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Accuracy of GeoWEPP in Estimating Sediment Load and Runoff from a Tropical Watershed

M. Ebrahimpour[1], S. K. Balasundram[2*], J. Talib[1], A. R. Anuar[1] and H. Memarian[1]

[1]Department of Land Management, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

[2]Department of Agriculture Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

ABSTRACT

GeoWEPP, an integration of WEPP and TOPAZ within a GIS interface, was used to predict sediment load and runoff at the Lui Watershed, Selangor, Malaysia. Input files for land cover, slope, climate, soil, and management were generated within GeoWEPP and WEPP interfaces and topographic data comprising 1017 hillslopes were parameterized using TOPAZ algorithm. CLImate GENerator (CLIGEN) was used to estimate stochastic climatic parameters. Soil properties such as frequency of soil particles, CEC, OC, and rock fragment were utilised to define a reasonable range of soil parameters. A management file was generated using EPIC algorithm for different land use types and for all hillslopes during the simulation period 1996 - 2008. The results showed an over-estimation of sediment load and an underestimation of runoff compared to measured data. This work shows that GeoWEPP is able to predict runoff more accurately than sediment load.

Keywords: GeoWEPP, sediment load, runoff, watershed, GIS

INTRODUCTION

Soil loss, and its associated impacts, can pose critical threats to the environment (Bhuyan *et al.* 2002; Akay and Sessions 2005; Akay *et al*. 2008). To effectively manage soil loss, it is important to understand soil loss processes. GIS-based spatial modeling has emerged as an important tool in soil erosion studies and consequently in the development of appropriate soil conservation strategies, especially at the watershed scale (Memarian *et al.* 2012; Sorooshian and Gupta 1995).

Water Erosion Prediction Project (WEPP), a spatially distributed model, allows the capture of terrain indices such as stream power, wetness index, sediment transport capacity index and erosion hazard index in three-dimension. WEPP model is used to predict soil erosion and sedimentation at the watershed scale. Integration of WEPP with a Geographic Information System (GIS) is desirable

*Corresponding author : E-mail: *siva@putra.upm.edu.my*

because it facilitates and improves model application. GeoWEPP is a geo-spatial erosion prediction model interfaced in ArcGIS. The limitations of WEPP, that is, manual generation of input data and its application in small watersheds, can be overcome by GeoWEPP.

This work was carried out with the aim of investigating the performance of GeoWEPP for sediment load and runoff prediction at the Lui Watershed.

MATERIALS AND METHODS

Study Area

The Lui Watershed is located 3° 07' - 3° 12' N, and 101° 52' - 101° 58' E on the upstream of Langat River with a drainage area of 68.25 km^2 and basin length of 11.5 km *(Fig. 1)*. Minimum and maximum altitudes of the basin are 61 and 1207 m, respectively, while the average height is about 354 m above sea level. The Lui Watershed is steep with an average slope of 35 % *(Fig. 2)*. About 60 % of the watershed area has a slope that is higher than 30 %. Sg. (river) Lui hydrometer station (Ref. No. 3118445) is located at the outlet of Lui Watershed with an average annual water discharge of 55.05 x 10^6 m^3 and an average annual sediment load of 5.88 x 10^3 tonnes. The average annual precipitation at Kg. Lui rain gauge station (Ref. No. 3118102)[1] is about 2188.3 mm. In terms of land use, the Lui Watershed comprises 80.35 % forest, 9.85 % rubber and 2.6 % orchards. The remaining portion of this watershed consists of mixed horticulture and crops, urban areas, and mining land[2].

GeoWEPP

GeoWEPP was developed as a combined project conducted by the Agriculture Research Service, Purdue University, and the USDA National Soil Erosion Research Laboratory (Minkowski 2007) to predict sediment load at the watershed scale. This interface integrates WEPP model and TOPAZ (TOpography PArameteriZation) algorithm within ArcGIS software. WEPP is a physically-based and daily continuous model that simulates soil erosion and deposition using a spatially- and temporally-distributed method (Amore *et al.* 2004; Aksoy and Kavvas 2005).

In WEPP, the runoff between rill and inter-rill regions is separated and this allows for soil erosion in the rills and inter-rill regions to be calculated separately. Steady-state sediment continuity equation is used to predict the quantum of rill and inter-rill erosion. Rill erosion happens when shear stress of flow exceeds critical shear stress, and sediment load in water flow is less than the transport capacity. In this model, inter-rill erosion is proportional to the square of rainfall intensity (Aksoy and Kavvas 2005). Sediment load resulting from inter-rill regions is delivered to rills. WEPP computes normalised sediment load using non-dimensional detachment and deposition equations. The normalised load is then converted into actual load (Aksoy and Kavvas 2005).

[1]Nearest to Sg. Lui hydrometer station

[2]Based on 2006 land use map

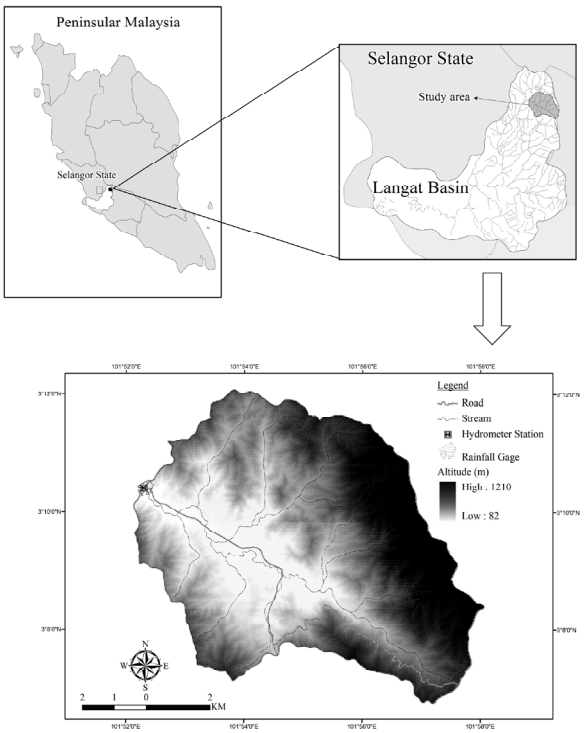

Fig. 1: Geographic location of the Lui Watershed

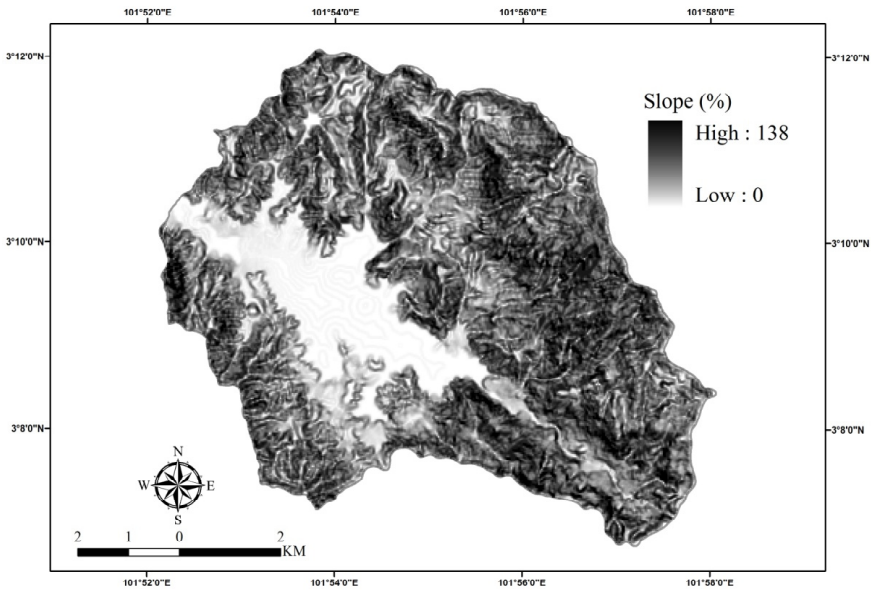

Fig. 2: Slope map of the Lui Watershed

Modelling

Input files such as land cover, slope, climate, soil, and management, of the Lui Watershed were generated within GeoWEPP and WEPP interfaces while topographic data comprising 1017 hillslopes were parameterised using TOPAZ algorithm, which is based on the digital elevation model.

TOPAZ determines channel network based on the steepest downward path, considering eight adjacent cells of each raster pixel. Channel network was adjusted by manipulating the values of Mean Source Channel Length (MSCL) and Critical Source Area (CSA). The MSCL defines the shortest channel length and the CSA is the minimum drainage area (Garbrecht and Martz 2005). Flow accumulation map was utilised as the base map to extract the above parameters *(Fig. 3)*.

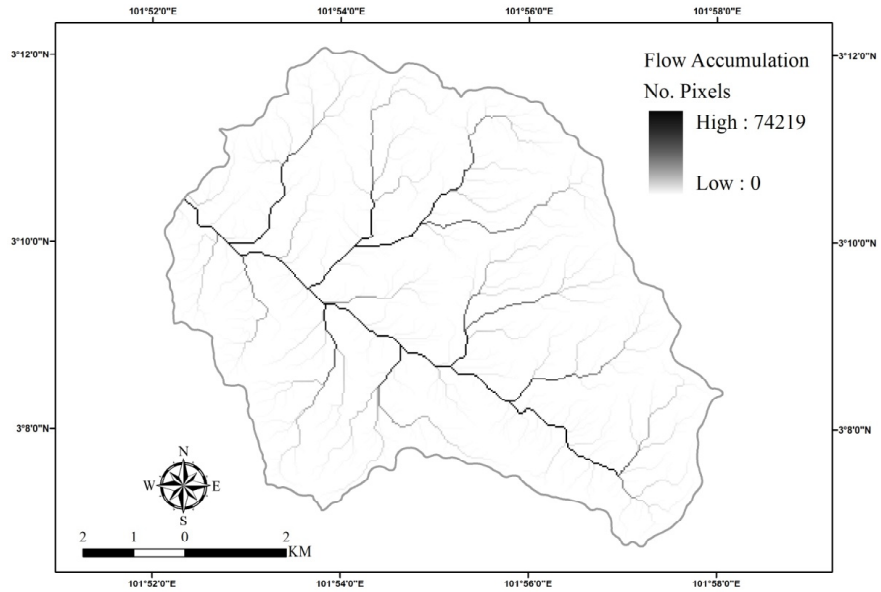

Fig. 3: Flow accumulation map of the Lui Watershed

Daily values of precipitation, temperature, solar radiation, relative humidity and wind speed, obtained from Kuala Lumpur International Airport and Petaling Jaya weather stations covering the period 1996-2008, were fed into CLIGEN (CLImate GENerator) to estimate stochastic climatic parameters.

The Lui Watershed consists of four dominant soil types, which are Steepland, Rengam-Jerangau association, Munchong-Seremban association and Telemong-Akob-Local alluvium association *(Fig. 4)*. The important physico-chemical soil properties used to define soil parameters such as soil texture, albedo, saturation level, hydraulic conductivity, rill erodibility and inter-rill erodibility, and critical shear stress are given in Table 1.

A management file was generated using EPIC algorithm for different land use types (i.e. urban areas, highway, quarry, bare land, grass land, forest,

secondary forest, marshland, orchard, rubber, mixed horticulture and other crops) at all hillslopes during the simulation period 1996-2008. In this process, WEPP generated inter-rill cover data for each year using growth parameters, soil and climatic data.

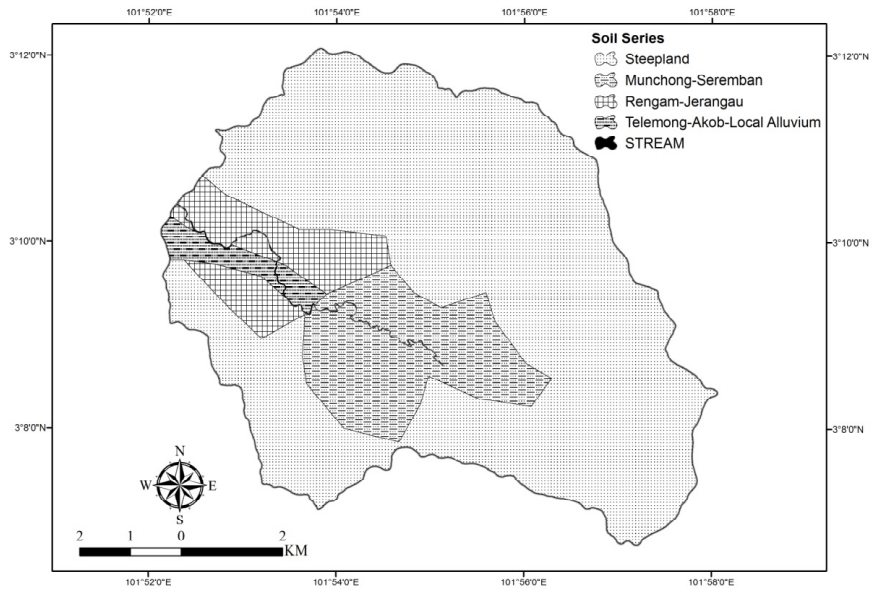

Fig. 4: Soil type map of the Lui Watershed

TABLE 1
Soil physico-chemical properties (adapted from Wong, 1970) used in GeoWEPP

Soil type	Depth (cm)	Particles (%)				CEC[1] (m.e./100g soil)	OC[2] (%)
		Clay	Silt	Fine sand	Coarse sand		
Steepland	0-15	32	8	30	30	6.64	0.9
Steepland	15-30	35	8	20	37	5.91	0.5
Steepland	30-60	38	7	20	35	5.66	0.4
Rengam-Jerangau	0-15	36	6	36	22	7.41	1.2
Rengam-Jerangau	15-40	45	6	29	20	5.66	0.5
Rengam-Jerangau	40-	47	6	29	22	5.52	0.4
Telemong-Akob-Local	0-15	59	31	4	6	22.76	4.0
Telemong-Akob-Local	15-30	64	29	4	Trace	20.52	1.3
Telemong-Akob-Local	30-45	62	32	2	Trace	21.20	0.6
Telemong-Akob-Local	45-90	60	34	6	-	24.48	0.4
Munchong-Seremban	0-15	45	10	35	10	12.83	1.6
Munchong-Seremban	15-20	57	9	32	Trace	10.22	0.6
Munchong-Seremban	20-60	60	13	20	7	8.90	0.5

[1]Cation Exchange Capacity, [2]Organic Carbon

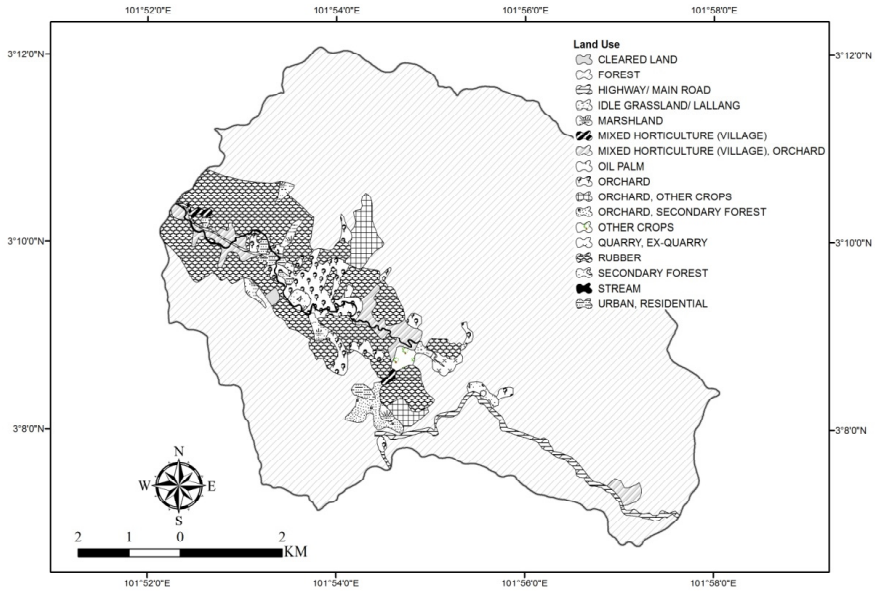

Fig. 5: Land use map of the Lui Watershed

RESULTS AND DISCUSSION

Monthly simulated sediment load from GeoWEPP was compared to monthly measured sediment load at Sg. Lui hydrometer station *(Fig. 6)*. Student t-test at 99 % confidence level showed a significant difference between simulated and measured sediment load. The measured annual sediment load (0.57 t ha^{-1} yr^{-1}) was almost half of the predicted annual value (1.1 t ha^{-1} yr^{-1}). Correlation between predicted and measured sediment load was 0.48 indicating that WEPP model overestimates sediment load. Similar results were reported for WEPP application in forest lands (Page-Dumroese *et al.* 2000; Rivera 2004). However, a better predictive ability of WEPP has been shown in other studies. For example, Zhange *et al.* (1996) showed that observed and WEPP-predicted erosion for single storm events under agriculture were fairly correlated (r = 0.77). In another study, Rivera (2004) showed that observed and WEPP-predicted sediment loads in a non-harvested forest were highly correlated (r = 0.8).

The Lui Watershed is subjected to anthropogenic manipulations in hydrological status. Some landforms resulting from urban development and agricultural activities were not captured in the land use and topography maps. This omission included most of the ponds, which can affect sedimentation process via an increase in deposition rate (Memarian *et al*. 2012). In addition, most of the empirical research built into the WEPP model is based on gentle slopes (Flangan and Nearing 1995). However, the Lui Watershed comprises steep slopes, and is exposed to high intensity rainfall. These WEPP limitations coupled with limited reliable range of calibration parameters possibly led to sediment load overestimation.

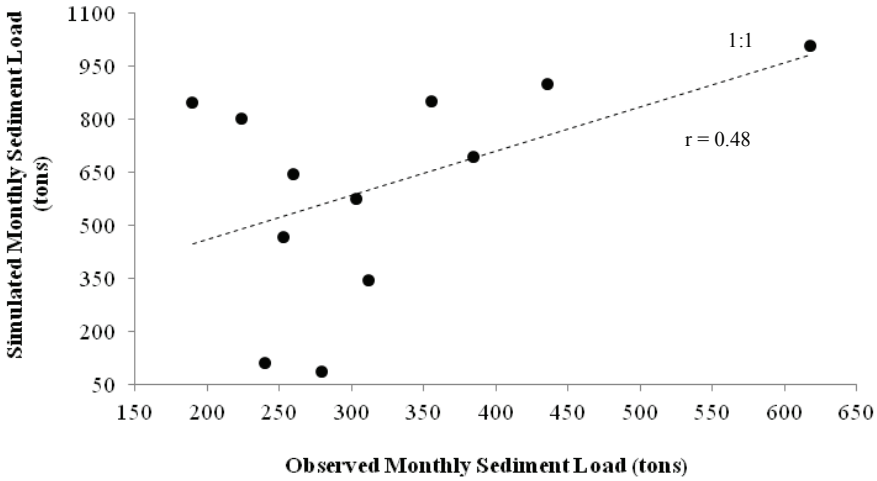

Fig. 6: Measured sediment load versus predicted sediment load

This study also examined the robustness of GeoWEPP in run-off prediction. Measured and predicted average monthly runoff were strongly correlated (r = 0.91) *(Fig. 7)*. However, several of the WEPP-predicted values were less than the measured values. The measured daily runoff value, averaged on a monthly basis, was 2.82 mm/day while the simulated value was 2.1 mm/day. The rainfall data in this work was collected from only one gauge station (i.e. Kg. Lui) while the watershed is naturally prone to high spatial variation in rainfall, which is a common meteorological characteristic in tropical watersheds (Memarian *et al.* 2012). This could have caused the underestimation of runoff values.

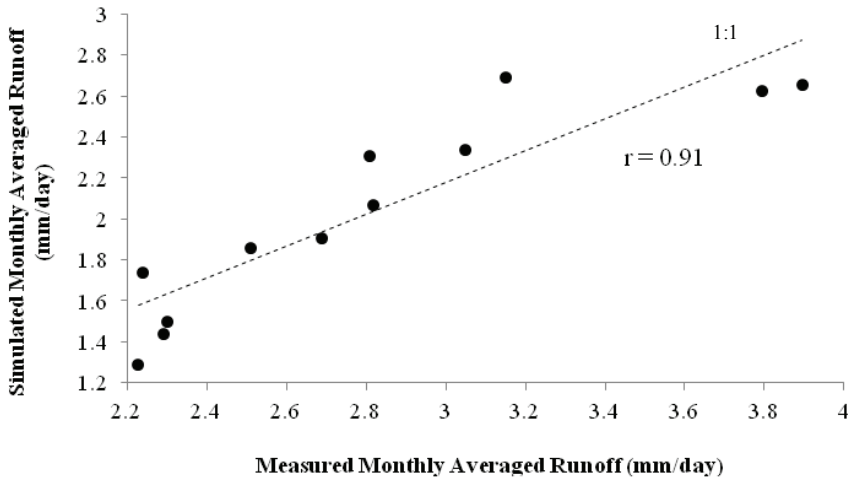

Fig. 7: Measured runoff height versus predicted runoff height

CONCLUSION

GeoWEPP, a geo-spatial erosion prediction model was applied to predict sediment load and runoff at the Lui Watershed, upstream of the Langat River, Selangor, Malaysia. Results showed that GeoWEPP overestimated sediment load and underestimated runoff. Sediment trapping features like ponds were not captured in the land use and topography maps, the base data source in this work, due to scale limitations. In addition, GeoWEPP was developed based on gentle slopes, while the Lui Watershed comprises steep slopes. These limitations are believed to have caused model over-prediction in sediment load at the watershed outlet. Model under-estimation of run-off was primarily due to isolated rainfall data, recorded from only one rain gauge. GeoWEPP robustness for sediment load prediction at Lui Watershed was poor and seriously limited by land cover data scale and basin geomorphologic/land cover properties. Based on correlation analysis and model bias, GeoWEPP was able to predict runoff more accurately than sediment load.

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