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Applications of AnnAGNPS model for soil loss estimation and nutrient loading for Malaysian conditions

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Abstract

The study evaluated the performance and suitability of AnnAGNPS model in assessing runoff, sediment loading and nutrient loading under Malaysian conditions. The watershed of River Kuala Tasik in Malaysia, a combination of two sub-watersheds, was selected as the area of study. The data for the year 2004 was used to calibrate the model and the data for the year 2005 was used for validation purposes. Several input parameters were computed using methods suggested by other researchers and studies carried out in Malaysia. The study shows that runoff was predicted well with an overall R^2 value of 0.90 and E value of 0.70. Sediment loading was able to produce a moderate result of $R^2 = 0.66$ and $E = 0.49$, nitrogen loading predictions were slightly better with $R^2 = 0.68$ and $E = 0.53$, and phosphorus loading performance was slightly poor with an $R^2 = 0.63$ and $E = 0.33$. The erosion map developed was in agreement with the erosion risk map produced by the Department of Agriculture, Malaysia. Rubber estates and urban areas were found to be the main contributors to soil erosion. The simulation results showed that AnnAGNPS has the potential to be used as a valuable tool for planning and management of watersheds under Malaysian conditions.

Keywords: AnnAGNPS; Runoff; Soil loss estimation; Nutrient loadings; RUSLE

1. Introduction

The non-point source (NPS) pollution has grown into a global environmental issue and has been the most talk-about environmental degradation caused in recent years (Thornton et al., 1999). Due to the NPS nature and the limitation of experiments and field measurements, its management is highly dependent on spatial simulation modeling which is an important technique commonly used in dealing with NPS pollution problems associated with spatial uncertainty.

In the last three decades, several computer simulation models have been developed to provide a better understanding of the hydrological system, sediment transport and associated pollutant loading. The variety of models ranges from simple planning models to complex hydrological processing models. The extensive grid-based models for assessing NPS pollution in agricultural fields may enable planners an in-depth-understanding of different policy options. Some existing examples of popular models include ANSWERS (Beasley et al., 1980), HSPF (Johanson et al., 1980), SPNM (Williams, 1980), EPIC (Williams et al., 1982), AGNPS (Young et al., 1989), WEPP (Nearing et al., 1989), PESTFADE (Clemente et al., 1993), EUROSEM (Morgan, 1995), SWAT (Arnold et al., 1998), LSPC (Shen et al., 2005), and many more. Detailed reviews of these models were given by Borah and Bera (2003), and Merrit et al. (2003) but differ in

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terms of complexity, processes considered, and the data required for calibration and validation of model. In general there is no single best model for all applications. Thus, the most appropriate model will depend on the intended use and the characteristics of the watershed under study.

The AnnAGNPS model combines the latest advances in GIS data manipulation and physical characterization of the catchments, offering modeling opportunities for ungauged areas or for areas with limited data prohibiting the use of models relying on calibration for derivation of input variables. AnnAGNPS is a continuous simulation, watershed-scale model intended to be used as a tool to evaluate the NPS pollution from agricultural watersheds ranging in size up to 300,000 ha. The model simulates runoff, sediment, nutrient and pesticide contributions from the overland to streams as a result of storm runoff (Young et al., 1989).

The Agricultural Non-Point Source (AGNPS) pollutant model is a watershed modelling tool to predict runoff, peak flow, sediment loading and nutrient loadings (Young et al., 1989). AGNPS was introduced in the 1980s and has since grown into a powerful watershed simulation model. The model was developed jointly by the Agricultural Research Service (ARS) and the National Resources Conservation Service (NRCS). Since the release of this model, various studies have been carried out to assess the NPS pollution. Besides USA, AGNPS studies have also been carried out in other parts of the world including Germany (Rode and Frede, 1999; Grunwald and Norton, 2000) and Ethiopia (Haregeweyn and Yohannes, 2003; Hassen et al., 2004). The successes of these studies show that AGNPS is able to adapt to various different conditions.

Other studies on AGNPS also highlighted some weaknesses of the model especially when handling massive amount of input and output data (Lenzi and Di Luzio, 1997; León et al., 2000). Without GIS support, providing input parameters for each of the cells that represent the entire watershed is often a tedious and time consuming task for AGNPS (He, 2003). To cope with these weaknesses, many studies have been carried out by incorporating AGNPS with GIS support (Lenzi and Di Luzio, 1997; Dayawansa, 1997; León et al., 2000; Chowdary et al., 2001; Ma and Bartholic, 2003; Phothong and Corner, 2004). The results of such studies showed significant improvements in data management and storage.

Realizing that incorporation with GIS was inevitable, ARS and NRCS joined up once again in 1990s to review the model. In 1998, the Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant model was released (Bosch et al., 1998). AnnAGNPS is an improved version of AGNPS, which supports continuous simulation and improved processing methods (Bingner and Theurer, 2005). As a new model, only few studies have since applied it in studying the effect of watersheds on surface water quality (Suttles et al., 2002; Baginska et al., 2003; Shrestha et al., 2005; Polyakov et al., 2007). The studies on AnnAGNPS concluded that the model is good in predicting runoff volume while other outputs are only of moderate accuracy.

In Malaysia, the non-point source pollution studies are still at an infant stage. Although soil erosion has been a major problem for many Malaysian soils, erosion studies are very much limited to the use of universal soil loss equation (USLE) method (Roslinah and Norizan, 1997; Kamaruzaman and Baban, 1999). Therefore, the objectives of this study are: (1) to prepare a database for the simulation of runoff and non-point source pollution using annualized agricultural non-point source (AnnAGNPS) model, and (2) to assess the applicability and predictive capability of AnnAGNPS in Malaysian conditions as a long-term watershed monitoring system for the country.

2. Methodology

2.1. Study area

The study area chosen for the testing and application of AnnAGNPS model was the watershed of River Kuala Tasik which is located in the two Malaysian states of Pulau Pinang and Kedah (Fig. 1). The watershed of River Kuala Tasik includes the area of two small watersheds, namely River Bukit Teh and River Tasik Chempedak. The total area of River Kuala Tasik watershed is 6309.25 ha while River Bukit Teh watershed and River Tasik Chempedak watershed cover an area of 3027.25 ha and 3174.75 ha, respectively. The rivers originate from small hilly terrain at an elevation of about 400 m. The outlets (sampling stations) of the watersheds are at elevations of about 1–2 m. The mean temperature in the region is 27 °C with high humidity varying from 50 to 70%. The study area is a tropical region which sometimes experiences heavy rainfall. The mean annual rainfall in the area varies from about 2200 to 2500 mm. The corresponding rainfall erosivity factor, *R* ranges from about 9000 to 14,000 MJ mm/ha/hour/year computed based on pluviographic records of 7–35 years. The daily rainfall data of seven rain-gauges was used in the study for simulation and modelling. The soil in the watersheds