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Application of the Agricultural Non-Point Source Pollution (AGNPS) model for sediment yield and nutrient loss prediction in the Dumpul sub-watershed, Central Java, Indonesia

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Abstract Soil erosion is one of Indonesia's most serious environmental degradation problems. Reliable measurements of erosion rates, however, remain uncommon, and estimates of soil productivity are even more rare. Assessing the extent and seriousness of erosion therefore remains a difficult task. Nevertheless, identification and assessment of erosion problems play an important role in bringing about better land-use and conservation practices. The Agricultural Non-Point Sources Pollution Model (AGNPS) model can be used for developing drainage basin management plans. The model was used to identify critical areas within the drainage basin where land treatment should be focused for optimal results. Furthermore, land and water conservation measures can be implemented in critical areas, while taking into consideration the bio-geophysical conditions in the drainage basin. Application of the AGNPS model to the Dumpul sub-drainage basin in central Java resulted in a coefficient of determination of 0.94 between observations and AGNPS results when the model was used for computing sedimentation rates. The relationship between modelled *vs* measured nutrient and phosphorus loss and chemical oxygen demand has a coefficient of determination of 0.98. Sediment yield, nutrient loss, phosphorus loss, and chemical oxygen demand calculated by the AGNPS model have values of 420, 6.8, 4.3 and 0.1 kg ha^{-1}, respectively. The modelling result for the Dumpul sub-drainage basin indicates that changing land use to housing areas would increase peak runoff volume, peak runoff flow rate, sediment yield, nitrogen loss, phosphorus loss, and chemical oxygen demand by 37, 40, 118, 87, 91 and 110%, respectively. Conversely, implementing land and water conservation in the form of contouring of the entire drainage basin would decrease these variables by 33, 30, 57, 46, 47 and 41%, respectively. AGNPS results indicate that a combination of contouring and terracing would decrease these losses by 52, 51, 77, 68, 69 and 72%, respectively.

Key words AGNPS; Indonesia; sediment yield

INTRODUCTION

The occurrence of heavy flooding and landsliding in some area of Indonesia indicated that there have been disturbances in the environment in terms of overland flow. Heavy flooding occurred recently in some areas of Indonesia such as Medan, Jakarta, Tangerang, Bekasi, Bandung, Surabaya, Semarang, Demak, Kudus, and Makasar. The floods not only caused damage to property, they also killed approximately 200 people and affected millions of others.

Flooding is one of the indicators of degeneration of drainage basin conditions. Up to now, drainage basin management programmes, which have been implemented for more than five decades, have not yet had optimal results. The increase in critical land area and land degradation shows that problems related to environmental degradation have not yet been totally handled.

The impact of land-use practices on natural resources systems can be classified into two impact categories based on the affected area: onsite impact and offsite impact. Onsite impacts occur in the area where the land use takes place. Common onsite impacts are soil erosion, barren land, and declines in soil fertility and productivity (Arsyad, 1989). Offsite impacts occur in low-lying areas downhill from the area where the land use takes place. Possible impacts on downstream areas within the drainage basin that have long been recognized as a major problem are: siltation on the river bed and in reservoirs and irrigation systems; decreases in the lifespan of manmade reservoirs; damage to estuarine mangroves and other coastal ecosystems; increased frequency of flood and drought; and deposition of chemical residues in river, lakes, and reservoirs. From the two impact categories, managing the offsite impact often is more difficult and complex than onsite impact management.

Managing nonpoint-source pollution caused by land-use practices is technically complex, in addition to being politically, economically, and socially difficult. Pollutant sources are often spread over a large geographic area, they may be located in remote, not readily identifiable areas, and are sometimes caused by many simultaneous activities. In determining the activities and agencies involved in managing impacts, there must be integrated assessment based on physical and technical considerations, but also on socio-economic aspects (Young *et al.*, 1989). The hydrological processes of water flow and sediment transport must be measured, problems must be investigated from institution to institution, from one stakeholder to the other, and the alternatives proposed must be technically applicable, economically feasible, implemented using local resources, and accepted by the local community and all stakeholders involved. On the other hand, the information needed is often scarce or absent, and, particularly in developing countries, research funding is limited. Earlier research is frequently limited in scope, technically conventional, only partially relevant, and cannot be implemented directly to solve the problems.

An important consideration for managing drainage basin resources is that activities in one part of the drainage basin (e.g. upland deforestation) can affect resources in different areas, especially those located downstream (e.g. sedimentation, flooding). This phenomenon is analogous to a basic concept in economics named “externalities”. This term describes a situation in which some of the benefits or costs of an action are external to the decision maker; that is, some of the benefits accrue to, or some of the costs are imposed upon, individuals who play no part in the decision.

Methods for predicting the impact of improper land-use practices on a drainage basin commonly involve conventional methods based on direct field measurements. Runoff and erosion rates associated with the specific land-use practice are measured using observation plots (Brakensiek *et al.*, 1979; Foster *et al.*, 1981). This method is not efficient in term of cost, manpower, and time needed in a drainage basin, which may contain many different types of land use (DeCoursey, 1985).

The Agricultural Non-Point Sources Pollution (AGNPS) model is a mathematical model based on the functional relationships between the influential factors in the drainage basin (Yoon, 1996a, 1996b). The AGNPS model can simulate surface runoff and sediment and nutrient transport in a drainage basin dominated by agricultural activity (Young *et al*., 1989, 1994, 1995). With this model it is possible to evaluate the impact of alternative land-use scenarios in the drainage basin.

METHODOLOGY

This research project uses information on the topography, land use and soils derived from maps, and rainfall and discharge data. The project consists of two parts: part one is an investigation of the impact of land management on streamflow quality and its distribution using the AGNPS (version 5.00) model; and part two focuses on the impact of land management on farmer's income through direct interviews with the farmers.

The input data were collected through map interpretation, field measurement, and laboratory analyses. Map interpretation using ortho-photo maps at a scale of 1:5000 was done to make a land unit map and a cell system, and to determine input parameters such as flow direction, flow receiving cell, slope length, slope shape, and slope level. Fieldwork was conducted to determine model input parameters, to collect soil and sediment samples, and to check parameters determined from the map. This field work consisted of automatic and manual rainfall data collection, measuring water level; collecting sediment from various high water levels; measuring infiltration rate and soil permeability on each land unit, collecting soil samples from each land unit; observing crop management and conservation practices; determining fertilization level factors by interviewing farmers; and estimating channel roughness to determine the Manning coefficients.

Three scenarios were considered during simulation: (a) conversion of crop and rice fields to housing areas; (b) introducing a contouring system; and (c) contouring plantations and bench terrace improvements in crop and rice fields. The first scenario was aimed at investigating the impact of extreme land-use conversion on runoff rates and sediment and nutrient loss. The second and third scenarios were formulated to investigate the high rates of erosion and sedimentation in the Dumpul sub-drainage basin relative to the tolerable soil loss.

RESULT AND DISCUSSION

The output of AGNPS can be divided into three parts: hydrology (volume and peak runoff rate), sediment load and nutrient loss (N, P, COD). The output can be presented as a graph or a table. The model output under current land-use conditions with a maximum rainfall of 74 mm day^{-1}, which has a return period of 2.19 years, showed a total runoff volume of 9221.3 m^3 and a peak discharge of 1.78 m^3 s^{-1}. The runoff volume was only 9% of the total rainfall in the Dumpul sub-drainage basin. The spatial pattern of the runoff volume and peak flow rate is presented in Figs 1 and 2.

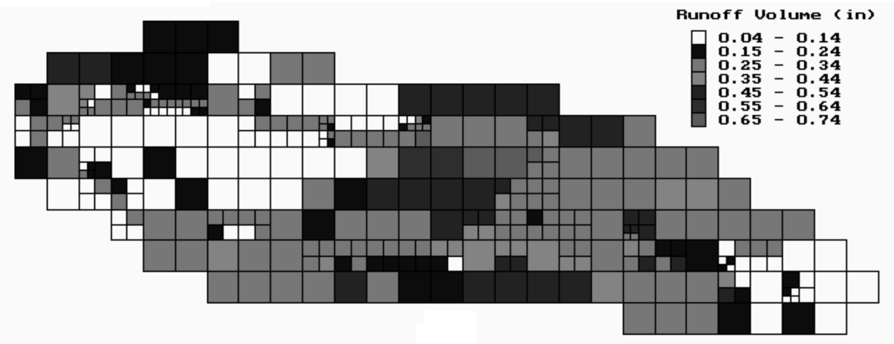

Fig. 1 Distribution of runoff volume from AGNPS model.

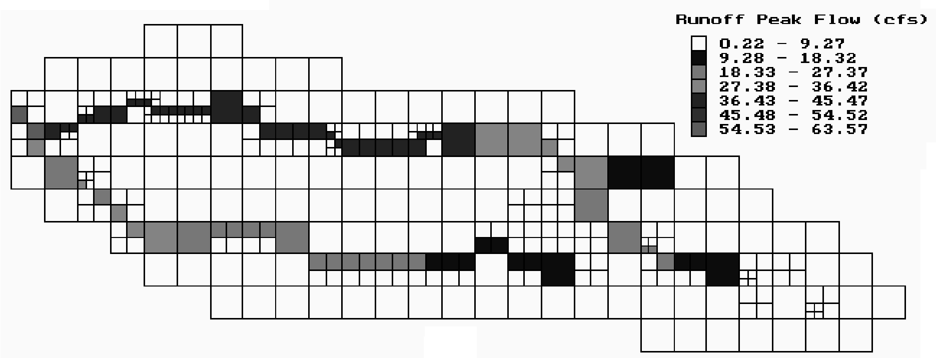

Fig. 2 Distribution of peak flow rate from AGNPS model.

The sediment yield depends on the runoff rate. Since the runoff coefficient was only 9%, the transport capacity was low. As a result, the sediment yield at the basin outlet was only 12% of the total erosion in the in Dumpul sub-drainage basin.

Of the sediment yield of 420 kg ha^{-1}, 76% was clay and 13% was silt. From these percentages it can be concluded that transport capacity is the limiting factor for the export of nutrients and sediment. The spatial pattern of sediment transport by overland flow is presented in Fig. 3. The nutrient losses are 6.8 kg ha^{-1} of total N, 4.3 kg ha^{-1} of total P and 0.1 kg ha^{-1} of COD, whereas the concentrations of dissolved N and P were 2.94 and 0.93 ppm, respectively.

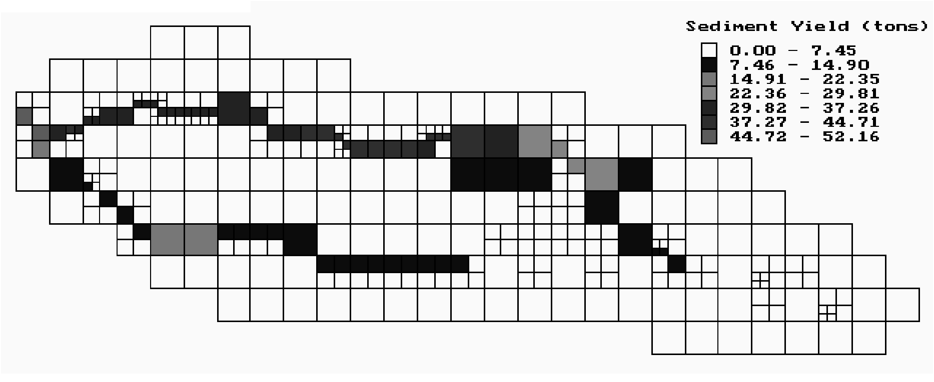

Fig. 3 Distribution of sediment yield from AGNPS model.

Table 1 Value and percentage change in model output.

Parameter	Existing conditions	Scenario 1: Value	%	Scenario 2: Value	%	Scenario 3: Value	%
Runoff volume (m^3)	9221	12587	37	6147	–33	4415	–52
Peak discharge (m^3 s^{-1})	1.79	2.51	40	1.26	–30	0.87	–51
Sediment yield (kg ha^{-1})	420.82	917.67	118	180.31	–57	95.01	–77
N-total loss (kg ha^{-1})	6.83	12.80	87	3.70	–46	2.17	–68
P-total loss (kg ha^{-1})	4.26	8.12	91	2.27	–47	1.34	–69
COD con.soluble (kg ha^{-1})	0.10	0.21	110	0.059	–41	0.028	–72

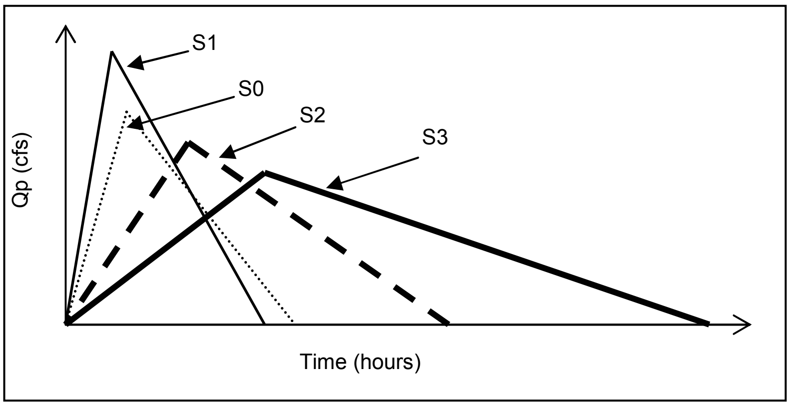

Fig. 4 SCS triangle synthetic unit hydrographic shape from simulation.

Conversion of cropland to housing area will increase the runoff volume, peak discharge, sediment yield, and nutrient loss (N, P, and COD) (Table 1). The increases were 37, 40, 118, 87, 91 and 110%, respectively. Based on the SCS triangle synthetic unit hydrograph shape, land conversion will also change the hydrographic parameter value. Land conversion to housing areas has the effect of raising peak discharge and shortening the time base (Fig. 4). On the other hand, when soil conservation measures are taken across the basin, the time base and the time to peak will increase and the peak flow will decrease. Under scenarios 2 and 3, the basin output (runoff volume, peak discharge, sediment yield, and nutrient loss) will decrease. The decreases of the basin output when applying contouring were 33, 30, 57, 46, 47 and 41%, respectively. By applying contour plantation and terrace improvements in crop and rice field, the basin output decreased by 5, 77, 68, 69 and 72%, respectively.

The main advantage of contour plantation and bench terracing is that the volume and velocity of overland flow will decrease whereas total infiltration will increase.

CONCLUSIONS

(a) The AGNPS model can be applied in the planning stage of drainage basin management, so that environmental degradation and critical land can be identified and analysed. By using the AGNPS model, soil and water conservation practices can be adjusted to the bio-geophysical conditions in the drainage basin.

(b) The results of simulation in the Dumpul sub-drainage basin show that the absence of soil and water conservation activities (Scenario 1) has the effect of increasing runoff volume, peak discharge, sediment yield, and nutrient loss (N, P, COD)

(c) Soil and water conservation practices, such as contouring ridges, in all cropland will reduce runoff volume, peak discharge, sediment yield, and nutrient loss.

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