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ESTIMATING SEDIMENT YIELD OF A SMALL CATCHMENT IN A TROPICAL REGION USING THE AGNPS MODEL: THE WATERFALL RIVER CATCHMENT, PENANG, MALAYSIA

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This paper presents the result of our research in testing the applicability and performance of the AGNPS (Agricultural Non-Point Source) model to estimate sediment yield of a small tropical catchment. The results of the modelling were compared with actual data collected in the field. Based upon limited sampling data, AGNPS produced variable results. At the lower end, the model underestimated the actual sediment yield by about 20 percent. On the other hand, at the extreme, the model overestimated the actual sediment yield by as high as 62 percent. The relatively high deviations between the actual and predicted sediment yield might be due to high rainfall intensity and its impact on the erosion index in the region. However, the results of this study are comparable to similar studies using AGNPS in other parts of the world.

INTRODUCTION

Sediment yield studies have received worldwide attention among earth scientists. Estimates of sediment yield and its temporal variation are needed for various purposes. Empirical methods have been quite commonly used in the past for sediment yield estimation (Walling, 1988; Williams, 1978). However, an appropriate way of studying the soil erosion and deposition processes is through the use of process-based models (Kothyari et al., 1997).

The spatial distribution of water and the sediment it carries is difficult to assess. This is because normally the sediment concentration is measured at a point in the catchment, usually at an outlet where the sediments are lumped together. With the help of environmental models the spatial distribution of sediment can be considered. Many process-based models have been developed in the past for rainfall-runoff-erosion modelling. These process-based models are advantageous as compared to the other methods of sediment yield estimation, particularly when the spatial and temporal distributions of net soil loss must also be determined for devising optimal soil conservation and management practices (Kothyari et al., 1997). These include ANSWERS (Beasley, et al., 1980), WEPP (Nearing et al., 1989), AGNPS (Young et al., 1987) and SHE (Abbott et al., 1986; Wicks and Bathurst, 1996). Of these models, AGNPS is becoming commonly and widely applied throughout the world to investigate various water quality problems. However, testing and validation of AGNPS using measured data is still scarce (Grunwald and Norton, 2000). AGNPS was developed by the Agricultural Research Service, U.S. Department of Agriculture, in co-operation with Minnesota Pollution Control Agency and the Natural Resource Conservation Service (NRCS)(Young et al., 1987; 1995). In the past, most of the application and validation of AGNPS was carried out in the United States (Young, et al., 1987; Panuska et al., 1991; Bingner et al., 1989; Kozloff et al., 1992; and Tim and Jolly, 1994). In recent years, AGNPS has also been applied and validated in other countries such as Germany and Slovakia (Grunwald and Norton, 1999; Grunwald and Frede, 1999; Prato and Shi, 1990; Rode and Frede, 1999; Grunwald and Norton, 2000; Pekarova, et al., 1999). With the exception of Lo (1995) and Chowdary et al. (2001), very little examination has been undertaken on the suitability of AGNPS or comparable water quality models for analysis of tropical catchment areas. Thus the uses and validation of AGNPS in tropical region is still lacking, and needs further research.

This article reports some results of our study in testing the applicability and performance of the AGNPS model to estimate sediment yields in a small tropical catchment area in Penang Island, Malaysia. It is hoped that the results of this study could provide some information on the usability of the model in such region.

MATERIAL AND METHODS

The AGNPS model

The hydrological model used in this study was the AGNPS (Agricultural Non-Point Source) model. AGNPS is an event-based distributed parameter model that was developed to analyse and provide estimates of runoff water quality (runoff volume, peak flow rate, sediment and nutrient yields) from medium to large-sized agricultural watersheds ranging from a few to 20,000 ha. The AGNPS model is made up of three major basic components: hydrology (e.g. runoff volume, peak discharge), sediment (e.g. sediment yield, sediment concentration, sediment particle sizes, deposition, enrichment ratio) and chemical transport (e.g. nitrogen, phosphorous, COD). Runoff, sediment and nutrient transport processes are simulated for each cell and routed to the outlet. Thus, flow, erosion, and chemical movement at any point in the watershed can be examined. Upland sources contributing to a potential problem can be identified and locations can be prioritized for remedial action to improve water quality most effectively. Runoff is predicted using the Soil Conservation Service (SCS) runoff curve method. Sediment yields are predicted using a modified version of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Nutrient movement components have been adapted from the CREAMS model (Frere et al., 1980). Chemical transport calculations are divided into soluble and sediment-absorbed phases. A comprehensive description of the AGNPS model can be found in Young et al. (1987, 1995).

The model subdivides a study area into uniform grid cells similar to a raster-based GIS. All watershed characteristics and inputs are expressed at the cell level. The cells are numbered consecutively from the upper left moving on the right direction and down. Potential pollutants are routed through cells from the watershed divide to the outlet in a stepwise manner so that flow at any point between cells can be examined. A single cell or a data unit can be at resolutions of 2.5 acres to 40 acres. Smaller cell sizes such as 10 acres are recommended for watersheds less than 2000 acres.

The model requires two groups of input: watershed level and cell parameter (watershed element). At the watershed level, five pieces of data are required: watershed identification/description, precipitation (inches), rainfall energy-intensity value (erosion index – EI value), area of each cell (acres) and outlet cell number. For each watershed element (cell), AGNPS requires 22 input data values (its distributed parameter information): cell number, number of the cell into which it drains, SCS curve number, average land slope (percent), slope shape factor (uniform, convex or concave), average field slope length (feet), average channel slope (percent), average channel side slope (percent), Manning's roughness coefficient for the channel, soil erodibility factor (K) for the USLE, cropping factor (C) for the USLE, practice factor (P) for the USLE, surface condition constant (factor based on land use), aspect (one of 8 possible directions indicating the principal drainage direction from the cell), soil texture (sand, silt, clay, peat), fertilization level (zero, low, medium, high), incorporation factor (percent fertilizer left in top 1 cm of soil), point source indicator (indicates existence of a point source input within a cell), gully source level (estimate of amount, tons, of gully erosion in a cell), chemical oxygen demand factor, impoundment factor (indicating the presence of an impoundment terrace system within the cell), channel indicator (indicating existence of a defined channel within a cell).

The distributed parameter approach of the AGNPS model preserves spatial characteristics and makes it appropriate to use a GIS system for storage of those spatial characteristics (Mitchell et al., 1993). Thus, the characteristics of raster GIS storage, retrieval and manipulation can be used effectively with the AGNPS model. The model is available for use on personal computers but can also, with slight modifications, be run on UNIX workstations. The model is becoming commonly and widely applied throughout the world to investigate various water quality problems.

Study area and database

A small watershed for the Sungai Air Terjun or Waterfall River (4.98 km^2) located at the Penang Hill, Malaysia (Figure 1) was selected for this study. It is part of the Penang Forest Reserve, which is under constant pressure for various agricultural and urban developments. Sediment yield is the environmental quality parameter of concern in this study. For this reason, only those parameters related to hydrology and sediment were captured and input into the database. The data for the parameters were collected either from local government offices, field sampling, or tables provided in the user's manual. The major elements of the watershed database include topography, hydrography, soil, land cover/use, land management and climate.

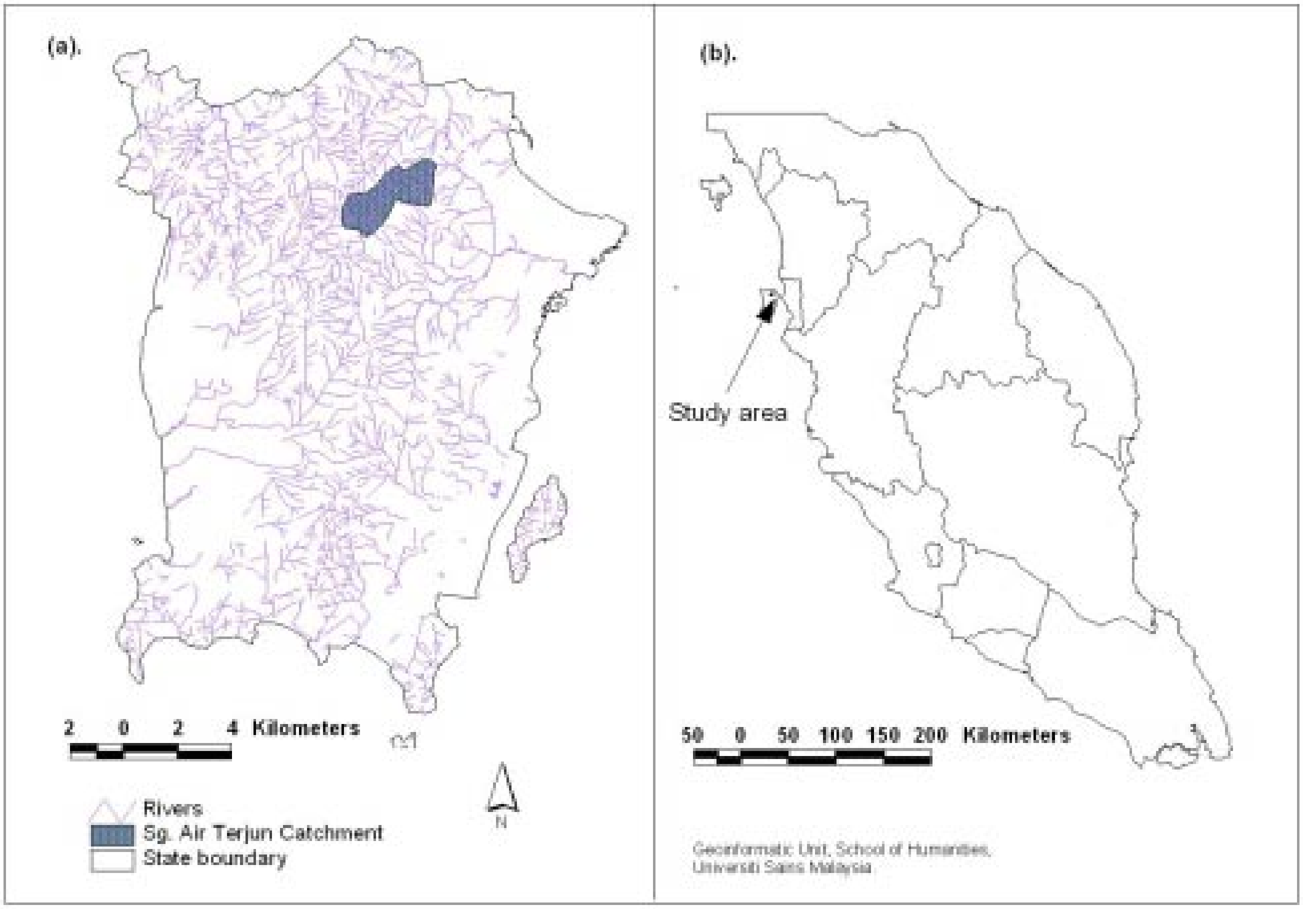

Figure 1. Location of study area in (a) Penang State river system and (b) peninsular Malaysia.

Most of the data required by the AGNPS model for the study area were obtained from paper maps. These data were digitized in vector format using Arc/Info software and transformed into the Malayan Rectified Skew Orthomorphic (RSO) projection system.

In this study the base map depicting drainage pattern and elevation contours of the study catchment were prepared using the topographic maps of George Town & Butterworth (Sheet 3265) and Kota Kuala Muda (Sheet 3266) maps at a scale of 1:50,000. The maps were then converted into digital form by manual digitizing and the selected catchment was converted into grids of 100 x 100 m (Figure 2). This grid was chosen to accommodate a total size of 1350 cells, which is the limit imposed by AGNPS. At present the land use is 92 percent forested, 6.4 percent scrubland, 0.3 percent agriculture and 1.3 percent residential, commercial and recreational land (Figure 3a). Any development on this area is expected to create massive erosion because of its rugged topography, which eventually flows downstream to nearby coastal areas. The elevations of the study area vary from 20 to 800 meters (Figure 3b). Land slope, aspect and curvature (slope shape factor) data layers for the study area were generated using the ArcView 3-D Analyst extension. The slope in the study area ranges from 0 to 152 percent.

A soil map was necessary for calculating the K factor and SCS runoff curve number. Unfortunately no detailed soil map was available for the study area. Therefore, several soil samples were collected throughout the study area and analyzed using standard laboratory procedures. Input parameter layers for the AGNPS model were then generated by interpolation or reclassification of the soil coverage.

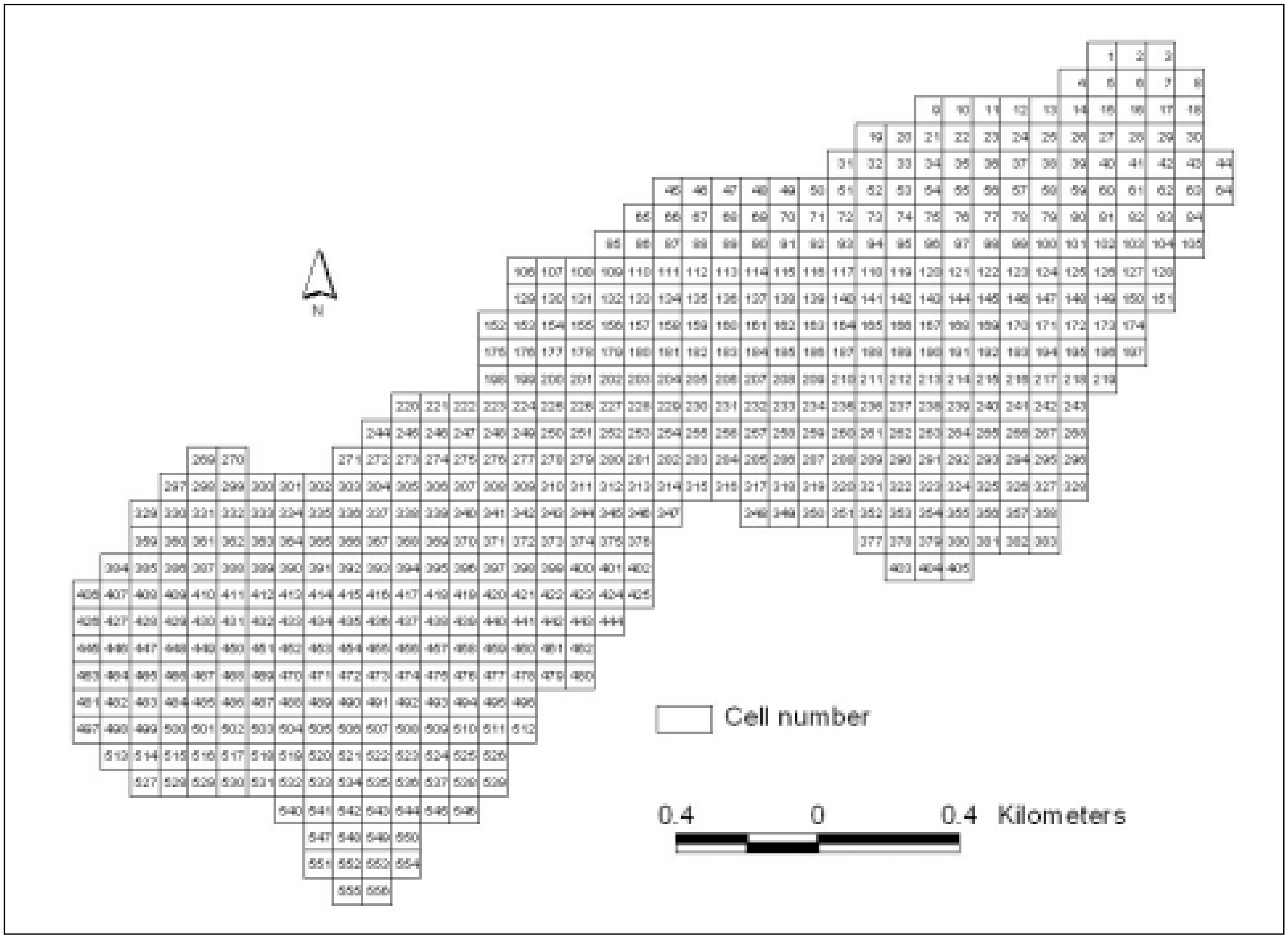

Figure 2. Basic configuration and cell numbering system of the study area in AGNPS model format.

Several of the AGNPS model inputs such as the SCS curve number, Manning's roughness coefficient, USLE cover (C) factor, USLE support practice (P) factor, and surface condition constant were derived from the land use/cover and land management data obtained from the local planning and agricultural departments. The land use/cover data was converted to raster format and reclassified with values for these parameters resulted in input parameter layers for the AGNPS model.

There is no official water quality monitoring station at the study area. Due to financial constraints, hydrological data and sediment yield were collected only for six separate events: 26 August 1991; 27 August 1991; 28 August 1991; 28 August 1991; 29 August 1991; 9 May 1993 and 25 May 1993. Table 1 shows the rainfall intensity and erosion index (EI30) for the sampling dates.

RESULTS AND DISCUSSION

The AGNPS model was run for each of the sampling dates. Sediment was the main pollutant modelled using the AGNPS model. Table 2 and Figure 4 show the actual and estimated sediment yields. The storm on 28 August 1991 was the largest storm of all the six storms reported in this study. Consequently, it produced the highest sediment yield. The total sediment yield from field sampling was 1106.12 tons km^{-2}, while the AGNPS estimated sediment yield at the outlet was 1289.04 tons km^{-2}.

The second largest storm occurred on 25 May 1993. It resulted in a slightly lower sediment yield than the 28 August 1991 storm, but greater than the 26 August 1991 storm. The maximum sediment

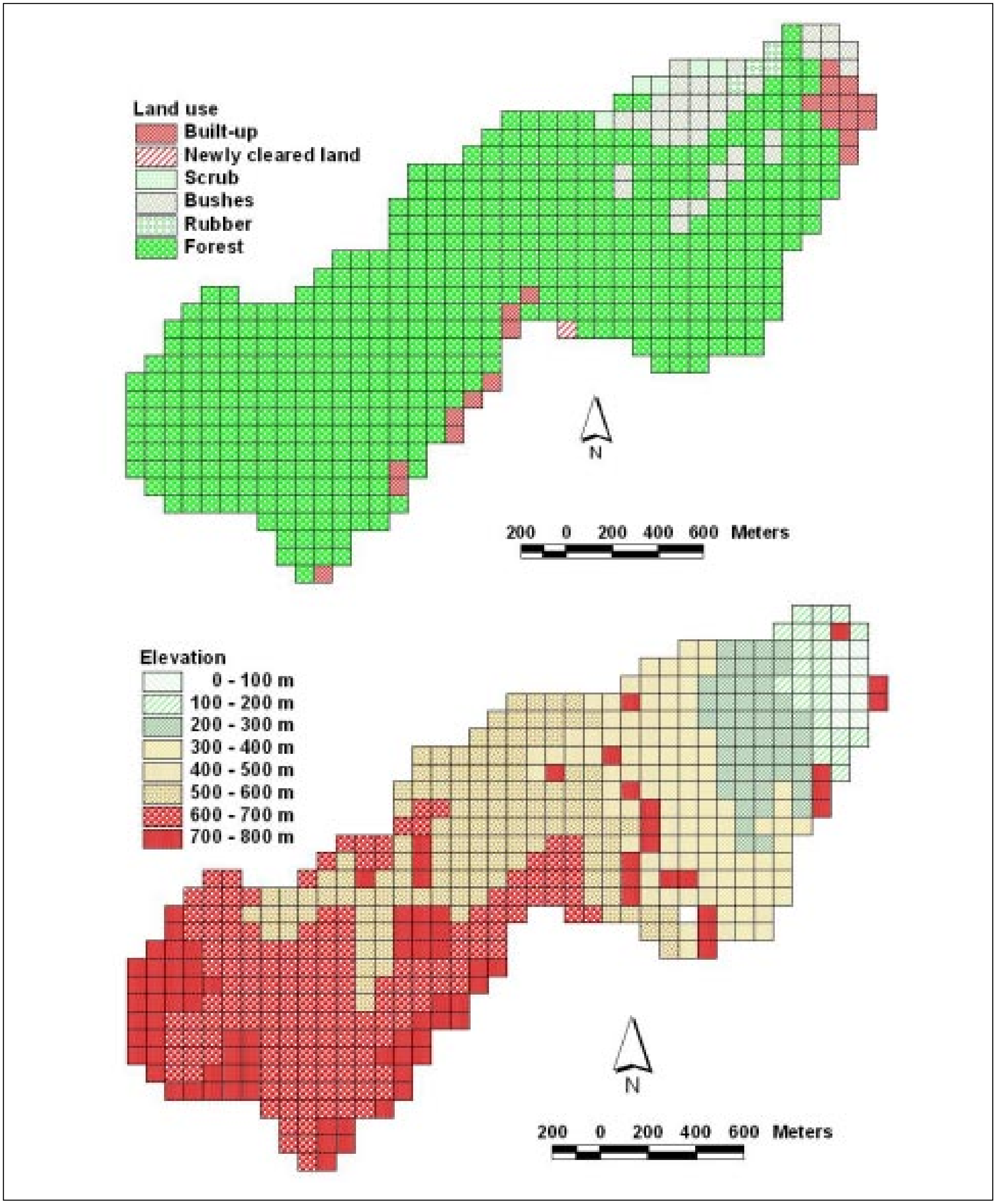

Figure 3. (a) existing land use and (b) elevation (DEM).

yield recorded from field sampling was 125.30 tons km^{-2} for a total of 336.12 tons km^{-2} of sediment, while the AGNPS estimated amount of sediment was 465.52 tons km^{-2}.

The storm on 26 August 1991 was the third largest storm recorded in this study. A smaller amount of sediment yield was observed from this storm compared to the two other storms. The maximum

Table 1. Rainfall Intensity and Erosion Index (EI30)

Sampling dates	Rainfall intensity (in/hr)	EI 30/100
26/8/91	2.84	254.33
27/8/91	0.16	1.00
28/8/91	6.36	1289.04
29/8/91	1.80	77.84
09/5/93	1.02	51.31
25/5/93	3.50	468.22
19/6/93	3.62	384.33

sediment yield recorded during field sampling was 55.35 tons km^{-2}, and the total sediment yield was 159.84 tons km^{-2}. The AGNPS model estimated the sediment yield to be 226.9 tons km^{-2}.

From the above argument and results tabulated in Table 2 we can see that, in general, the AGNPS model produced variable results. It underestimated the sediment yield between 4.68 to 19.46 percent, and overestimated up to a high of about 62 percent (Table 2). Two of the AGNPS sediment yield estimates were within a reasonable range i.e. 20 percent. The high overestimation may be due to the high rainfall intensities in the study area (Table 1), which is typical to many tropical areas.

Based on the limited sampling data (6 in all), the relationship between the actual sediment yield and estimated sediment yield using the AGNPS model were analysed using several regression models. The relationship is best fit with the following regression equation (Figure 4):

$$Y = 0.6091X + 22.76;\ r^2 = 0.9982 \quad df=5 \qquad (1)$$

where

Y = actual sediment yield

X = AGNPS estimated sediment yield

Both the regression equation and X coefficient are significant at the 0.01 level, but the intercept is only significant at the 0.10 level.

Table 2. Summary of the Actual and AGNPS Simulated Sediment Yields

Date	Sediment yields (tons km^{-2})								
		Actual				Simulated			Deviation (percent)
	Minimum	Maximum	Mean	Total	Minimum	Maximum	Range	At the Outlet	
26/8/91	0.012	55.35	10.66	159.84	0.03	1287.52	1287.49	226.90	41.95
27/8/91	0.008	0.6	0.15	2.21	0.00	11.43	11.43	1.78	-19.46
28/8/91	0.008	176.5	44.24	1106.12	0.11	10600.92	10600.81	1791.17	61.93
29/8/91	0.133	37.22	2.84	68.21	0.01	334.69	334.68	59.49	-12.78
09/5/93	0.070	9.03	1.62	34.00	0.00	181.62	181.62	32.41	-4.68
25/5/93	0.022	125.3	16.81	336.12	0.04	2648.52	2648.48	465.52	38.50
Mean	0.042	67.333	12.720	284.42	0.03	2510.78	2510.75	429.55	17.58
Minimum	0.008	0.600	0.150	2.21	0.00	11.43	11.43	1.78	-19.46
Maximum	0.133	176.500	44.240	1106.12	0.11	10600.92	10600.81	1791.17	61.93
Std.Dev	0.050	69.542	16.693	420.12	0.04	4083.45	4083.41	689.06	34.02

The results of this study are comparable to the results of other studies using AGNPS. Bingner et al. (1989) presented the results of testing AGNPS with three small watersheds that indicated variable results. Simulated total annual sediment yield varied from 29 percent to 557 percent of measured yield. Panuska et al. (1991) used five rainfall-runoff events for the validation of the AGNPS model. The predicted sediment yield values ranged from a maximum underestimation of 60 percent to a maximum of 1.4 percent compared to measured sediment yield values. Mitchell et al. (1993) used AGNPS to compare simulated and measured values for 50 rainfall-runoff events. The deviation

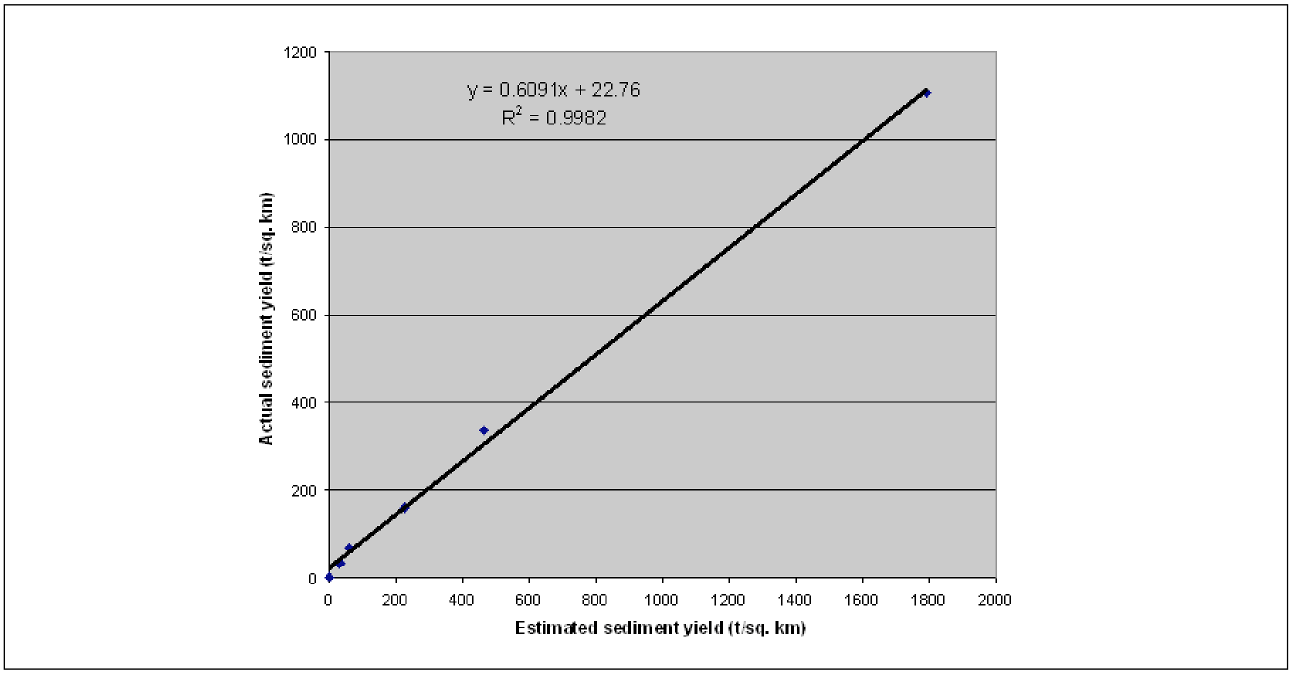

Figure 4. Relationship between actual sediment yield from field sampling and the estimated sediment yield using AGNPS.

between the arithmetic mean of measured and simulated values was 1.65 tonnes for sediment yield. Grunwald and Norton (2000) in their study to investigate the performance of AGNPS model on two small agricultural watersheds in Germany also produced variable results. The sediment yield for many rainfall-runoff events was considerably underpredicted compared to measured values. The coefficient of efficiency (E) varied between 0.26 and 0.57, which was poor compared with the ideal E of 1. Similarly, Rode and Frede (1999) in their study on testing AGNPS for soil erosion and water quality modelling at two medium-sized watersheds in the lower Hessian uplands of Germany also produced interesting results. In one of the watersheds, the simulated sediment yield corresponds relatively well to the measured sediment yield (5 percent deviation). However, for the second watershed, AGNPS overestimates the yield considerably, with 51 percent deviation. They pointed out that the overestimation resulted from a systematic overestimation of small runoff events.

The relative differences between the simulated and observed sediment yields obtained in this study might be due to several factors including the parameters used and the algorithms for calculating some of the parameters. AGNPS model uses many empirical and quasi-physically based algorithms. Some of the original parameters of the model might not be appropriate for a tropical country like Malaysia where the rainfall intensity is relatively high as compared to the United States where the model was originally developed. Some of input data were generated using GIS software and it is well known that different GIS software use different algorithms for analysis. An example is slope analysis, which is one of the major parameters used in the AGNPS model. Furthermore, soil loss (closely related to sediment yield) is too complicated to be estimated accurately, and its processes are still not well understood (Al-Sheriadeh et al., 2000). These issues of applicability and suitability will need to be addressed further before AGNPS can be universally applied to other locations.

CONCLUSION AND SUGGESTION

This article has demonstrated the use of the AGNPS model to estimate sediment yield of a small tropical catchment. Based on limited actual sampling data, the AGNPS model has produced variable results. In some events the AGNPS model overestimated the actual sediment yield, while in some other events it underestimated the yield. However, some of the AGNPS model results were reasonable (within 20 percent deviation). These results are comparable to other similar studies using AGNPS. Validation of the AGNPS model using measured data is scarce (Grunwald and Norton, 2000). The study reported in this article provides another example towards this goal. Despite the simulation problems, the AGNPS model is a valuable tool to analyse non-point source pollution in agricultural watersheds. Further improvement in accuracy and applicability are recommended. More detail samplings of the storm events are suggested in order to reduce the error between the sampling and model estimation. The AGNPS model uses many empirical and quasi-physically based algorithms that might not be appropriate for tropical country like Malaysia. Therefore, one possible future effort is to modify the various equations used in the AGNPS model to suit local conditions, similar to the work carried out by Grunwald and Frede (1999) and Grunwald and Norton (1999).

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