ANALYSIS OF NON-POINT SOURCE POLLUTION LOADING IN A SMALL RURAL WATERSHED USING HIGH SPATIAL RESOLUTION IMAGE

Jong Yoon Park
Master Candidate, Dept. of Civil & Environmental System Engineering, Konkuk University, bellyon@konkuk.ac.kr

Mi Seon Lee
Doctoral Candidate, Dept. of Rural Engineering, Konkuk University, misun03@konkuk.ac.kr

Seong Joon Kim
Professor, Dept. of Civil & Environmental System Engineering, Konkuk University, kimsj@konkuk.ac.kr

ABSTRACT: This study is to test the applicability of QuickBird image for non-point source pollution assessment. SWAT (Soil and Water Assessment Tool) model was adopted and the model was calibrated for a stream watershed of 255.4 km^2 Landsat land use data. For model application with QuickBird image, a precise agricultural land use map of 1.16 km^2 area located in the upstream watershed was produced by field investigation. The model was run with the combination of land use and soil map scales (1:5,000, 1:25,000 and 1:50,000). The results were compared and analyzed for the contribution of non-point source pollution by the land use scale and contents.

KEY WORDS : High Resolution Image, QuickBird Satellite Image, Non-point Source Pollution, SWAT

1. INTRODUCTION

Recently, practical use of high spatial resolution image such as IKONOS, QuickBird and KOMPSAT-2 is accommodated in various land use related application fields. Researches in agricultural field as well as natural hazard and environmental assessment field are now increasing.

Environmental problem by Non-Point Source (NPS) pollution in our country becomes the big issue for the healthy watershed management. The accurate NPS evaluation will improve efficient watershed management which will eventually improve the stream water quality.

Land use is the essential information in NPS assessment. The information affects the hydrological components such as evapotranspiration, infiltration and soil water storage, the dynamics of surface runoff, subsurface flow and groundwater recharge. The effects of land use are directly linked to changes in streamflow and NPS pollution load such as sediment, T-N (Total Nitrogen) and T-P (Total Phosphorus). Therefore, the precise and accurate information of land use data will enhance the evaluation of NPS load from a watershed.

KOMPSAT (KOrea Multi-Purpose SATellite)-3 that will have spatial resolutions of 0.8 m panchromatic and 2.8 m multi-spectral images is scheduled to launch in 2008. KOMPSAT-3 image can produce USGS (United States Geological Survey) Level IV (0.25 - 1.0 m spatial resolution) land use data. This data can be used to identify detail hydrological cycle, soil erosion process, sediment and pollutant transport mechanism (Kim et al., 2007).

The main objective of this study is to test the applicability of QuickBird image for NPS pollution assessment as a future potential application of KOMPSAT-3 in agriculture field. For a small catchment of 1.16 km^2, SWAT (Arnold et al., 1993) was adopted for NPS evaluation. Three kinds of land use (QuickBird, 1:25,000 produced from SPOT, and Landsat) were prepared as an input for model run. Other spatial data such as elevation and soil were also prepared.

2. MATERIAL AND METHODS

2.1 The Study Area Description, and Hydrologic and Water Quality Data for Model Test

The watershed (255.4 km^2) for SWAT basic setup using Landsat land use is the part of Gyeongan-Cheon watershed located in Gwangju-Si and Yongin-Si of Gyeonggi Province in South Korea, and the NPS evaluation with 3 cases of land use was carried out for a 1.16 km^2 catchment located in the upstream within the watershed (Figure 1). The Gyeongan-Cheon is the main tributary of Han river basin which is directly linked to the Paldang lake. Paldang lake, a supplying source of vast range water works in the capital region, is one of the most important lake which supplies to 12 million citizens with 3.9 million ton water per day, and approximately 27 million ton water for electric power generation and irrigation water (Choi et al., 1991). So, the environmental protection of the watershed from NPS is important before the streamflow goes to the Paldang lake by maintaining a certain level of water quality.

For the model test, 4 years (1999-2002) daily weather data were collected from 3 weather stations (Suwon, Icheon, Yangpyeong) and 7 AWSs (Automatic Weather Station) rainfall data within the watershed, and the streamflow and water quality data at the watershed outlet (Gyeongan water level and water quality station).

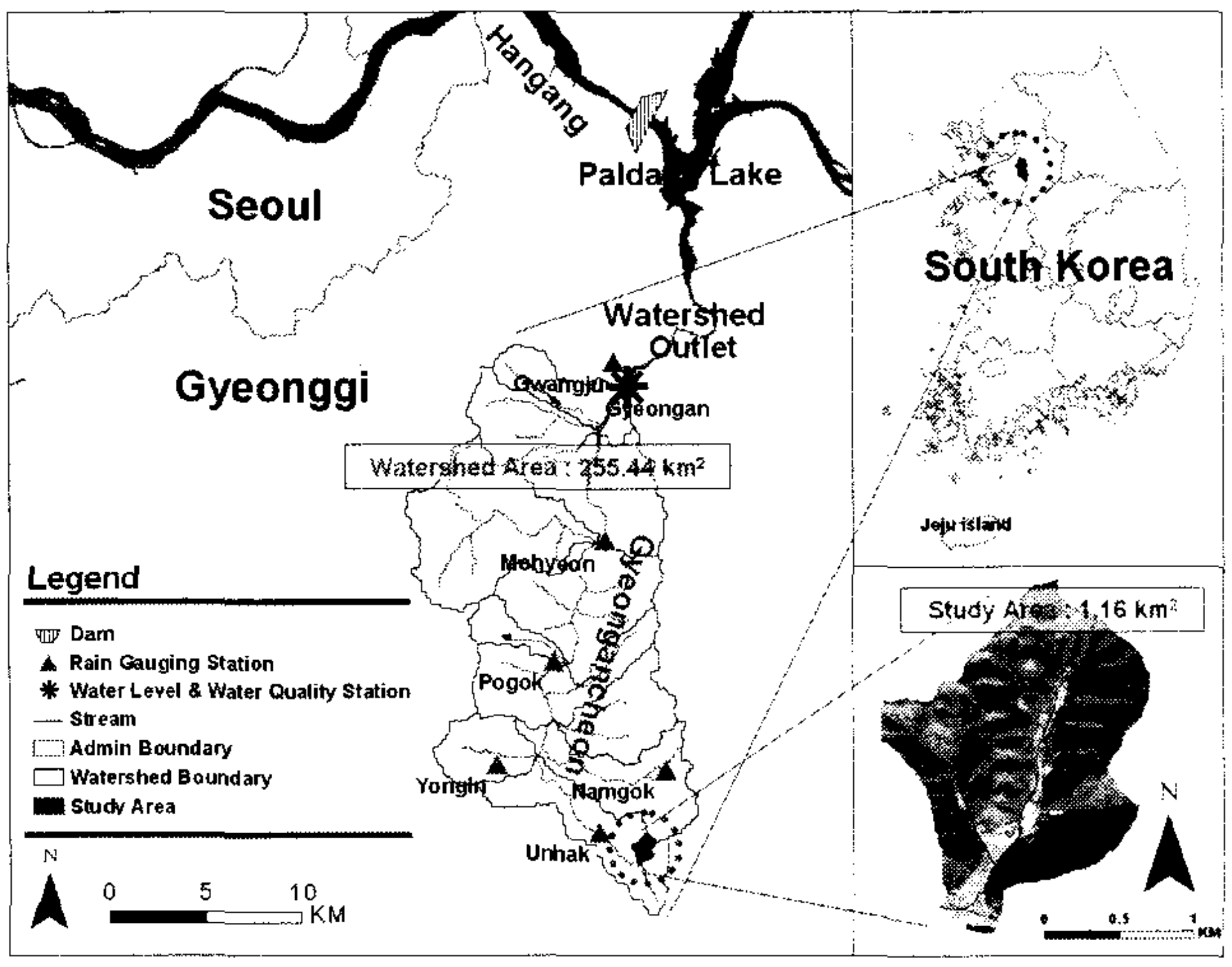


Figure 1. The study area.

2.2 Land Use Data Preparation Using QuickBird Satellite Image

KOMPSAT-3 has similar spectral characteristics with QuickBird image. QuickBird-2 satellite data can get the image of the spatial resolution of 0.61 m at perpendicular, 0.73 m at angle of 30 degrees in the case of panchromatic, and 2.44 m at perpendicular, 2.9 m at angle of 30 degrees in the case of multispectrum.

In this study, 1st May 2006 QuickBird image was used. It lies between the coordinates of latitude N 37° 11' 5" to N 37° 12' 0" and longitude E 127° 15' 46" to E 127° 16'"36". The mean spatial resolution of two images is each by 0.635 m in panchromatic, and 2.538 m in multispectrum. The image was ortho-rectified and geometrically corrected using 2 m DEM (Digital Elevation Model) from NGIS (National Geographic Information System) 1:5,000 digital map and 30 GCPs (Ground Control Points) acquired from SOKKIA GPS (Global Positioning System) equipment. The land use was produced by on-screen digitizing method with GPS field investigation data. The land use was classified with more than 23 categories (Table 1).

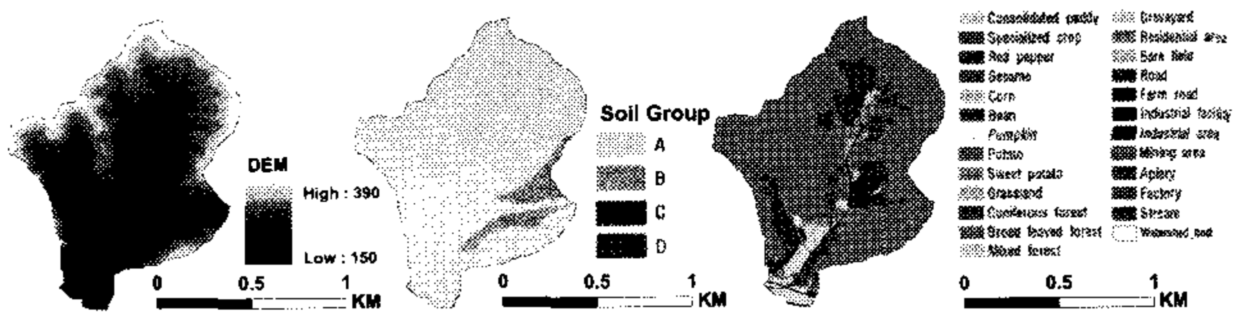
2.3 GIS Data Preparation

Three kinds of spatial resolution (2 m, 10 m and 30 m) for elevation, land use and hydrologic soil group were prepared using NGIS digital map respectively.

Elevation data were rasterized as 2 m DEM (Digital Elevation Model) from a 1:5,000 vector map that was supplied by the Korea National Geography Institute (Figure 2a). The other 10 m and 30 m DEM were resampled from 2 m DEM.

Soil data were rasterized as from a vector map (1:25,000 and 1:50,000) that was supplied by the Korea Rural Development Administration. Hydrologic soil group was obtained from the attributes of soil map (Figure 2b). The soil group A, B, C, and D indicates high, moderately high, moderately low, and low infiltration rate for rainfall respectively.

The 2 m land use data were prepared by resampling the originally digitized QuickBird land use (Figure 2c). The 10 m (1:25,000) land use data were obtained from the Ministry of Environment. The 30 m (1:50,000) land use data were prepared by classifying the Landsat TM (Thematic Mapper) satellite image of 3rd June 2004.



(a) (b) (c)

Figure 2. GIS data.

Table 1. Land use area for 3 cases of map scale

Classify item	QuickBird		1:25,000		Landsat	
	Land use item	Area (km^2)	Land use item	Area (km^2)	Land use item	Area (km^2)
Agriculture field	Paddy	0.049	Paddy	0.112	Paddy	0.025
	Specialized crop	0.010				
	Red pepper	0.001				
	Sesame	0.001				
	Corn	0.002	Upland crop	0.030	Upland crop	0.077
	Bean	0.002				
	Pumpkin	0.001				
	Potato	0.001				
	Sweet Potato	0.001				
	Total	0.068		0.142		0.102
Grass	Grassland	0.034	-	-	Grassland	0.033
	Graveyard	0.001				
	Total	0.035				0.033
Forest	Coniferous forest	0.212	Coniferous forest	0.522	Forest	0.989
	Broad leaved forest	0.794	Broad leaved forest	0.500		
	Mixed forest	0.004				
	Total	1.010		1.022		0.989
Urban	Bare field	0.013	-	-	Bare field	0.040
	Residential	0.018				
	Road	0.002				
	Farm road	0.009				
	Factory	0.001				
	Industrial facility	0.001				
	Mining area	0.001				
	Apiary	0.001				
	Total	0.046	-	-		0.040
Water	Water	0.005	-	-	-	-
Total area		1.164		1.164		1.164

2.4 Distribution of SCS-CN Using Land Use and Hydrologic Soil Group Data

The SCS (Soil Conservation Service)-CN (Curve Number) data is used to calculate direct runoff and the time of concentration. Figure 3 shows the comparison of 2 m, 10 m, and 30 m resolution SCS-CN distribution and Table 2 shows the summary of the catchment average CN values for 3 different land use data. AMC I, II and III represent dry, medium, wet soil moisture condition before storm event, respectively. The average CN value from QuickBird 2 m land use data at AMC II condition showed the highest value comparing with those of 10 m and 30 m land use.

Table 2. Summary of watershed characteristics and average CN for three AMC conditions

Land Use	Soil	Hydrologic Soil Group (%)				Land Use (%)		CN Value			CN AMC II (%)	
		A	B	C	D	Pervious	Impervious	AMC I	AMC II	AMC III	> 60	< 60
QuickBird (2 m)	1:25,000	92.5	7.5	0	0	96.3	3.7	32.8	52.0	70.4	12.5	87.5
1:25,000 (10m)	1:25,000	92.5	7.5	0	0	100	0	32.4	51.6	70.1	17.7	82.3
Landsat (30 m)	1:50,000	83.4	16.6	0	0	96.6	3.4	31.2	50.2	69.0	17.4	82.6

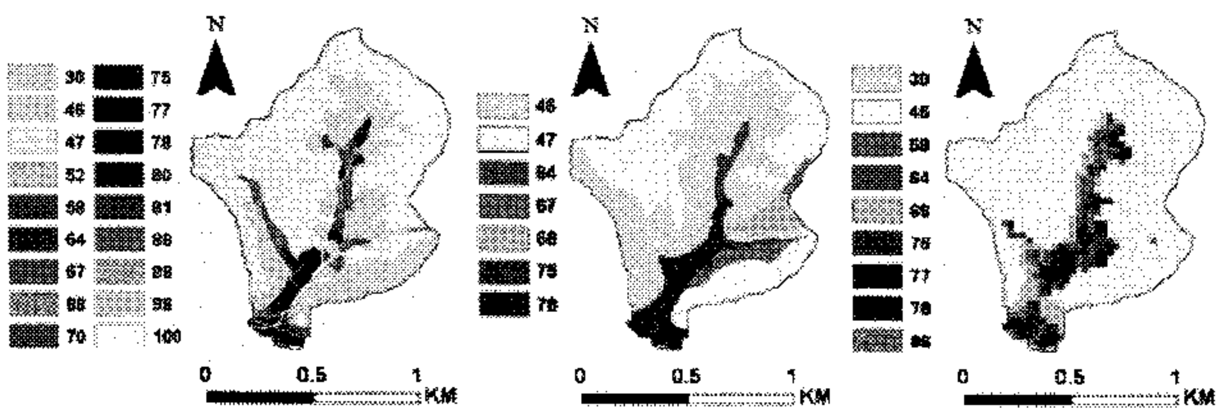

(a) (b) (c)

Figure 3. SCS-CN distribution from (a) 1:25,000 soil and QuickBird land use, (b) 1:25,000 soil and land use, (c) 1:50,000 soil and Landsat land use.

2.5 Sediment and Nutrient Transport by Soil Erosion

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) in SWAT model. USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. The modified universal soil equation (Williams, 1995) is :

$$Sed = 11.8(Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} K \cdot C \cdot P \cdot LS \cdot CFRG \quad (1)$$

where Sed = sediment yield on a given day (metic ton)
Q_{surf} = surface runoff volume (mm/ha)
q_{peak} = peak runoff rate (m^3/s)
$area_{hru}$ = area of the HRU (ha)
K = ULSE soil erodibility factor
C = USLE cover and management factor
P = USLE support practice factor
LS = USLE topographic factor
CFRG = coarse fragment factor

The model tracks nutrients dissolved in the stream and nutrients adsorbed to the sediment. Dissolved nutrients are transported with the water while those sorbed to sediment are allowed to be deposited with the sediment on the bed of the channel. Nutrients may be introduced to the main channel and transported downstream through surface runoff and lateral subsurface flow.

3. RESULTS AND DISCUSSION

3.1 Calibration and Verification of the SWAT Model

For the 255.44 km^2 watershed, the SWAT model was calibrated for 2 years (1999-2000) using daily streamflow and monthly water quality (SS, T-N, T-P) records from 1999 to 2000, and verified for another 2 years (2001-2002) The average Nash and Sutcliffe model efficiency (Nash and Sutcliffe, 1970) was 0.59 for streamflow and the coefficients of determination were 0.88, 0.72 and 0.68 for SS, T-N and T-P respectively.

3.2 Comparison of SWAT Simulated Results for 3 Cases of Land Uses

After the model test, the SWAT model with 3 cases of land use was run for a 1.16 km^2 catchment. Table 3 summarizes the SWAT simulated results of hydrology for 3 cases of map scale.

The results showed that the runoff by 2 m QuickBird land use showed the highest value than those by other 2 land uses. Correspondingly, the Sediment, T-N and T-P by 2 m QuickBird land use were also higher than those by other 2 land uses. We can infer that the main reason of the above results came from the increase of CN value by QuickBird 2 m land use. The newly revealed impervious land use in 2m spatial resolution influenced an increase in watershed average CN value.

Table 3. Summary of monthly runoff simulated results for 3 cases of map scale under AMC II

Year	Rainfall (mm)	Total Runoff (mm)			Runoff Ratio		
		S = 1:5,000	S = 1:25,000	S = 1:50,000	S = 1:5,000	S = 1:25,000	S = 1:50,000
1999	108.1	29.16	28.61 (1.89)	27.88 (4.39)	0.27	0.26 (3.70)	0.26 (3.70)
2000	92.3	23.60	23.25 (1.48)	22.57 (4.36)	0.26	0.25 (3.85)	0.24 (7.69)
2001	93.2	24.57	24.36 (0.85)	23.40 (4.76)	0.26	0.26 (0.00)	0.25 (3.85)
2002	122.0	32.84	32.31 (1.61)	31.33 (4.60)	0.27	0.26 (3.70)	0.26 (3.70)

Mean	103.9	27.54	27.13 (1.49)	26.30 (4.53)	0.27	0.26 (2.8)	0.25 (4.7)

( ) : Percent of decrease based on 1:5,000

Table 4. Summary of monthly total NPS load simulated results for 3 cases of map scale under AMCⅡ

(Unit : Sediment = tons/ha, T-N and T-P = kg/ha)

Year	Rainfall (mm)	Scale = 1:5,000			Scale = 1:25,000			Scale = 1:50,000		
		Sediment	T-N	T-P	Sediment	T-N	T-P	Sediment	T-N	T-P
1999	108.1	0.25	35.25	5.26	0.16	20.31	2.47	0.12	16.27	1.77
2000	92.3	0.19	34.25	5.16	0.10	17.88	2.24	0.10	13.50	1.59
2001	93.2	0.19	34.82	5.25	0.11	18.63	2.33	0.09	13.74	1.59
2002	122.0	0.30	38.33	5.66	0.19	22.62	2.82	0.15	16.50	1.85
Mean	103.9	0.23	35.66	5.33	0.14 (39.78)	19.86 (44.31)	2.47 (53.77)	0.12 (50.54)	15.00 (57.93)	1.70 (68.12)

( ) : Percent of decrease based on 1:5,000

3.3 Evaluation of Non-Point Source Pollution Load Using MUSLE for Each Spatial Resolution

Figure 4 shows the mean monthly results of 4 years sediment, T-N and T-P for 3 cases of map scale, and Table 4 summarizes the comparison results. As the sediment yield increased, T-N and T-P load also increased.

As shown in Figure 4, the sediment by 2 m QuickBird land use showed higher value than the other 2 land uses especially for the rainy season. On the other hand, the T-N and T-P by 2 m QuickBird land use showed higher value than the other 2 land uses through the year.

This means that sediment responds sensitively to rainstorm while T-N and T-P respond to all ranges of rain event.

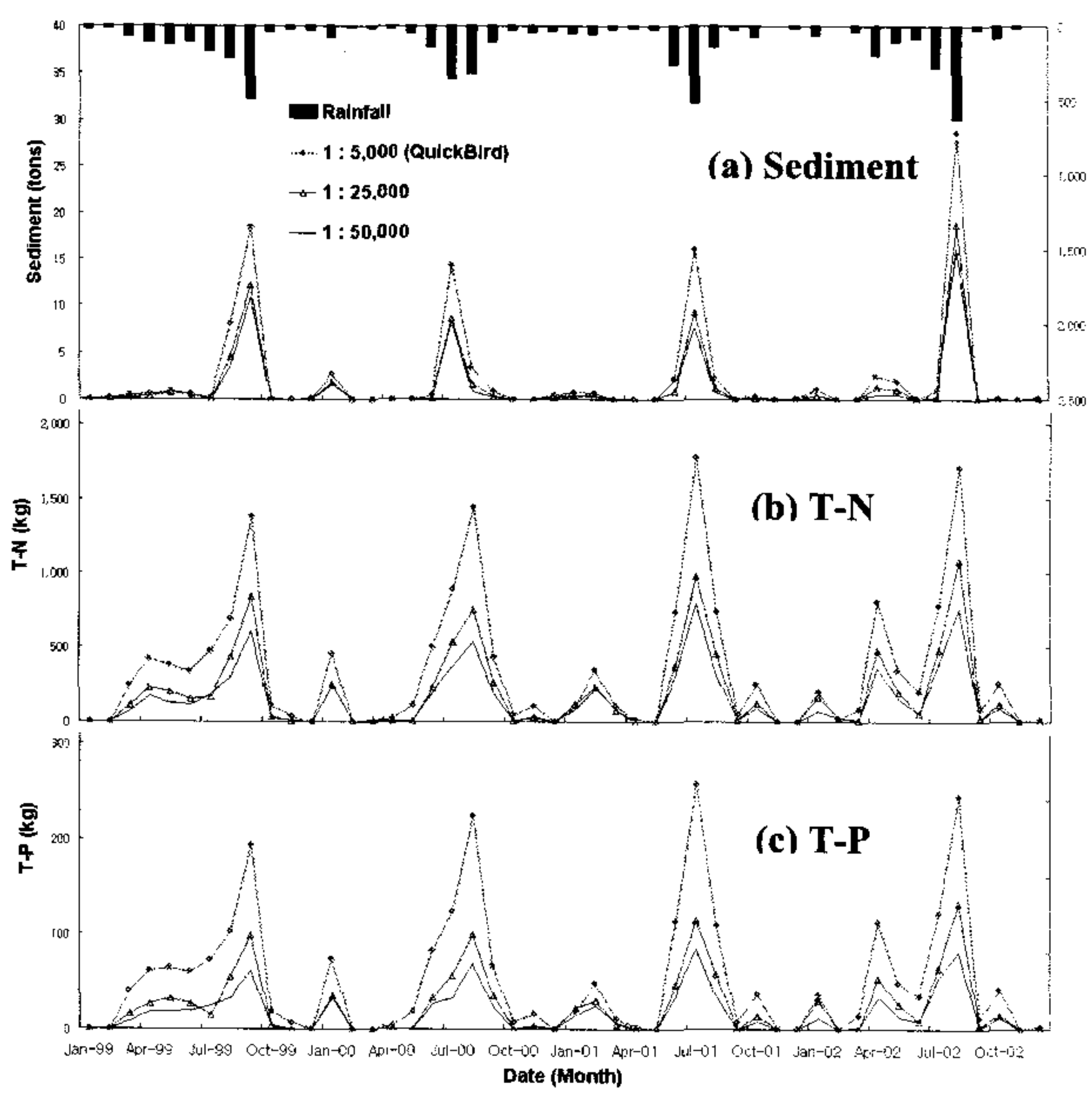


Figure 4. Comparison of sediment, T-N and T-P for 3 cases of map scale.

4. SUMMARY AND CONCLUSIONS

This study conducted an evaluation of Non-Point Source Pollution Load using SWAT model and QuickBird derived land use data.

The model was calibrated and verified for the 255.44 km^2 watershed using Landsat land use data. After that, the model was applied in a 1.16 km^2 catchment for the NPS evaluation with 3 land use data (QuickBird 2 m, 1:25,000 10 m and Landsat 30 m). The results showed that the CN value of QuickBird 2 m was higher than the other 2 land uses. This caused the higher catchment runoff and sediment, T-N and T-P. The results showed that the precise land use can give the more reliable hydrological and water quality simulation.

For better NPS evaluation, the crop management information such as irrigation, fertilization, pesticide application is requested.

4.1 References

Arnold, J.G., Allen, P.M. and Bernhardt, G. (1993), A comprehensive surface-groundwater flow model, *Journal of Hydrology*, Vol. 142, pp. 47-69.

Choi, K.S., Kim, H.S. (1991), A study on pollution loads and flow characteristics flowing into Paldang potable water source, *Journal of The Environmental science*, Vol. 21(0), pp. 151-17.

Kim, S.H., Lee, M.S., Park, G.A. and Kim, S.J. (2007), Application of QuickBird satellite image to storm runoff modeling, *Korean Journal of Remote Sensing*, Vol. 23, No. 1, pp. 15-20.

Nash, J.E. and Sutcliffe, J.E. (1970), River flow forecasting through conceptual models, Part I-A discussion of principles, *Journal of Hydrology*, Vol. 10, No. 3, pp. 282-290.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. (2001), *Soil and water assessment tool theoretical documentation version 2000*: Draft-April 2001, US Department of Agriculture – Agricultural Research Service, Temple, Texas.

Williams, J.R. (1975), Sediment-yield prediction with universal equation using runoff energy factor, *In present and prospective technology for predicting sediment yield and sources*, ARS-S-40, USDA-ARS.

Williams, J.R. (1995), The EPIC model, In *Computer models of watershed hydrology*, Singh, V. P., (ed.), Chapter 25: pp. 909-1000, Water Resources Publications.

4.2 Acknowledgements

This study was funded by the research project "Development of Information extraction and Analysis Technique for Precision Agriculture and Forestry (M104DA010004-06D0101-00412)" of remote sensing technology development program by Ministry of Science and Technology.