Erosion evaluation and prediction in mountain regions of Taiwan

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Abstract Watershed data are being collected in Taiwan for testing the AGNPS model. Preliminary testing with data from a small experimental agricultural basin at Tahu, Miaoli County, has produced reasonable estimates of sediment yield. Further testing with proper modifications of the Universal Soil Loss Equation factors, performed on larger basins located in Taoyuan, Nantou and Tainan also produced excellent agreement between the simulated and measured sediment yields. The refined AGNPS model has also been used to predict soil erosion and sediment yield within the Bajun River basin. The model input data are collected initially using remote sensing and a Geographic Information System, and processed with the ARC/INFO Geographic Information System software. The predicted soil loss for the Bajun River basin corresponds closely with previous estimates based on major river and reservoir sedimentation data. This is a clear indication that the AGNPS model is capable of providing a quantitative evaluation of on-site/off-site damage, rating basin response, and planning conservation strategies on the local, regional and even national level.

INTRODUCTION

Land use and land management practices that formerly were sustainable may become detrimental as a result of population increase, sometimes causing irreversible damage (Eckholm, 1976; Brown, 1978). These land use changes often lead to increased on-site erosion rates. The major concern related to erosion is generally the damage done to the soil itself – the loss of soil and of soil productivity. However, when eroded soil is carried off the farm by runoff, it may end up in local streams, rivers, canals, or in irrigation and hydroelectric power scheme reservoirs. The loss of topsoil that reduces land productivity may also reduce irrigation, electricity generation, and the navigability of waterways. In Taiwan, most of the large reservoirs have already experienced serious siltation problems resulting from natural landslides and improper land use in the upper reaches (Chang *et al.*, 1989). The useful life of these reservoirs will probably be considerably shorter than originally planned.

Further downstream, sedimentation can increase flood hazards, degrade water quality, and harm coastal resources, including corals, mangroves, and fisheries. In fact, Crosson (1984) estimates off-site damage to be much higher than on-site damage in the United States. Another problem of more recent concern involves contaminants that are carried into the streams. Fertilizer nutrients and pesticides may be carried into streams and rivers, affecting the plants and aquatic life and even land animals and man. Hence, there is a critical need to identify site specific off-site damage caused by sheet and rill, wind, ephemeral gully and gully erosion.

Recently, many erosion and sedimentation models have been developed for predicting fluvial soil erosion and sediment yield. One such model, with the acronym AGNPS (Agricultural Non-Point Source Pollution model), has the capability of evaluating nonpoint source pollution at any point and predicting site-specific sedimentation within a catchment. This paper describes the adaptation of this model to evaluating and predicting soil erosion in Taiwan.

THE AGNPS MODEL

The AGNPS model was developed by the USDA Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (Young *et al.*, 1987). It is a computer simulation model designed to analyse nonpoint source (NPS) pollution in drainage basins. The primary objectives of AGNPS development were to:

1. obtain uniform and accurate estimates of runoff quality with primary emphasis on sediment and nutrients,
2. analyse the potential impacts of conservation alternatives (and land uses) for watershed management, and
3. provide a flexible and easy-to-use model.

AGNPS also provides a means for assessing watershed condition and for objectively evaluating storm-related generation and transport of NPS pollutants within watersheds.

The model subdivides the drainage basin into uniform grid squares called "cells". Potential pollutants are routed through these cells in a stepwise manner, proceeding from the headwaters of the basin to the outlet. This allows flow as well as water quality parameters to be examined at any point. All characteristics of the basin are expressed at the cell level.

AGNPS is an event-based model. The basic model components include hydrology, erosion, and sediment and chemical transport. In the hydrology component, runoff volume and peak flow are calculated. The erosion portion computes total upland erosion, total channel erosion, and a breakdown of these sources into five particle size classes (clay, silt, sand, small aggregates, and large aggregates). Upland erosion is routed through the watershed. Sediment transport is also calculated for the five particle classes as well as the total. The chemical transport portion is separated into one part handling dissolved pollutants and another part handling sediment-associated pollutants. Transport of nitrogen, phosphorus, and chemical oxygen demand (COD) are estimated throughout the watershed. The model also treats sediment eroded from gullies and inputs of water, sediment, nutrients, and COD from animal feedlots as point sources and routes them through the basin with the contributions from nonpoint sources. Water impoundments, such as tile-outlet terraces, are treated as depositional areas for sediment and sediment-attached chemicals.

Various output options are available with the model. The outputs can be examined for a single cell or for the entire drainage basin. A preliminary output includes basin and cell area, storm precipitation and erosivity, runoff volume and peak rate, and a detailed analysis of the sediment and nutrient yields. Also given are estimates of sediment delivery ratio, sediment enrichment ratio, sediment concentration and sediment yield for each of the five particle size classes. The detailed nutrient analysis includes the unit area amount of N, P, and COD in runoff and N and P for sediment-associated nutrients; and the N, P, and COD concentration in the runoff.

ADAPTATION OF THE MODEL FOR TAIWAN

The AGNPS model has been successfully used in several areas in the USA to rank upland catchment areas for remedying downstream problems (Onstad & Young, 1988; Young *et al.*, 1989). To demonstrate its applicability in Taiwan, four small agricultural basins located in Miaoli, Taoyuan, Nantou and Tainan counties were selected for this purpose (Fig. 1). A brief description of the drainage basins selected is as follows:

The Miaoli basin The basin is located near Miaolin Village, Tahu District, Miaoli County. The total area is approximately 3.44 ha. The soil texture is loam or sandy loam and is derived from sandstone and shale. The pH of this soil ranges between 4.05 and 5.60, and the organic matter content averages about 1.63%.

The original terrain was extremely irregular causing difficulties for cultivation. The slopes were then reshaped. Gullies were filled using heavy earthmoving equipment. Orchard hillslide ditches were then established across the prevailing slope at an interval of 15 to 18 m. The ditch bottom was 2.5 m wide with a gradient of 1 to 1.5%. Soon after the completion of the necessary conservation works, bahia grass (*Paspalum notatum*) was planted throughout the basin to provide fast ground cover. Fruit trees were later planted.

The Taoyuan basin This basin is located within the Taiwan Tea Experiment Station. The total area is about 56.5 ha and is planted with tea. Soil and water conservation practices such as bench terraces, cover crops, and contour farming were used to control erosion losses. The average annual rainfall ranges between 1200 and 2500 mm, and is concentrated between July and September. The slope of the basin is about 17%. The soil texture is clay loam. The soil is a reddish-brown latosol which has been severely eroded. It

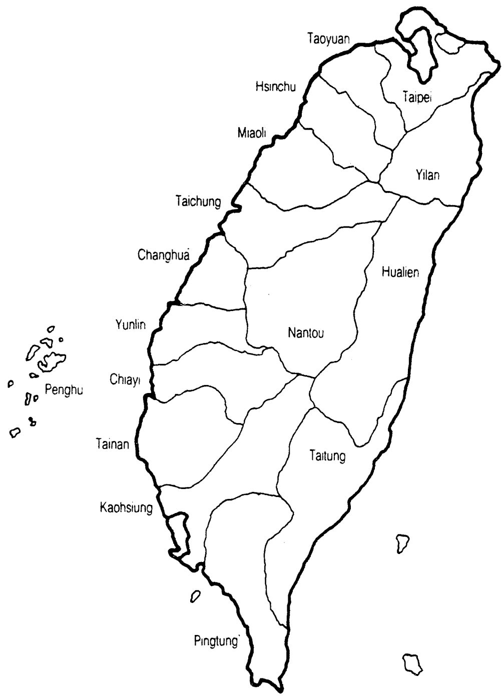

Fig. 1 Location map of the selected drainage basins.

is slightly acidic, of shallow depth, and low in organic matter. Soil erosion measurements were conducted between 1958 to 1965.

The Nantou basin This basin is located in Chungliao Village, Nantou County. The total area is about 1.62 ha. The soil is a yellow soil derived from sandstone and shale. The soil texture is loam. The average slope ranges between 19 and 21%. Annual rainfall is about 1700-3000 mm, and is concentrated between March and September. Orange trees were planted in 1982, bahia grass was also planted all over the area as a cover crop and as a mulching material.

The Tainan basin The basin is situated within the Taiwan Livestock Research Institute, at Hsinhua, in Tainan County. The soil texture is sandy loam, and the soil is acidic, and low in organic matter. The total area is about 9.31 ha. The average slope is about 32.5%. Annual rainfall ranges between 1600 and 2800 mm. Most rainfall is usually received between May and September. Soil erosion measurements began in 1971 after hillside ditch construction and the planting of pangola grass.

To form the input data file needed to operate the model, the basin was first divided into 40-89 uniform cells. Each cell occupied approximately 400-6400 m^2 in area. Basic catchment input data are summarized in Table 1.

Table 1 Basic input data for the selected basins.

Site	Basin area (ha)	Cell area (ha)	Number of cells	Annual rainfall (mm)	Erosivity index (EI)
Miaoli	3.44	0.04	84	1520	850
Taoyuan	57.46	0.64	89	2027	659
Nantou	1.62	0.04	40	2301	782
Tainan	9.31	0.16	58	2200	836

Rainfall related parameters, including rainfall amount and the rainfall erosivity factor (*R*), were calculated for the Miaoli basin from continuous rainfall records provided by an automatic recording gauge. The *R* factors for the other basins were obtained from the iso-erodent map of Taiwan published by Huang (1979). The soil erodibility factor (*K*) values were based on the estimates of Wann & Hwang (1989) calculated using the Wischmeier & Smith (1978) nomograph. Topographic parameters such as slope shape, slope gradient, slope length, aspect, channel slope, and channel side slope were obtained from field survey maps, 1:5000 topographic maps, and site inspection. Parameter values such as the SCS curve number, Manning's roughness coefficient, and surface condition, were based on actual land use conditions at the time of the storm and the corresponding values tabulated in the model users' guide (Young *et al.*, 1987).

For the Miaoli basin, a continuous function was assumed to approximate the crop management factor (*C*); with an initial value of 1.0 and declining exponentially to less than 0.05 one year later. The *C* factors for the other basins and the conservation practice factors (*P*) were based on a synthesis of representative *C* and *P* values obtained from field experiments under natural conditions.

Fertilization rates were assumed to be low and incorporated into the soil. No point sources, gully sources and impoundments were included. The COD factor usually varies according to different land use. A value of 50-60 mg l^{-1} was used, corresponding the "pasture and open" land use type (Young *et al.*, 1987).

A total of 37 storms were recorded between May 1987 and March 1988 for the Miaoli basin. The model simulations were performed for each storm. The annual erosion damage at this site is caused by five to six significant storms during the summer months (May to July). Therefore, good conservation management practices to reduce sediment yield would have to be emphasized during this vulnerable period. A total of 400 erosion stakes (5 m apart) have been installed along 10 transects throughout the watershed. Three measurements have been undertaken during this time period to assess the erosion depth. A comparison between the measured and simulated sediment yield is presented in Fig. 2. In general, there is an excellent agreement between both estimates.

Data from 11 years, four years, and five years of measured rainfall/runoff events for the Taoyuan, Nantou, and Tainan basins, respectively,

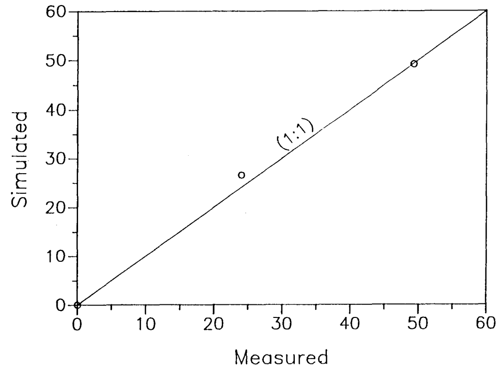

Fig. 2 Measured *vs* simulated sediment yields (t ha^{-1}).

were used to test further the applicability of the model to Taiwan. Table 2 compares the simulated results obtained using the annual rainfall and rainfall erosivity index for each watershed and the average annual soil loss for the test period. The model estimates of soil loss compared favourably with the measured rates. This is a clear indication that the AGNPS model can complement field measurements in providing a quantitative understanding of off-site damage from small agricultural basins.

Table 2 Comparison of measured and simulated sediment yields for the Taoyuan, Nantou and Tainan basins.

Site	Sediment yield (t ha^{-1}):		Difference (%)
	Measured	Simulated	
Taoyuan	1.243	1.309	+5.3
Nantou	1.674	1.458	−12.9
Tainan	2.447	2.051	−16.2

MODEL APPLICATION

The refined AGNPS model has been used to predict soil erosion and sediment yield in the Bajun River basin, Chiayi County. The prevailing slope of the Bajun River basin is towards the west (Fig. 3). The entire length is about 74 km. The average inclination ratio is about 1:42. The total area of the river basin is around 475 km^2. There are two major soil groups in the study area. The first group is located in the western flood plain. It represents the Pleistocene or Pliocene alluvium, consisting of alluvial material washed down from undulating hills and ridges in the east. It is the main agricultural area in Taiwan. The other group represents the Sandstone-Shale Pale Colluvial Soils.

Land use in the study basin often varies widely due to variability in topographic setting, soil properties, climate, market accessibility, and the farmers' cultural preferences. In general, rice is grown in areas with adequate

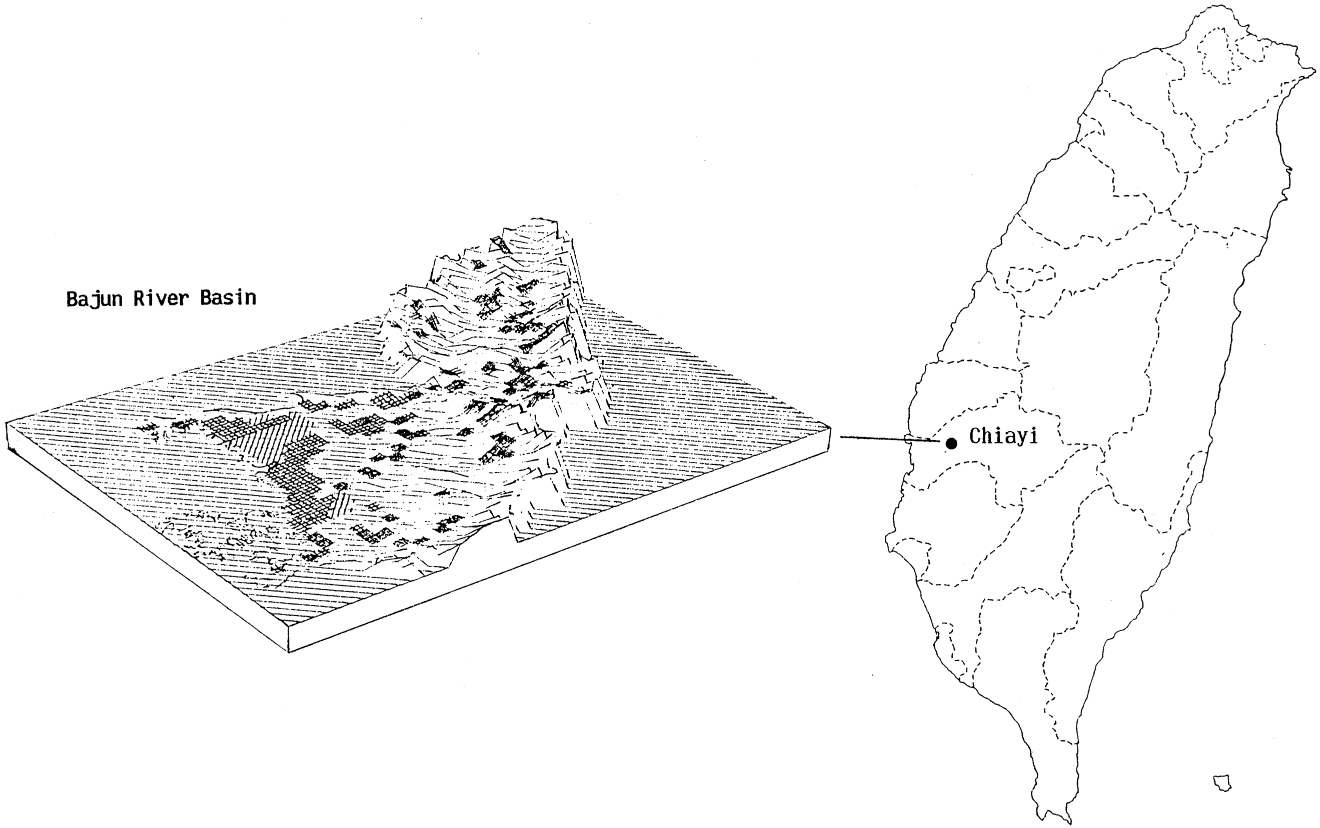

Fig. 3 The Bajun River basin.

supply of water, such as river valleys and tablelands near the river banks. Long-term crops such as fruit trees and bamboo are grown on the hillslopes. The major agricultural crops in this area include rice, oranges, longans and lichees. The main forest trees include both broad-leaf and coniferous trees as well as bamboo.

The procedure used for prediction in this study is presented in Fig. 4. The ARC/INFO GIS computer software was employed to process and analyse the necessary input data. The data base for the entire study area was structured using the Integral Terrain Unit Mapping (ITUM) system. Data layers consist of:

(a) the Ministry of the Interior 1:25 000 topographic maps,
(b) the Central Geological Survey Institute 1:50 000 geological maps,
(c) the Soil and Water Conservation Bureau 1:25 000 soil maps.

AGNPS was used to determine the erosion potential within the Bajun River basin assuming an annual rainfall of 1000 mm and a rainfall erosivity index of 2000. The *P* factor was allocated the maximum value of unity to represent the worst case when no conservation control measures are used. The total average annual soil loss for the entire Bajun River basin is estimated to be about 259 t ha^{-1}. The total sediment yield is approximately 1.29×10^6 t.

Assuming an average bulk density of 1.4 g cm^{-3} (or t m^{-3}), the annual depth of soil loss is about 18.5 mm. The Water Resource Planning Commission (WRPC) reported that the average soil erosion depth for Taiwan was about 5 mm $year^{-1}$, based on river sediment transport measurements (WRPC, 1973).

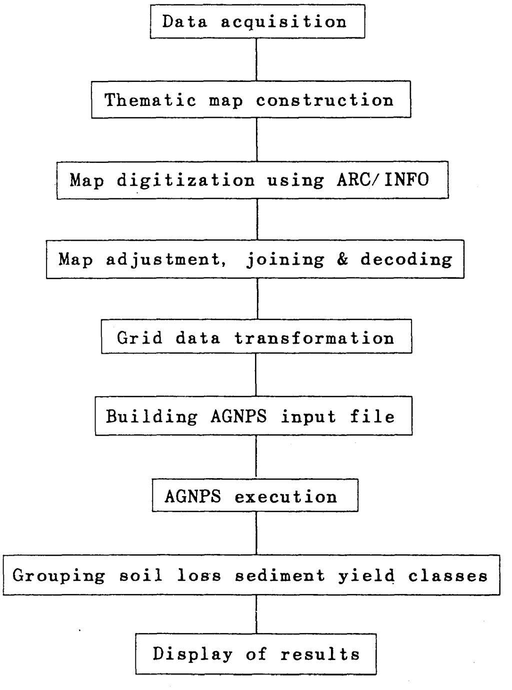

Fig. 4 Procedures used to integrate the GIS with the AGNPS model.

Lee (1985) also estimated the average soil erosion from mountain lands based on sedimentation data from nine reservoir basins. His value was about 9.2 mm $year^{-1}$. Using an area-weighted average, Wu (1986) revised Lee's estimated to 4.8 mm $year^{-1}$. Therefore, if the effects of land management or conservation control practice are taken into account, the annual soil loss rate estimated by this model would not be too different from those of the WRPC, Lee and Wu. These findings further emphasize the applicability of AGNPS in estimating soil loss in Taiwan. However, the estimated erosion rate is much higher than the permissible value of 5-11 t ha^{-1} adopted by the USA. Although an appropriate soil loss tolerance limit has not yet been determined for the tropics and Taiwan, it is clear that the soil conservation programmes need to be intensified in Taiwan in order to preserve the precious soil resource which has a direct influence on the stability of agricultural development.

Figure 5 subdivides the amount of soil loss for each cell into four groups, namely nil (<20 t ha^{-1}), low (20-500 t ha^{-1}), medium (500-1000 t ha^{-1}), and high (>1000 t ha^{-1}). Out of the entire basin area, over 79% has a soil loss less than 20 t ha^{-1}. Of the remainder, about 11% belongs to the low level class; 3% to the medium class; and 7% to the high level class. Based on the cell output, areas of high erosion may be easily identified within the basin. Subsequent land development should avoid such areas because they need to be adequately protected with appropriate conservation strategies.

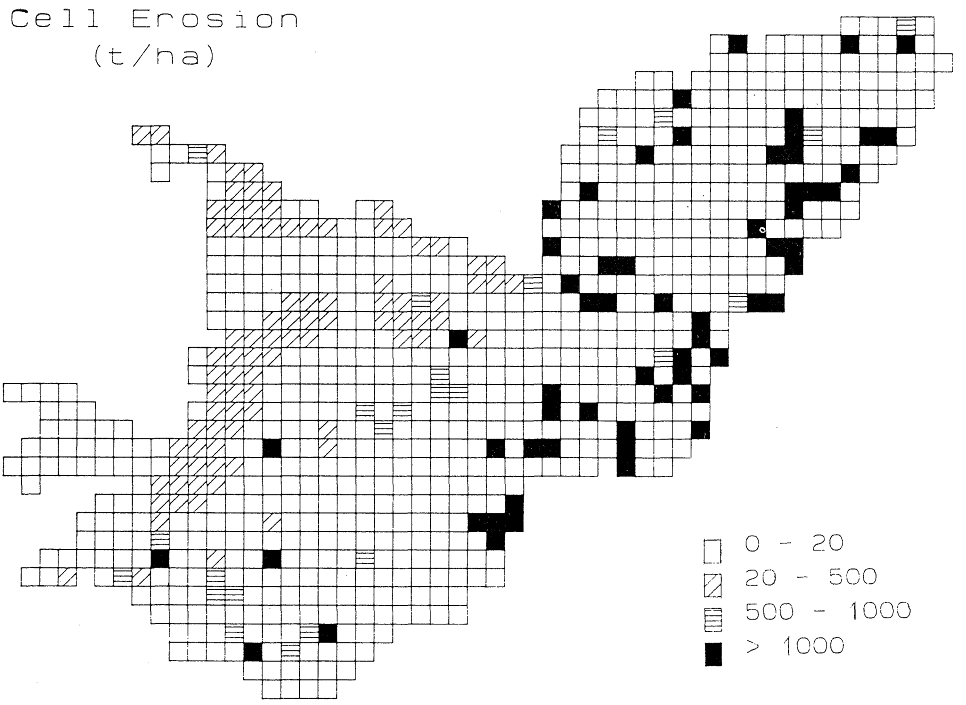

Fig. 5 Soil erosion classes for each cell within the basin.

CONCLUSIONS

The AGNPS model is a computer simulation model designed to analyse nonpoint source pollution in watersheds. It has the capability of evaluating nonpoint source pollution at any point within a basin. It also allows a more realistic view of the sediment and nutrient yields on an areal basis. With adequate modification and adaptation, the model has been shown to produce reasonable estimates of sediment yield for the Bajun River basin. The annual erosion rate is estimated to be about 18.5 mm.

A Geographic Information System has been shown to be a powerful and efficient tool in capturing, storing, updating, manipulating, analysing, and displaying all forms of geographically referenced information. If combined with tools such as Artificial Intelligence and Expert Systems, it can carry out even more complicated spatial analyses and effectively manage large geographic data base systems.

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