well as in areas with low vegetative cover and steeper slope gradient. The capability of GIS-assisted model in predicting the location of erosion hotspots is a significant finding and this approach is a valuable tool in the formulation of a good watershed rehabilitation program.

Keywords: Catchment Runoff and Erosion Simulation Technology (CREST); soil erosion; GIS-assisted modeling; Geographic Information System; PCRaster

INTRODUCTION

Soil erosion is a major problem in watershed whose end products are differentiated into soil loss and the sediment yield. Soil loss is the quantity of soil move off from an area in a slope while sediment yield is the eroded soil that is delivered to a specific point in the watershed under evaluation. The former affects soil productivity while the latter the quality of stream water. The process is a result of complex process determined by mutual interaction of many factors (Bradford and Huang [1996]; Suri et. al. [2002]). Proffitt et. al. [1991] stated that it occurs even with slopes considerably lower than 5% especially with less surface cover due to raindrops impact and significant overland flow. Generally, high precipitation, steep slopes and intensive agriculture in hillslopes in the humid tropics favor the high risk of soil erosion. However, the severity of erosion may differ in time and space because the amount of soil loss resulting from an individual rainfall event is dependent upon the integrated effects of edaphic and other environmental factors.

Soil erosion occurs at a range of temporal and spatial scales that cover from plot-size scales where individual measurements are made, via the field scales which concerns the farmer, and up to the catchment scales which can influence the major planning formulations and interventions (Kirkby et. al. [1996]). The complexity of the process increases from the plot-size to catchment scale that leads most researchers in the past to work on plot-size models, but bound to some constraints on their application. Moore et. al. [1988] asserted that such plot-size models cannot successfully represent the spatial variability of the dynamic process in a real three-dimensional system like a watershed. Thus, the issue of upscaling becomes a relevant issue because of the current threats of the watershed ecosystems.

The paper aims to validate and conduct sensitivity analysis of CREST, a GIS-assisted soil erosion model at watershed level, to predict runoff and soil erosion of a given rainfall at watershed level, and to assess the realism of extrapolation in space from the smaller-scale plot studies to catchment scale, and to predict runoff and soil erosion of a given rainfall at watershed level.

REVIEW OF LITERATURE

Generally, research on soil erosion process is linked to the use of the Universal Soil Loss Equation (USLE) which summarizes a large and long-term experimental database (Wischmeier and Smith [1978]). However, there is a paradigm shift as evidenced by the development of process-oriented, event-based erosion models to achieve better understanding on soil erosion and the contributing factors towards using individual rainfall events (Foster [1982]; Govers and Poesan [1988]; Nearing et. al. [1989]; Misra and Rose [1989]; Hairsine and Rose [1991] and [1992]; Morgan et. al. [1992]; Mitasova [1998]). Suri [2002] cited that physically-based models are usually spatially distributed trying to predict soil erosion rates at a time level in a single erosion event.

Modeling soil erosion is a sound approach in planning conservation strategies and programs. However, Moore et. al. [1992] mentioned that modeling erosion at watershed level is a complex process because of the integrated effects of climate, terrain and substrate that affects the hydrological, erosional, and biological processes occurring in a natural landscape. Nevertheless, various models have been developed and applied in watershed such as MUSLE (Williams [1975]), ANSWERS (Beasley et. al. [1980]), CREAMS (Knisel [1980]), APNPS (Young et. al. [1987]), WEPP (Foster and Lane [1987]; Nearing et. al. [1989]; Laflen et. al. [1991]). Furthermore, advancement in computer technology gearing towards integration of GIS functionalities and environmental dynamic modeling presents an unparalleled approach of modeling soil erosion (PCRaster [1996]; Lanuza [1999]). The The Catchment Runoff and Erosion Simulation Technology (CREST) is a spatial distributed model developed through GIS-assisted approach using PCRaster (Lanuza and Paningbatan [2001]). It was developed in an effort to generate the desired information on runoff and soil erosion with due consideration of the spatial heterogeneity and temporal distribution of the watershed. Moreover, CREST supports a strong spatial referencing of the modeled processes and associated parameters. Nevertheless, it is not enough to predict the net effects of partial areas on a catchment scale but also identify and determine specifically where those areas are located.

Lanuza [1999] noted that GIS-assisted modeling becomes a reliable tool for obtaining information on spatial variability of soil erosion at watershed. For research on detailed scales such as in a watershed, GIS functionalities and analysis are integrated in simulating natural processes with consideration of subprocesses of soil erosion. Models developed through GIS-assisted modeling approach addressed the complexity of an ecosystem in terms of spatial heterogeneity and temporal distribution and predict the processes at watershed level. On a regional scale, Suri [2002] stated that the aim is a general evaluation of the landscape and its susceptibility to soil erosion by water taking into account only the main factors influencing the process and the erosion subprocesses are not studied.

The work of Lanuza [1999] aimed in developing a GIS-assisted methodology for modeling of soil erosion at watershed level with time element. The approach involved the integration of the concepts of soil erosion with the Geographic Information System and dynamic environmental modeling (PCRaster [1996]). The task in devising the methodology seemed to be difficult; however, the enthusiasm and challenges became the motivating factors for a successful endeavor. The Catchment Runoff and Erosion Simulation Technology (CREST) is designed with some flexibility. Generally, most models are either products with no source code readily available, or are too complex to be modified by anyone other than the programmers. Users are only limited in experimenting the input parameters but not on the model structure and design. However, CREST can be conveniently modified to customize or adapt the representations of the physical processes modeled.

MATERIALS AND METHODS

Site Description

The Tanghaga Watershed is one of the micro-catchments of Manupali Watershed characterized by an elongated catchment with an average slope of 15% and a dimension of 2.6 km long and 0.29 km wide on the average (Agua [1997]). It is situated at geographic coordinates between 124°59’3” to 124°59’53” East longitude and 8°1’18” to 8°3’15” North latitude. A barangay road at the bottom of the catchment serves as the boundary at the lower portion. Its highest and lowest elevations are about 1,210 and 758.9 m above sea level. West [1994] as cited by Agua [1997] mentioned that the soil is generally loamy with fine to granular structure developed from volcanic ash. The soil type of the catchment belonged to Kidapawan clay loam. The watershed is agriculturally active as noted by various farming activities that included land preparation, seeding, off-barring, and hilling up. Moreover, farming activities were continuously year-round except for a lull for about three weeks from mid-December until first week of January for each year (Agua [1997]) being favored by adequate rainfall.

Gathering of Information and Generation of GIS Maps

Secondary information relevant in the GIS-assisted modeling of the selected micro-catchment were gathered. These included maps and reports of the selected micro-catchment such as topographic map, existing landuse map, soil map, vegetation map, and rainfall station were accessed and secured from ICRAF, DENR-10, DA-10, SANREM and Central Mindanao University. In addition, watershed discharge, sediment concentration, peak discharge, and soil loss were also gathered from Agua [1997]. Actual field visit was also conducted to have an ocular observation and ground checks on watershed characteristics particularly on drainage network, topographic divide, Manning's roughness coefficient, present landuse type, flow width, cropping system and surface contact cover.

Geo-relational Database Creation and GIS-assisted Model Development

A combination of GIS operations was used to generate the geo-relational databases (PCRaster 1996). Map attributes for each spatial data were transformed into computer binary format. Digitized maps were processed to generate the catchment-based databases using the cartographic modeling (Lanuza [1999]; Lanuza [2001a]; Lanuza [2001b]).

The GIS-assisted approach involved five general steps, namely, a) model development and structuring, b) formulation of assumptions, c) gathering of information, d) database creation, manipulation and processing with GIS, and e) dynamic modeling with PCRaster (PCRaster [1996]). The dynamic model included the hydrology, sediment transport and routing, sediment concentration, and soil loss within the selected catchment. The hydrology modeling comprised the following: a) rainfall model, b) infiltration model, c) runoff or discharge model. The model calculated the spread of rainfall from the rainfall station generated using the rainfall zoning, calculated the rainfall intensity at the designated timestep, and then calculated the infiltration capacity, runoff and water discharge. The rainfall flux or intensity was assumed to follow a sine curve and modeled based on the amount of rainfall. The area of the curve represented the cumulative rainfall for the specific rainfall event. The infiltration was modeled using the different factors such as soil type, landuse and cropping pattern and their interaction. The amount of excess rainfall that overflows governed the transport of detached particles. Therefore, the runoff was modeled by knowing the total rainfall and the amount of water that infiltrated. The height of water was computed as the initial water height plus the amount of runoff. The details on the equations used in the model are described in Lanuza [1999] and Lanuza and Paningbatan [2001].

The process of soil erosion was modeled following the concept of Rose et. al. [1983] which calculate the amount of soil loss (SL) from the product of sediment concentration (C, in kg m-3) and water discharge rate (Q). Sediment concentration is estimated using the simplified Equation (1) by Rose and Freebairn [1985] which is expressed as:

$$C(L,t) = 2700\,\lambda\,S\,(C_r) \tag{1}$$

Thus, the total sediment loss can be calculated from Equation 2:

$$SL = = 2700\,\lambda\,S\,(1 - C_o) \tag{2}$$

where SL is the sediment loss (kg per timestep), λ is the factor approximating efficiency of entrainment, S is the sine of slope angle, $(1 - C_o) = C_r$ where C_o is the ratio of the area not exposed to runoff or the contact cover fraction, and Q is the water discharge rate (m^3 per timestep).

The GIS-assisted models were validated using the actual data gathered from the monitoring station. Sensitivity analysis was also made to determine the sensitivity of the model output to the changes of the model input.

RESULTS AND DISCUSSION

Model Description and Inputs

CREST is a processes-based and event-oriented runoff and erosion model in a watershed. It is a cell model that divides the watershed into small, homogenous cells. Each model calculation is performed for each cell with cell-to-cell interactions handled. The schematic diagram of the model is shown in Figure 1. CREST is composed of the runoff and sediment concentration sub-models. Each sub-model is a representation of the processes that controlled the mass balance within a hydrologic subsystem. The detailed model script that can be run in PCRaster is presented in Lanuza [1999]. Model development did not only focus upon a single process as the key, but rather recognized that it was necessary to incorporate all the most important processes. The use of current GIS technology enables the construction of a physically-based erosion model.

The primary model inputs were maps on topography, soil, landuse, rain gauge station and monitoring station of the catchment. Other inputs were set of reclassification rules to govern the generation of secondary input values. These secondary or derived input values, although requiring interpretative rules, were still closely tied to easily observable or obtainable characteristics of the watershed. These input databases were generated using cartographic modeling of PCRaster (Figure 2, 3, and 4).

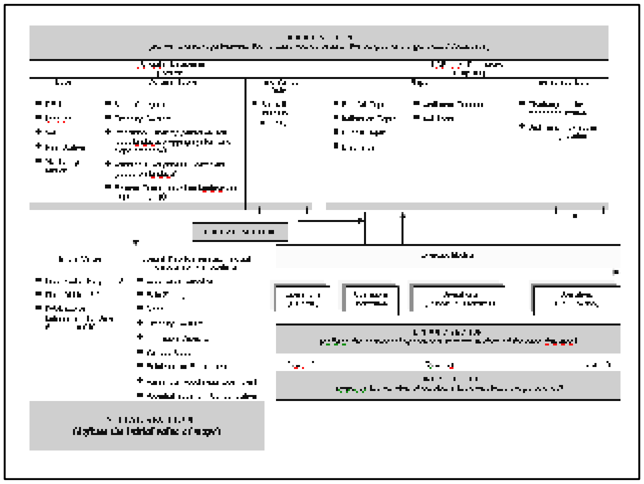

Figure 1. The schematic diagram of the GIS-assisted soil erosion model

The hydrology and soil erosion models were developed using the dynamic modeling of PCRaster. Hydrology models comprised the following: a) rainfall model, b) infiltration model, and d) runoff model. Soil erosion was modeled following the concept of Rose *et al.* [1983] and that considers the amount of soil loss as the product of the suspended sediment concentration and volume of runoff. The total sediment loss can be computed using the simplified equation (Equation 2).

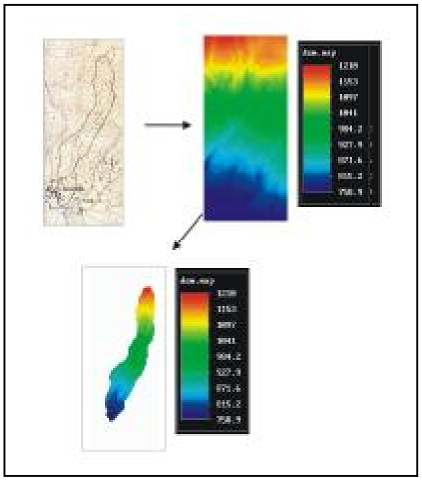

Figure 2. GIS-assisted methodology of catchment delineation using cartographic modeling (Lanuza 2001b).

Predictive Capability of CREST and Validation

CREST was able to predict the runoff rates and cumulative sediment fluxes with time (Figure 5 and 6) and these data were validated using existing information. Actual data, such as peak runoff rate (Q_p) and soil loss, generated by Agua [1997] at Tanghaga Watershed were used to validate the developed GIS-assisted models. The peak rates generated from computer simulation were validated using 12 selected rainfall events only due to limited observed values that are suited for validation. The predicted Q_p derived from the hydrographs generated for each model run using the selected rainfall events as input to the GIS-assisted model. Based on the test of difference of means using Student t-test, no significant differences were noted between the observed and predicted Q_p. This implies that the model could accurately represent the actual hydrologic system of the catchment. The coefficient of correlation (r) was considerably high with a value of 0.869. The data points are seemingly within the equality line (Figure 7). Furthermore, the coefficient of determination (r^2), 0.75 of the regression equation between the observed and predicted

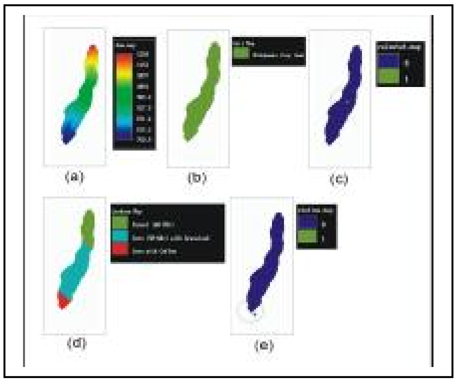

Figure 3. Main geographic input databases generated through cartographic modeling using PCRaster; a) DEM map, b) soil map, c) rain station map, d) landuse map, and e) monitoring station.

Q_p using the GIS-assisted model was highly significant (Figure 7). It implies that 75% of the variation of the observed Q_p can be explained by the predicted Q_p. This is expected because of the complex process occurring in a natural landscape with the model failed to consider. The Q_p is highly dependent on several factors and their interactions.

The GIS-assisted model considered only factors that can be easily measured and estimated such as depth of runoff, Manning's roughness coefficient and flow width. However, the model failed to consider the initial moisture condition prior to each rainfall event as well as the behavior of infiltration at different moisture contents. Apparently, infiltration of same soil type varies at different moisture regimes. Drier soil has higher infiltration rate at the start of the rainfall than for an initially wetted soil and finally attained a steady rate infiltration under saturated conditions. Since CREST considers only the percentage of rainfall that infiltrated, peak runoff rate may be underestimated if the soil is initially wet but overestimated if initially dry prior to a rainfall event. It could be that at the start of the rainfall event until the time that infiltration capacity is attained, infiltration is relatively higher at dry conditions compared to moist conditions. This implies the importance of incorporating an infiltration equation that accounts for the infiltration behavior at different moisture contents and the time in which runoff would start to occur to improve the predictive capability of the model. The magnitude and the time that runoff would start serves as reference point to account for the amount of runoff rather that the percentage of rainfall that infiltrated.

CREST was validated using six rainfall events only due to limited data suited for validation with rainfall intensities and amounts ranging from 4.6 to 36.5 mm/hr and 5.6 to 20.6 mm, respectively. The predicted total soil loss was computed by summing up the specific soil loss in each designated timestep. The test of differences of means showed no significant differences between the observed and predicted soil loss. Thus, CREST could approximate the actual soil erosion in the catchment. In addition, a considerably high positive correlation was noted between the predicted and observed soil loss with a value of 0.865. This implies that the predicted values are closer to the observed values. The coefficient of determination (r^2) value of 0.74 was significant (Figure 8). This indicates that 74% of the variation of the observed soil loss could be explained by the predicted soil loss using CREST. It is expected because aside from the minor deficiency of the hydrology model, the detailed landuse and farming activities were not properly accounted. Available landuse map used was general thereby it did not indicate the specific spatial variation within each landuse type which is expected in a natural landscape.

The occurrence of this spatial variation greatly affects the extent and nature of vegetative cover as well as the related farming activities, which ultimately affect both runoff and soil erosion. The value of the fraction of soil surface exposed to erosion (C_e) under croplands depends on the growth stage and type of crop while for bare surface is unity. Bare grounds are more susceptible to the erosive power of rainfall than a vegetated surface. This is brought

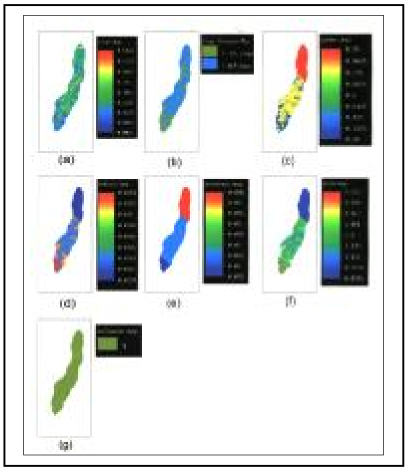

Figure 4. Spatial maps generated through cartographic modeling using PCRaster; a) slope map, b) slope category map c) vegetative cover map, d) entrainment map, e) Manning's roughness map, f) potential sediment map, and g) rain zone map.

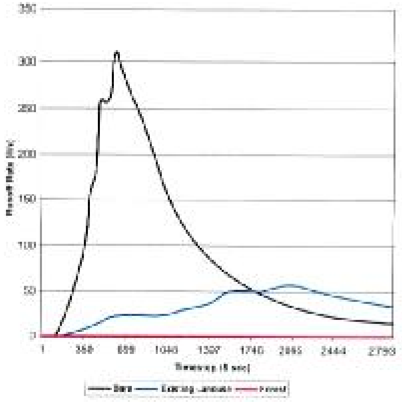

Figure 5. Predicted runoff rates as affected by surface cover at watershed level.

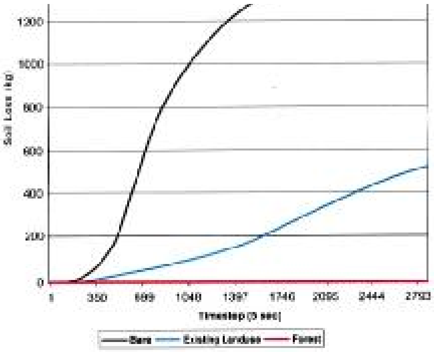

Figure 6. Predicted cumulative soil loss as affected by surface cover at watershed level.

about by the kinetic energy of raindrops that cause the detachment of soil particles from the soil mass. Al-Durrah and Bradford [1982] stated that the raindrop impact on bare soil creates intense shear stress, which can detach large quantities of sediments. The detached particles are the potential sediments that tend to increase the sediment concentration in runoff water.

Nonetheless, the process-based GIS-assisted erosion model was able to predict the rate and amount of soil loss at watershed level. Its predictive capability could be rather improved by refining the hydrology model and incorporating a comprehensive database on the landuse and farming systems. With its limitations, it implies further validation of the model to have a wider applicability considering all relevant factors and their possible interactions.

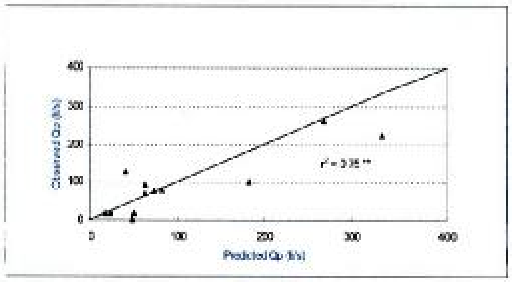

Figure 7. Scatter diagram of observed against predicted peak runoff values at Tanghaga Watershed.

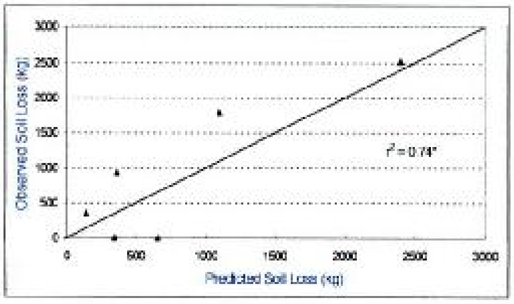

Figure 8. Scatter diagram of observed against predicted soil loss at Tanghaga Watershed.

Sensitivity Analysis

The basic objective of sensitivity analysis is to determine the magnitude of changes in the response of the model due to changes in the value of the specified parameter. In this paper, sensitivity analysis was conducted on the effects of four watershed parameters on runoff rate and soil loss considering realistic ranges of values under field conditions. The effect of each parameter was studied by varying its values while keeping the other parameters constant. While performing the sensitivity analysis, the values of Manning's roughness coefficient, flow width, percent of water that infiltrated and surface cover were held constant as 0.065, 3.0 m, 80% and 0.80, respectively. In all cases, the August 26, 1996 rainfall event with an intensity of 37.2 mm hr-1 that lasted for 15 min was used as the rainfall input. However, the sensitivity results are site specific and may differ with locations of different landuse, topography, soil and watershed characteristics.

Effect of Manning's Roughness Coefficient

Three Manning's roughness coefficients, such as 0.02, 0.065 and 0.13 were selected to evaluate the effect on runoff rate and sediment loss. There was an inverse relationship of the Manning's n both at runoff rate and soil loss. The Q_p was found to decrease by 546% as the roughness coefficient increased from 0.02 to 0.13 (Table 1). The reason is that an increase in roughness induces microdepression storage resulting in delayed initiation of the runoff process that in turn delayed the time to peak. Since the total runoff does not vary significantly, the reduction in runoff due to delayed initiation of peak rate is compensated by prolonged period of recession flow (Sharda et. at. [1994]). A decrease in the velocity of runoff due to increasing roughness tends to decrease the sediment concentration in the runoff water thereby decreasing the amount of potential sediment to be entrained. Moreover, increasing the n value from 0.02 to 0.13 decreased the soil loss by 1,144% (Table 1).

Effect of Flow Width

The peak runoff rates were increased with increasing flow width. The Q_p was increased by 51% as flow width increased from 2.0 to 3.0 due to reduce opportunity time (Sharda et. al. [1994]). An increase in the flow width shortens the recession curves of the hydrographs and the flow occurs in a shorter period at a faster rate. Thus, an increase in water flow will increase the runoff volume and eventually the total sediment loss. The predicted soil was increased by 45% as the flow width was increased from 2.0 to 3.0 m (Table 1).

Effect of Percent Water that Infiltrated

The peak runoff rates were found to decrease by increasing the percentage of water that infiltrated. The Q_p was reduced by 216% as percentage of infiltration increased from 80% to 90%. The amount of runoff was calculated as the difference of rainfall amount and infiltration. Therefore, an increase in infiltration would decrease the amount of runoff. Moreover, the predicted soil loss was also decreased by 207% (Table 1).

Effect of Surface Cover

The value of cover may vary from zero for bare surface to one for very good vegetative cover. As the value of cover increases from 0.2 to 0.95, the total sediment loss was decreased by 1,567% (Table 1). The presence of surface cover dissipates the kinetic energy of raindrops that causes the detachment of soil particles. Moreover, surface cover serves as physical barriers that reduce the velocity of water moving across the soil surface.

Table 1. Effect of changes of the values of model inputs on the predicted Q_p and soil loss (SL) at Tanghaga Watershed.

Parameters	Parameter Values	Predicted Values	
		Q_p (li/s)	SL (kg)
Manning's Roughness Coefficient	0.020	534.4	450.4
	0.065	165.7	80.6
	0.130	82.7	36.2
Flow width (m)	2.0	109.6	228.0
	2.5	137.7	288.2
	3.0	165.8	329.8
Percent Infiltration	80	165.7	329.8
	85	102.9	215.1
	90	52.5	107.3
Vegetative Cover (%)	0.20	-	1,343.3
	0.50	-	862.6
	0.95	-	80.6

Prediction of the Location of High Erosion Risk

Prediction of sediment fluxes at watershed level was done by combining a soil erosion model with a quantificative three-dimensional description of the hydrology of the catchment on a digital elevation model (DEM). The erosion rates on cell location basis was predicted by dividing the catchment into equal-sized cells and by accounting the sediment flux in and sediment flux out of each cell element at each rainfall event.

The topographic variables such as slope, upslope contributing area, slope length, and local drain direction were used to predict the watershed discharge per unit time or the average flow velocity, V, at any point in the catchment. These defined three-dimensional runoff process affecting soil erosion and sediment transport. The assumption of these predictions was that sediment transport is transport limited and not detachment limited. The erosion model developed by the technique was use to predict and identify areas of high potential erosion that require special soil conservation management without resorting to management of the whole watershed. This approach would allow more efficient and effective use of the limited financial resources available for reducing erosion and sediment discharges from watersheds (Moore et al. [1988]).

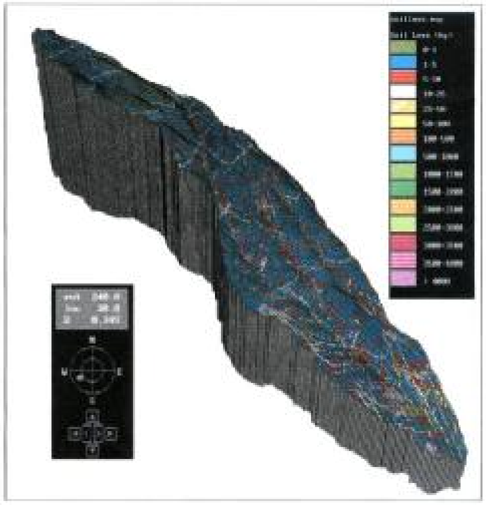

Figure 9. The predicted location of areas of high erosion risk at Tanghaga Watershed after 1,500 timesteps (2 hours) taken from simulated rainfall with intensity of 37.2 mm/hr.

Computer simulation showed that the zone or locations of erosion hot spots are located in areas within channel of tributaries and in steeper slopes (Figure 9). It is expected because most runoff waters are concentrated in the channels thereby increasing the water depth that tends to increase the velocity of runoff resulting to more scouring effect. This effect is aggravated in areas with steeper slopes because the slope gradient has a positive exponential increase in soil erosion. However, the presence of obstruction such as tree trunks, grass waterways and other runoff reducing structures will likely reduce the amount of soil loss. The capability of CREST in predicting the zones in the catchment with high erosion risk is a significant finding. Thus, this could be an alternative tool for prediction and help the planners and decision-makers in formulating strategies for a cost-effective and efficient watershed rehabilitation and management.

CONCLUSIONS AND RECOMMENDATIONS

The GIS-assisted modeling is considered an alternative approach that offers an option for modeling a complex three-dimensional system such as a watershed. This procedure using PCRaster transformed the spatial and temporal information into computed binary format and performed an iterative calculation of hydrology and soil erosion processes based on the model structure, assumptions, and constants. The dynamic modeling language of PCRaster is considered something very unique in the sense that the models can calculate new map attributes as a function of changes in the attributes over time. Thus, the model can be viewed as a temporal sequence of static changes of attribute that represent the change in the state of the modeled process per unit time. Furthermore, this paper showed the capability of PCRaster in combination with GIS softwares for modeling soil erosion at watershed level.

The development of CREST, a GIS-assisted erosion model, has facilitated the prediction of runoff hydrographs, the rate of soil loss and the total soil loss in a watershed per rainfall event, which is characterized by spatial variability. The model was most sensitive to Manning's roughness coefficient (n) for peak runoff rates with 546% decrease when n was increase from 0.02 to 0.13. For soil loss, the model was most sensitive to vegetative cover having a decrease of 1,567% when vegetative cover is increased from 0.20 to 0.95. Moreover, prediction of the location of areas of high erosion is a significant finding. Therefore, the model has put some meanings on the realization of upscaling soil erosion from the plot size to a catchment or watershed scale. However, models need to be revised to improve their predictive capability. This can be achieved by incorporating other important parameters such as infiltration patterns, initial moisture contents, evapotranspiration, and detailed database on landuse, cropping system and farming activities. Further validation of the model must also be carried out to determine the certainty and reliability of its predictive capability. Validation should be conducted under a wide range of conditions.

CREST needs to be revised to improve the predictive capacity. This can be achieved by incorporating information such as infiltration pattern at varies soil conditions, initial moisture contents, evaporation, detailed database on landuse, cropping calendar and farming activities.

The model is site specific, thus, there is a need to modify the model parameters that will represent the actual characteristics of the watershed where the model has to be applied. Moreover, further validation of the model must be carried out.

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REFERENCES

Agua, M. M., Predicting peak rates of runoff and soil loss from a watershed, Ph.D. thesis, University of the Philippines at Los Baños, College, Laguna, 1997.

Al-Durrah, M. M. and J. M. Bradford, The mechanisms of raindrop splash on soil surfaces, *Soil Sci. Soc. Am. J.*, *46*, 1086-1090, 1982.

Bradford, J. M. and C. Huang, Spash and detachment by waterdrops, In: Soil Erosion, Conservation, and Rehabilitation. Ed. M. Agassi. Marcel Dekker Inc., 61-76, 1996.

Foster, G. R., Modelling the erosion process, In: Hydrologic modeling of small watershed. American Society of Agricultural Engineering Monograph No. 5, Hann C. T. (ed), St. Joseph, Michigan, 297-379, 1982.

Foster, G. R. and L. G. Lane, *User requirements: USDA-Water Erosion Prediction Project (WEPP)*, NSERL Report No. 1, USDA-ARS National Soil Erosion Research Laboratory, Purdue University, West Lafayette, Ind., 1987.

Govers, G. and J. Poesen, Assessment of the interill and rill contribution to total soil loss from an upland field plot, *Geomorphology*, *1*, 343-354, 1988.

Hairsine, P. B. and C. W. Rose, Rainfall detachment and deposition: Sediment transport in the absence of flow-driven processes, *Soil Sci. Soc. Am. J.*, *55*, 320-324, 1991.

Hairsine, P. B. and C. W. Rose, Modelling water erosion due to overland flow using physical principles: I Uniform flow, *Water Resource Res*., *28*, 237-243, 1992.

Knisel, W. G., *CREAMS: A field scale model for chemicals, runoff and erosion from agricultural management systems*, USDA Conservation Research Report No. 26, USDA-ARS, Washington, D.C., 1980.

Laflen, J. M. L. J. Lane and G. R. Foster, WEPP: A new generation erosion prediction technology, *J. Soil Water Cons*., *46*, 34-38, 1991.

Lanuza, R. L. and E. P. Paningbatan, Jr., GIS-assisted approach in modeling soil erosion at watershed level: III. The development of Catchment Runoff and Erosion Simulation Technology (CREST), *DENR-7 Ecosystems Research Digest*, *11(2)*, 9-24, 2001.

Lanuza, R. L., GIS-assisted approach in modeling soil erosion at watershed level: Methodology for creation of the main geographic databases and validation, *DENR-7 Ecosystems Research Digest 11(1)*, 1-17, 2001a.

Lanuza, R. L., GIS-assisted approach in modeling soil erosion at watershed level: Methodology for catchment delineation, generation of catchment-based geographic databases and validation, *DENR-7 Ecosystems Research Digest, 11(1)*, 18-40, 2001b.

Lanuza, R. L., Modeling soil erosion in a watershed. MS thesis, University of the Philippines at Los Baños, College, Laguna, 1999.

Misra, R. K. and C. W. Rose, *Manual for use of program GUEST*, Division of Australian Environmental Sciences, Griffith University, Brisbane, Australia, 1989.

Moore, I. D., E. M. O'loughlin and G. J. Burch, A contour-based topographic model for hydrological and ecological applications, *Earth Surface Processes and Landforms*, *13*, 305-320, 1988.

Moore, I. D., J. P. Canberra, J. P. Wilson, C. Bozeman, C. A. Ciesiolka, Toowoomba, Soil erosion prediction and GIS: Linking theory and practice. Geographic Information System for Soil Erosion Management, Taiyuan, Shanxi Province, China, 1992.

Morgan, R. P. C., J. N. Quenton and R. J. Rickson, *EUROSEM: Documental manual*, Silsoe College, Silsoe, UK, 1992.

PCRASTER, *PCRaster manual*, PCRaster, Department of Physical Geography, Utrecht University, The Netherlands, 1996.

Proffitt, A. P. B., C. W. Rose and P. B. Hairsine, Rainfall detachment and deposition: Experiments with low slopes and significant water depths, *Soil Sci. Soc. Am. J.*, 55, 325-332, 1991.

Rose, C. W. And D. M. Freebairn, A new mathematical model of soil erosion and deposition processes with applications to field data, In: El Swaify, S. A. Moldenhauer, W. C. And Lo, A. (eds) Soil Erosion and Conservation, Soil Conservation Society of America, Iowa, 549-557, 1985.

Rose, C. W., J. R. Williams, G. C. Sanders and D. A. Barry, A mathematical model of soil erosion and deposition processes. I. Theory for a plane land element, *Soil Sci. Soc. Am. J.*, *47*, 991-995, 1983.

Sharda, V. N., S. R. Singh, G. Sastry and V. V. Dhruvanarayana, A finite element model for simulating runoff and soil erosion from mechanically treated agricultural land. 2. Field validation and applications, *Water Resour. Res.*, *30,* 2299-2310, 1994.

Suri, M., T. Cebecauer, J. Hofierka and E. Fulajtar Jun, Soil erosion assessment of Slovakia at a regional scale using GIS, *Ecology (Bratislava), 21(4)*, 404-422, 2002.

Williams, J. R., Sediment routing for agricultural watersheds. *Water Resources Bulletin, 11(5),* 956-974, 1975.

Wischmeier, W. H. And D. D. Smith, *Predicting rainfall erosion losses*, Agr. Handbook No. 537, U.S. Department of Agriculture, 1978.

Young, R. A., C. A. Onstad, D. D. Bosch and W. P. Anderson, *AGNPS: An agricultural non-point source pollution model, A watershed analysis tool*, USDA Conservation Research Report 35, 1987.