A SYSTEM DEVELOPMENT FOR ESTIMATING NON-POINT SOURCES POLLUTANT LOADS FROM WATERSHEDS USING GIS

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Abstract: The purpose of this study is the development of a system for estimating non-point source pollutant loads from a watershed, which enables users to get insights of pollutant load distribution in the watershed during rain as well. Based on the Geographic Information System, this non-point source pollutant loading estimation system(NSPLES) consists of three distinct models such as a distributed rainfall-runoff model, a soil loss and delivery model, and a non-point source pollutant model. It also includes GIS modules for preprocessing the input data for the models and graphical postprocessing of the model outputs The system outputs aren't only the hydrograph, sedimentograph, and pollutograph at the watershed outlet, but also various maps that show the distribution of soil loss over the watershed. The developed system was applied to the two upper stream areas of Sumjin river basin, Ssangchi and Gwanchon basins, and three rainfall events for respective subbasins during 1992 and 1998 were selected for the system application. The results of this system showed relatively higher corelation between observed data and simulated data, and proved the applicability of the system.

Key Words: GIS, non point source pollutant, rainfall-runoff, distribution model, USLE, soil loss

1. INTRODUCTION

The better water quality management requires a clear knowledge on the mechanisms of pollutant growth and loading as well as moving behaviors of them through the water bodies of rivers and reservoirs. Therefore, it is strongly necessary to investigate vastly the fates of the pollutants and accumulate the data, while the appropriate tool for simulating them is waiting to be developed.

Recent issues of water pollution problem tend to focus on the non-point source pollution problems, while in the past, the point sources pollution problems were concentrated, which are massively loaded at a certain point. The non-point source pollution, as is meant by its terminology, is loaded at an unspecified wide area by rainfall-runoff and does not flow out through the immutable exit like as point source pollution so that it is not acceptable to apply control method by collecting process.

For an efficient water quality management at this situation, it is very important to develop the technologies to find out the potential areas where the mass products of soil erosion and pollutants could be occurred and to estimate the accurate pollutant loads quantitatively. The policy making to regulate the potential pollution loads is still needed.

The purpose of this study is to develop a system for estimating non-point source pollutant loads from watersheds using Geographic Information System (GIS). This system which has distributed data structure consists of a distributed rainfall-runoff model, a newly proposed soil loss and delivery model, and a non-point source pollutant loading model.

2. DEVELOPMENT OF THE SYSTEM

Most of the non-point source pollutants are loaded with the soil particles by the runoff of excessive rainfall. Therefore, it is necessary to model the rainfall-runoff and soil loss and delivery processes as well as the pollutant loading. In this study, all these respective models were integrated to develop the Non-point Sources Pollutant Loading Estimation System (NSPLES). Fig. 1 shows the configuration of the NSPL ES.

In the NSPLES, TOPMODEL is used as a rainfall-runoff model, which was developed by Beven and Kirkby (1979) and is a physically based distributed model. The soil loss and delivery model adopts the Wischmeier and Smith's USLE equation for the soil loss estimation and Roehls equation (1962) for routing the transports of the suspended material from a grid to a grid by the distance between them (Fig. 2). Non-point source pollution loading model was developed based upon the idea that the amounts of pollutants loaded depends on the runoff discharges of rainfall. Regression models such as in Table 1 were derived through statistical analysis of observed data.

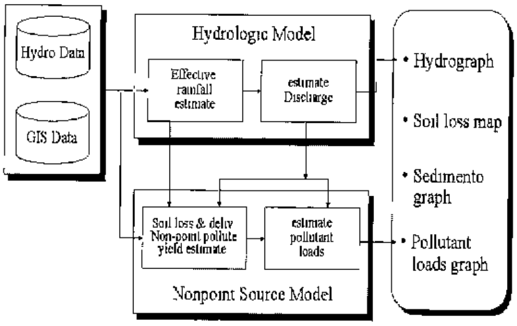


Fig. 1. System Configuration of NSPLES

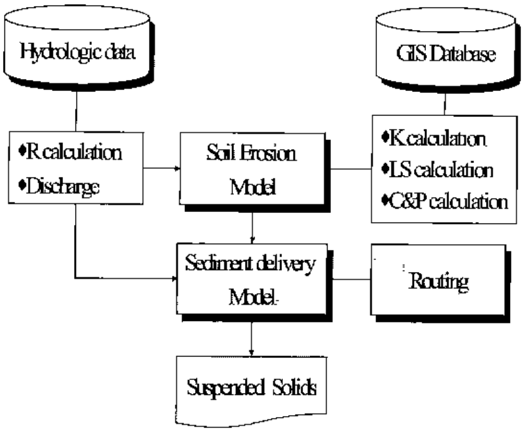


Fig. 2. Configuration of Soil Loss and Delivery Model

All the models were coded in the FORTRAN programming language to be run on a personal computer under Microsoft Windows 95 or 98. Interfaces between the models as well as the pre- and post processing were performed by Microsoft Excel spreadsheet software using macro functions.

Table 1. Various Types of Regression Equations for Estimating Pollutant Loads

No	Equation Types	Parameters
1	$y = Ax + B$	A, B : constants
2	$y = A \cdot (x)^B$	y : concentration of pollutant
3	$y = A \cdot e^{Bx}$	
4	$y = A + B \ln x$	x : discharge

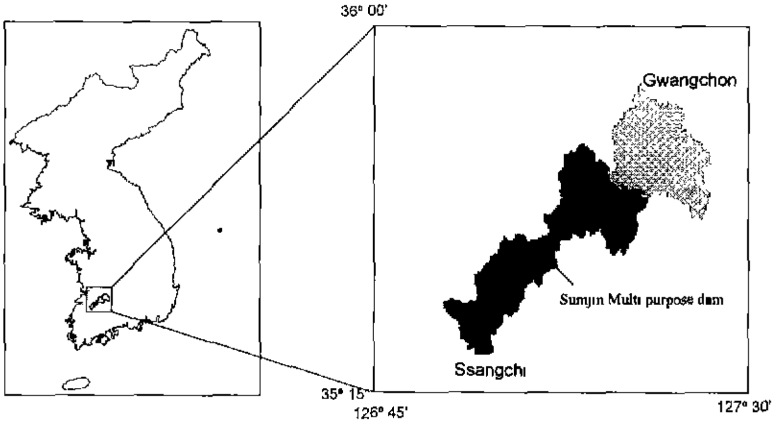
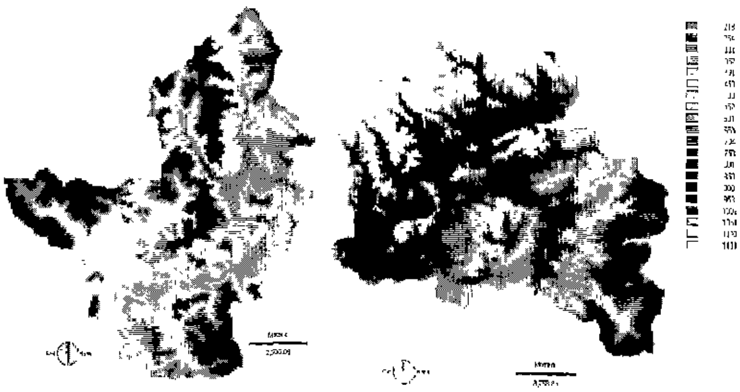


Fig. 3. Location Map of Study Area



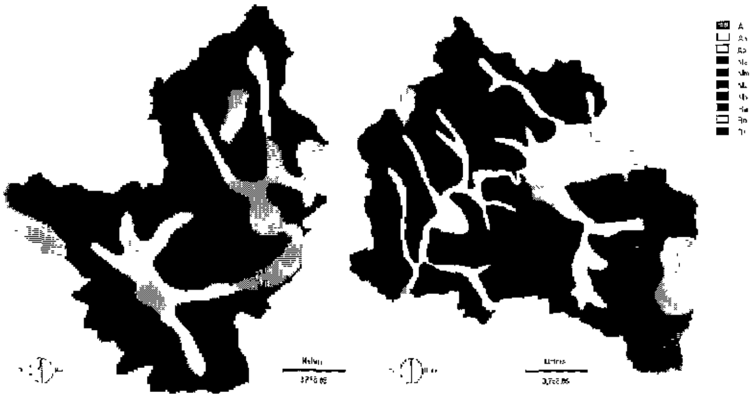
(a) Ssangchi (b) Gwangchon

Fig. 4. Digital Elevation Model of Each Subbasin

3. GEOGRAPHIC INFORMATION SYSTEM

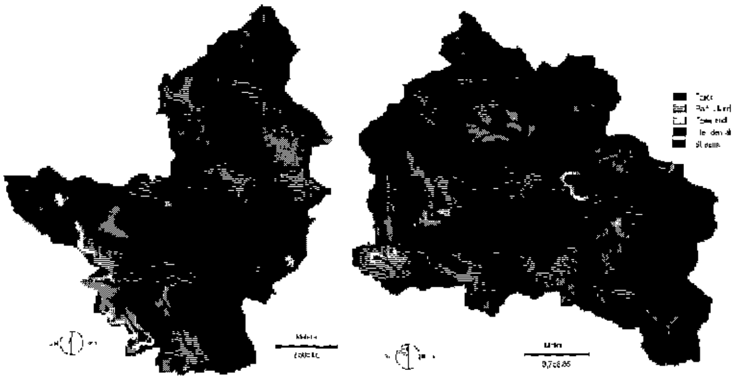
Study area is the catchment of the Somjin multi-purposed dam in the Somjin river. It flows through the southern part of Korean peninsula into the South Sea. The whole watershed area is 763.82 ㎢. For the application of the developed system, the whole watershed is devided into three subbasins such as Gwanchon (301.776 ㎢), Ssangchi (117.895 ㎢), and near reservoir area (344.145 ㎢) as in Fig. 3.

Digital Elevation Model (DEM), land use maps, and soil maps of all subbasins were collected and used to generate the spatial input data of the models. UTM-52n geographic coordinate system was adopted in this study, and the IDRISI(Ver. 2.0), and PC-ARC/INFO (Ver. 3.4.2) software were used for processing raster and vector spatial data, respectively. DEM data used on this study was the Digital Terrain Elevation Data (DTED) level-1 from U.S. Defense Mapping Agency. The resolution of the data was three seconds for each grid cell. DEM of each subbasin was resampled into the grid size coincided with the modeling grids and trans-



(a) Ssangchi (b) Gwangchon

Fig. 5. Soil Maps of Each Subbasin



(a) Ssangchi (b) Gwangchon

Fig. 6. Landuse Map of Each Subbasin

formed into ASCII format for use as inputs to the models.

Original soil map published by Rural Development Administration has a scale of 1 to 250,000 and 10 categories according to the soil particle size and vegetation. The map was digitized into vector format and afterward transformed into the raster soil map. Fig. 5 shows the soil maps of subbasins.

Landuse of eachsub basin was digitized from the 1 to 50,000 scale topographic maps and categorized into five. Landuse map of each basin is shown in Fig. 6.

4. SYSTEM APPLICATION

4.1 Rainfall-runoff Analysis

Three storm events for each subbasin during 1992 and 1998 were selected for the system application. Selected storm events and their 1 hr maximum rainfall intensities and peak discharges are presented in Table 2.

Simulated runoff hydrographs were well coincided with the observed ones as in Fig. 7 and the simulated peak discharges have relative errors in the range of 1.5 to 18.4 percents. And the relative errors of total water yield range from

Table 2. One Hour Maximum Rainfall Intensity and Peak Discharge of Selected Storm Events

event	date	I_{60} max (mm/hr)		peak discharge (m^3/hr)	
		Gwanchon	Ssangchi	Gwanchon	Ssangchi
1	92. 8. 24~8. 27		18		85.48
2	93. 9. 16~9. 27	15		148.40	
3	98. 8. 1~8. 3	14	27	110.04	219.2
4	98. 8. 11~8. 13	31	28	270.02	110.04

Table 3. Comparison of Simulated and Observed Runoff

rainfall event	total rainfall (mm)	peak discharge (m^3/sec)			total runoff volume (m^3)		
		observed	simulated	related error (%)	observed	simulated	related error (%)
Gwanchon							
G1	82	157.59	147.53	6.4	5031.4	4435.4	11.8
G2	70	109.81	108.14	1.5	1831.8	1705.9	6.9
G3	152	275.79	285.01	3.3	6663.4	7644.4	4.7
Ssangchi							
S1	88	85.47	93.53	9.4	5277.0	5171.0	2.1
S2	165	219.09	178.81	18.4	5695.0	4954.8	13.0
S3	107	110.04	110.04	6.3	2812.3	3130.2	11.3

2.1 to 14.7 percents. For the storm case of August 1, 1998 of Ssangchi, the influence of antecedent rainfall was not reflected in the simulation pertinently resulting in the low estimation of runoff discharge at the early stage. It must be due to the insufficient information about the antecedent rainfall. However, it could be regarded that, in most cases, the runoff simulations by TOPMODEL were excellent and acceptable for the scales of such basins as Gwanchon and Ssangchi.

4.2 Analysis of Soil Loss and Delivery

For the analysis of soil loss, the rainfall energy factors (R) were calculated from the rainfall data of the storm events. However, the analysis was carried out only for the storm events in 1998, because water quality data were measured only for 1998 events. Rainfall energy factors estimated for the events are presented in Table 4.

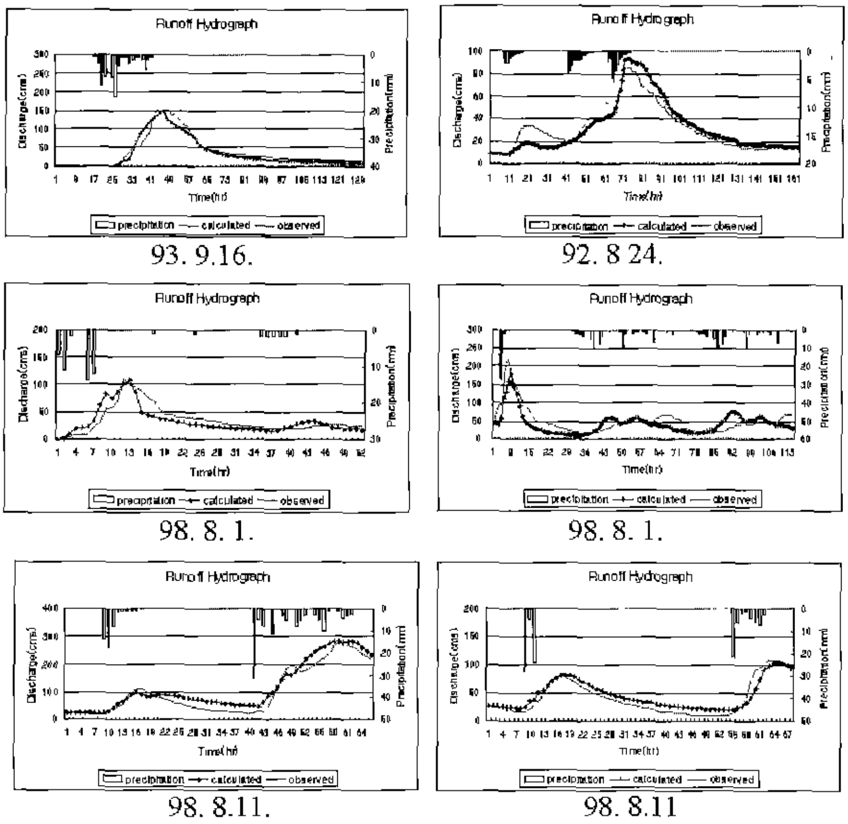
Table 4. Rainfall Energy Factors of Selected Events

(unit : 10^7 joule/ha-mm/hr)

Rainfall event	Gwanchon	Ssangchi
98. 8. 1~8. 3	12.37	27.93
98. 8. 11~8. 13	65.52	38.53

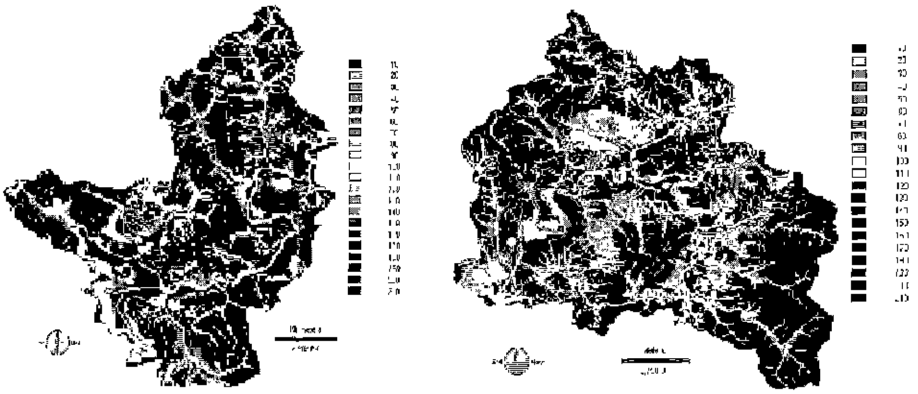
Soil erosion factors (K) were generated for every grid cells from the soil map referencing the nomograph data by Wischmeier (1971). LS factors related with the basin slope were calculated for every cell from the slope map generated by the DEM. The calculation of LS factors was done by the Wischmeier and Smith's method. Generation of C&P factors regarding the surface cover condition are done by using landuse map.

Distribution of the soil loss by the storm event of August 11, 1998 was mapped as in Fig. 8 for Gwanchon and Ssangchi subbasins respectively and unit soil loss per a square kilometer was estimated as in Table 5.



(a) Ssangchi (b) Gwangchon

Fig. 7. Comparison of Simulated and Observed Hydrographs of Gwangchon & Ssangchi Subbasins



(a) Ssangchi (b) Gwangchon

Fig. 8. Soil Loss Map of Subbasins (98. 8.11.)

The modeling of soil delivery was carried out from the relationship between the soil loss and the concentration of suspended solids at the basin outlet. As mentioned above, Roehls equation

Table 5. Unit Soil Loss per a Square Kilometer for Each Storm Event (unit : ton/km^2)

Rainfall event	Gwanchon	Ssangchi
98. 8. 1~8. 3	1.878	4.518
98. 8. 11~8. 13	9.945	6.232

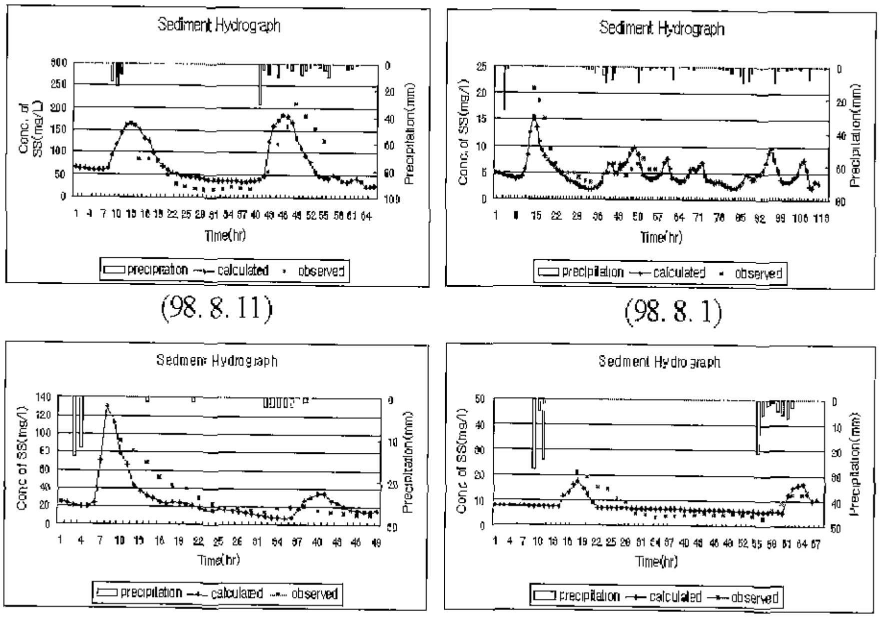
was applied with such parameters as the reaching distances at every lag time, loading ratio of runoff volume to the occurred, area and slope ratio of the basin, and others.

The observed and simulated sedimentographs are presented in Fig. 9. As shown in Fig. 9, though the simulated lag time is somewhat earlier than the observed, the simulated results were mostly agreed with the observed. It was conceived that the simulation of soil loss and delivery would be more successful with more careful consideration on the lag time. However, total volume of suspended soil delivered was estimated with the least errors.

4.3 Analysis of Non-point Source Pollutant Loads

The regression models were developed and applied in the estimation of non-point source pollutant loads. They were developed respectively for such water quality factors as COD, T-N, T-P and PO_4-P. The comparisons of simulated and observed water quality factors were presented in Figs. 10 and 11 respectively for Gwanchon and Ssangchi subbasins.

The results showl that simulated COD of the Gwanchon has the squared regression coefficient (r^2) of 0.7497 against the observed, which might be regarded as a quite good result. Whilst, the r^2 between the simulated and observed T-N, T-P, and PO_4-P were 0.752, 0.7803, and 0.6898 which were within the reasonable range. The highest accuracy of simulating T-P proves that the phosphor has a nature of moving attached to



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(a) Ssangchi (b) Gwangchon

Fig. 9. Comparison of Simulated and Observed SS

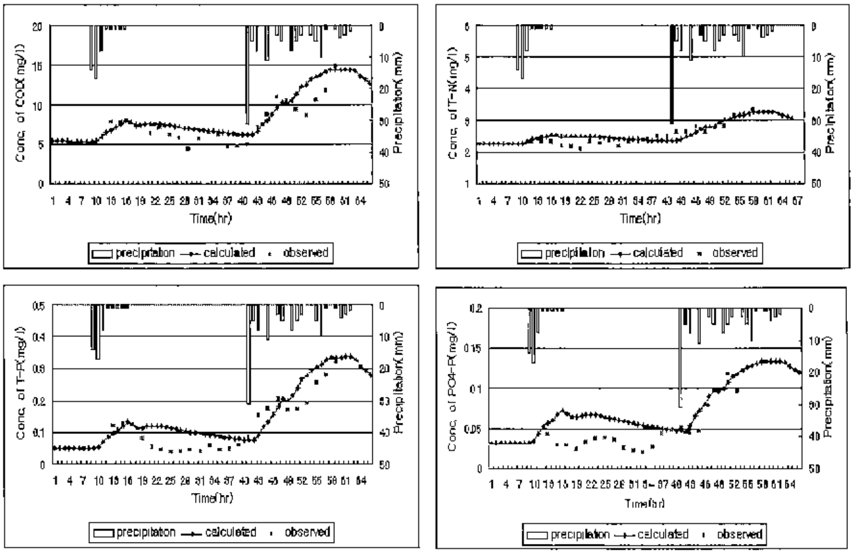

Fig. 10. Comparison of Simulated and Observed Water Quality Factors of Gwanchon sub-basin

the soil particles without fading out and the fate of it has a close relationship with soils and the rainfall-runoff.

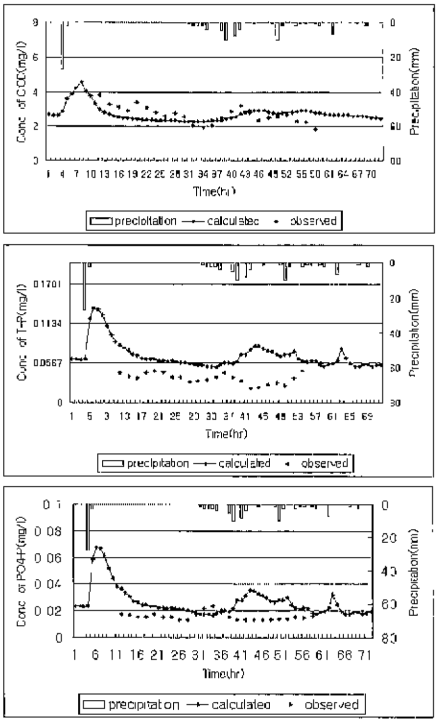

Fig. 11. Comparison of Simulated and Observed Water Quality Factors of Ssangchi Sub-Basin

The nitrogen comes mostly from the animal wastes and fertilizers, so the load of it depends upon the antecedent accumulation of such pollutants on the ground. More consideration on the antecedent conditions of soil surface ensures the better estimation of the non-point source pollutant loads.

5. CONCLUSION

NSPLES, a system for estimating non-point source pollutant loads from a watershed was developed in this study. NSPLES consists of three distinct models such as a distributed rainfall-runoff model, a soil loss and delivery model, and a non-point source pollutant model. It also includes GIS modules for preprocessing the input data for the models and graphical post-processing of the model outputs. The developed system was applied to the two upper stream areas of Sumjin river basin, Ssangchi and Gwanchon basins, and three rainfall events for respective sub basins during 1992 and 1998 were selected for the system application.

Rainfall-runoff was simulated by the distributed rainfall-runoff model, the TOPMODEL, and the simulation results shows the relative error ranging from 1.5 to 18.4 percents for the peak discharges and from 2.1 to 14.7 percents for the total water yields. It could be concluded that the runoff simulation by TOPMODEL is acceptable for the scales of such basins as Gwanchon and Ssangchi. Although the comparison of sedimentographs shows that the simulated peak of suspended materials are somewhat earlier than the observed, total volume of suspended soil delivered was estimated with the least errors. This means that more careful consideration on the lag time leads to the better simulation of soil loss and delivery. The simulated COD of the Gwanchon has the squared regression coefficient (r^2) of 0.7497 against the observed, while r^2 between the simulated and observed T-N, T-P, and PO_4-P were 0.752, 0.7803, and 0.6898 with the highest accuracy of simulating T-P.

From the application results as above, it was concluded that the NSPLES is worth while being used as a valuable tool for the efficient water quality management of the watershed with continuous efforts to accumulate the observed data and improve the system.

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