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Estimation of NPS pollutant properties based on SWMM modeling according to land use change in urban area

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ABSTRACT

The amount of non-point pollutants discharged into rivers is greater in urban regions than forests and farmlands due to a higher population density and a larger impermeable area. The analysis and research of non-point pollution in urban areas have been focused upon monitoring the basin outlets, and estimating the environmental loads as well as the unit load. However, the estimation based on the measurements of a single representative spot in the large basin is often calculated, compared to the measurements based on the area and the land use. A less credible method to estimate the load cannot be effectively used in quantifying the non-point pollutant loads caused by the individual land uses. Therefore a method that segments the basin according to the land use in the urban region is required. This is the key to a credible quantified analysis of non-point pollutant loads and enables a rational and scientific estimation of significance, cut rate, and establishing reduction plans. The goal of this research was to estimate the load with segmenting the urban region into different sections based on the land use and constructing a model that reflects the traits of each section. The data was compiled by observations of the Busan City separated into residential districts, business districts, industrial districts, and greens. SWMM was used to simulate the target area, while attempts to compare it with prior researches were made to evaluate the validity and applicability of this research and to ensure its credibility.

Keywords: Non-point source pollutant loads; Land use; Urban area; SWMM

1. Introduction

Non-point pollutant loads seriously affect water environmental management, especially in urban regions with high impermeability where the release of these pollutants directly becomes the pollution of rivers. Estimating the load may be done by applying the unit load to each land type or by modeling the sources. Ease of use and the compatibility to existing data led to the former method, whose core is the unit load relational expression which is connected to land use, soil quality, and other hydrologic factors. However, the NIER's 2007 article [1], "the Second Technical Guideline of Managing Gross Water

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Pollution", caused a debate by introducing a standardized unit called "Total Land Per-Type Annual Average Load Source Generation Unit". Another demerit of the unit load estimated this way is its drastic regional variability that a value drawn from one basin cannot be applied to another. As the precision of the unit load method depends on the amount of load, the absence of a long-term load measurement data results in errors.

Park et al. [2] segmented the region according to the land use, collected samples every other hour since before the rain outflow until the peak outflow, with the concept of EMC; event mean concentration. The limits to this research include that the criteria is not rigorous to separate the urban region and that the concept of EMC does not sufficiently reflect the wash off phenomenon of pollutant that takes place in a short period of time.

To estimate the load and unit load of a large urban area, observing a smaller basin and promoting it as representative normally over generalizes the traits of the smaller region and causes the load and unit load to be inaccurate.

A call to estimate basins for each land use rises, instead of a single representative basin. The load and unit load have to be estimated by applying a proper model deduced by monitoring each of them to measure the pollutant concentration and the flow rate. In this research, the urban region was segmented into four sections and SWMM was used as the model to estimate the load.

2. Materials and methods

2.1. Study site

Busan City, the target area of this research, locates in the Southern end of Korean peninsula, where the Busan Gulf is surrounded by hills from 400 to 800 m high, juxtaposed with a plain around the mouth of Nakdong River.

A segmentation of areas according to the land use was composed in order to construct a rainfall-runoff model based on the division of Busan's water system, field research of each area, and analysis of area traits and related data. Concerns are how properly represented the area is in terms of its land use status and how excluded the influence of sewage combined system by choosing the right region in which the amount of non-point pollutant can be accurately estimated. In addition, the top priority regions in the segmentation were regions heavily influenced by non-point pollutant sources, regions with predicted changes in future so that a comparative follow-up research can be conducted, and regions with easily obtainable related data. Hence, in this research, the load and unit load were estimated by picking the spots that represents each of the land use traits among the 44 regional streams. As a result, the chosen areas include Oncheon Stream for residential, Dong Stream for business, Hakjang Stream for industrial, and Dongbak for greens. Field monitoring was carried out in order to construct the input data and to draw a credible conclusion. The stream's unique ID and the land use classification, whose overview is shown in Table 1, was taken from WAMIS [3]; Water Resources Management Information System (http://www.wamis.go.kr/). An outlook of numbers including the stream's area, length, average width, and shape factor for each land use were presented in Table 2. The land covering degree and the land use for each river basin computed by a GIS analysis tool are in Fig. 1.

Table 1
Land uses characteristics based on data from water management information system (WAMIS, http://www.wamis.go.kr/) in objective sub-watersheds

Land uses	Stream number	Stream name	Land uses characteristics (%)						
			River	Urban	Bare ground	Grass	Forest	Paddy	Field
Residential	8	Oncheon	0.03	40.91	0.22	0.48	46.55	9.28	2.52
Commercial	12	Dong	0.29	45.49	0.17	0.03	41.31	10.07	2.64
Industrial	20	Hakjang	0.02	34.40	0.07	0.01	56.94	7.07	1.49
Vegetated	39	Dongbak	0.00	1.88	0.97	1.62	57.97	25.05	12.51

Table 2
Geomorphic characteristics including area, stream length, average width and shape factor in object watersheds

Land uses	Stream name	Area A (km^2)	Length L (km)	Average width A/L (km)	Shape factor A/L^2
Residential	Oncheon	56.28	14.85	3.79	0.26
Commercial	Dong	30.60	8.80	3.48	0.40
Industrial	Hakjang	19.42	7.39	2.63	0.36
Vegetated	Dongbak	3.39	4.23	0.80	0.19

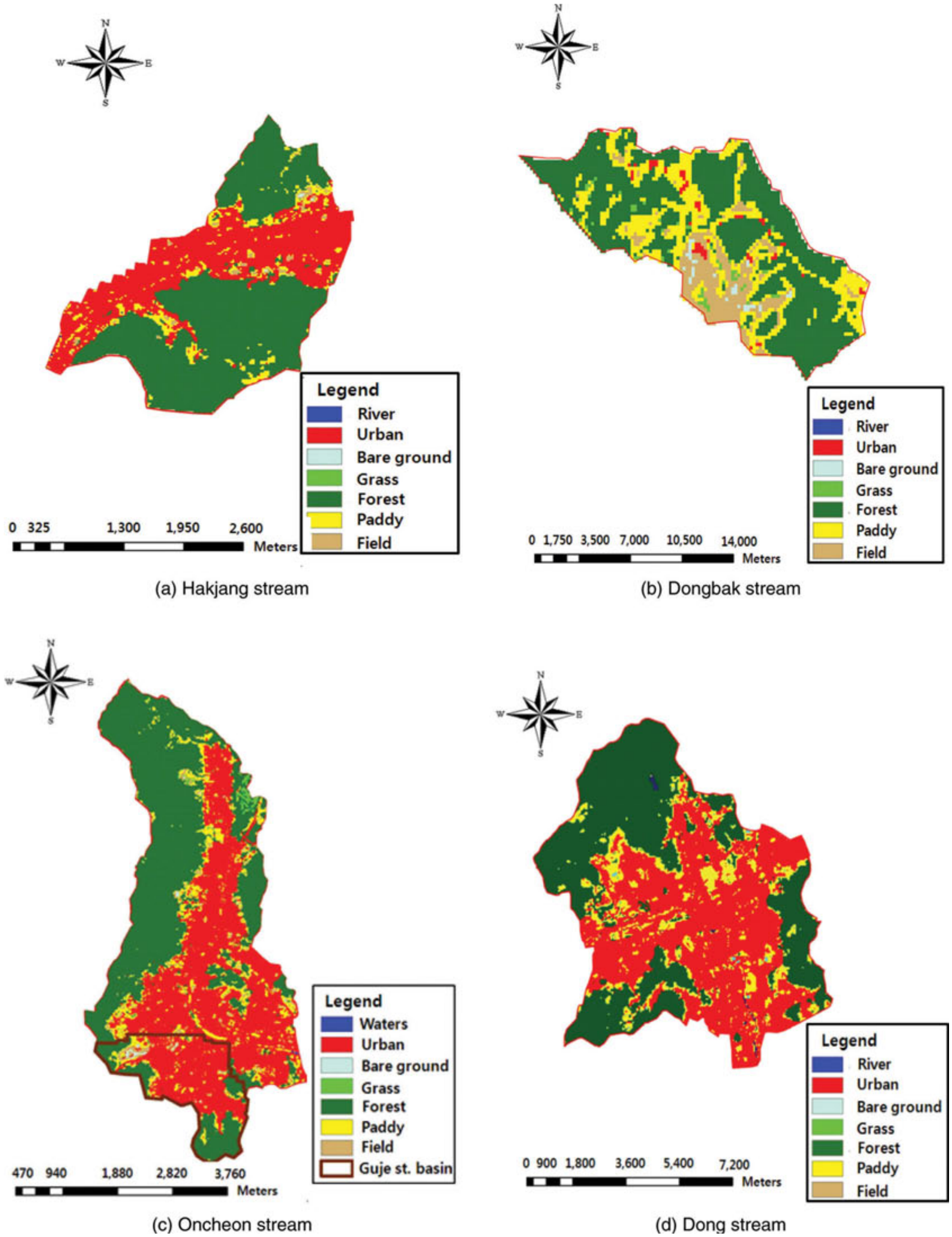

Fig. 1. Land use maps for watersheds of interest.

2.2. Method to estimate NPS properties in urban area

In this research, a relatively accurate rate of outflow can be obtained by minimum calibration. Various polluted substance model method can be applied and can be considered by sub watershed soil usage status which is often used in water quality estimation and outflow rate of river basin in rain fall, especially SWMM that has been selected for its common use in analyzing rainfall- water outflow.

In order to obtain non-point pollution source load amount by using SWMM; first, rainfall-runoff's correlation must be considered and after extracting favorable precipitation events, results from repeatedly changed parameter is compared with actual measurement data to carry out optimized operation. Independent rainfall-runoff data is used to optimize parameter and a final model with acceptable tolerance is completed through calibration and validation process for degree of generalization. When modeling water quality to obtain non-point pollution source load amount through the final model, erosion and sedimentation in pipes are not considered and elements of water quality originated from rainfall is only assumed to have been caused by runoff. In order to obtain parameter of water quality model, assessment of land use by sub watershed, decision in assessment method of build up and related parameter, and lastly, decision in assessment method of wash off and related parameters is needed.

To model the pollutant concentration of rainfall-runoff due to non-point pollution source, land usage status is categorized into urban and rural areas whilst setting input data related to polluted substance build up and wash off. The build up equation of polluted substance refers to the existing research data and is set to a limit in the Michaelis-Menton form of equation. Wash off equation for polluted substance is set to Event Mean Concentration. Loading amount obtained from the above process is divided into subject river basin area and can be converted into basic unit by applying the precipitation high in terms of time unit that was used in modeling and dividing again. As shown, basic unit is derived from the basis of loading amount and a credible model structuring is required in the process of calibration and validation, and optimization of the model.

2.3. SWMM modeling and monitoring process of SWMM

Amongst the categorized five districts of Busan city, four representative river basins were chosen according to land usage characteristics adequate to basin selection standard. Water quality and outflow data had been collected by designating monitoring points at each river basins and precipitation data were based on those from Busan Meteorological Office. Amongst these, Oncheon stream that represents residential area had the characteristics of joining another district stream known as Geoje stream, and due to the CSOs created by high residential population density around the basin of Geoje stream, the water quality of the Oncheon stream is being greatly affected. Thus, this research is striving to help in the interpretation of the measured data of Oncheon stream's water quality and outflow by choosing Geoje stream as another point for monitoring. In order to collect the required outflow and water quality data for revision and examination of model optimization, monitoring had been operated at the selected river basin, outflow measurement used small and large river hydrometer and water quality had been measured by sampling. The location points of monitoring in the use district chosen in this research are shown in Table 3.

By carrying out non-point pollution loads monitoring for the four representative river basins chosen according to land usage in rainfall, outflow state of non-point pollution source had been attempted to be identified. It was measured six times to obtain flow data and highest water quality concentration value. In the case of water quality, nine items of water quality measurement include pH, DO, BOD, COD, SS, T-N, T-P, NO_3-N, NH_3-N. The pH and DO that cannot be preserved had to be measured on the spot and the concentration of remaining items were measured by test and analysis after water sampling. The next Table 4 shows measurement time and precipitation amount by history and Table 5 shows the highest water quality concentration measured in rainfall.

Table 3
Monitoring location and factors in each objective sub-watersheds

Land uses	Stream name	Location	Item
Residential	Oncheon	Junction of Oncheon stream and Guje stream (Sebyeong bridge)	Water quality parameters, discharge
Commercial	Dong	Beom 4th bridge	
Industrial	Hakjang	Juction of Hakjang stream and Eomgung reservoir	
Vegetated	Dongbak	Estuary of Dongbak stream	

Table 4
Description of selected rainfall event during 2008–2009 including starting/end date and total rainfall

Event No.	Starting date (yyyy-mm-dd)	End date (yyyy-mm-dd)	Total rainfall (mm)
1	2008-07-20	2008-07-20	16
2	2008-10-05	2008-10-05	1.5
3	2009-10-22	2008-10-23	50
4	2009-01-29	2009-01-30	11.5
5	2009-02-13	2009-02-13	27
6	2009-06-21	2009-06-22	88.5

Table 5
Maximum concentration of BOD, COD, SS, T-N and T-P in rainfall event at monitoring points of four objective sub-watersheds

Land uses	Stream	Maximum concentration (mg/l)				
		BOD	COD	SS	T-N	T-P
Residential	Oncheon	19.2	16.8	756.3	31.520	3.543
	Guje	59.7	37.5	69.5	30.077	3.722
Commercial	Dong	16.8	16.9	92	21.680	1.220
Industrial	Hakjang	31.5	27.4	320	12.465	1.198
Vegetated	Dongbak	10.9	12.1	473	14.335	3.556

Especially for the Oncheon and Geoje stream that reflects the characteristics of the residential area within Busan city, basin rainfall data is stored in the database system that is transported through a PC remote transmission from a bucket type rain gauge installed at the Busan University. Moreover, real time urban river monitoring system structured in Busan University River and Water Resource Laboratory measures precipitation data updated on real time. Therefore, use of monitoring data in this research for measuring non-point pollutant loads amount of the residential area of Oncheon stream is significant. Actual application in this research was implemented in the studies of Shon et al. [4] and Kang [5] on "Assessment on the weakness of city region domestic flooding by use of SWMM". Also, it has been used as input data in the structuring of forecasting and warning system for unexpected city flooding through the data obtained by real time monitoring system at the Pusan National University [6] (http://164.125.169.48) over a five year (2004–2008) research carried out by Urban Flood Disaster Management Research Center. Data on geographic and drainage characteristics required of subject basin when structuring rainfall-runoff model used numerical map and topographic map. Basin area, basin width, impervious areas, average slope etc. were contained in the geographic data, and amount of evapotranspiration (mm), infiltration rate (%) etc. were considered in the climate factor.

3. Results and discussions

3.1. SWMM model calibration and verification

Through measurement method for load amount and basic unit using the selected SWMM in this research, runoff analysis had been carried out through model structuring and calibration and verification for residential, natural, commercial, industrial region within the city area. Amongst them all, a non-point pollution source loading amount and basic unit measurement method from the calibration and verification processes in the optimization for the structuring of a model at the chosen Oncheon-Geoje stream basin for residential area had been presented. In order to reflect the runoff properties of non-point pollutant in the time of rainfall at the residential area, input data of structured model known as outflow quantity (Q) was calibrated and verified. In addition, calibration process on parameters that affect outflow was carried out to ensure optimum model is structured when using SWMM. A model verification had been carried out as subject of applied rainfall history and the applied residential region model structuring data are precipitation history, geographic data, climate data and rainfall data as shown in Table 6. Moreover, Fig. 2 shows a model optimization through calibration and verification, compared the computed value of Oncheon-Geoje stream through monitoring to the outflow amount obtained by SWMM (Table 7).

According to the method used above, the other sub watersheds' modeling of the remaining three use districts of commercial, industrial, and green zone were calibrated and verified using actual measurement data from the basis of their monitoring points.

3.2. Results and comparison of NPS estimation

After using the actual measurement data from this research to calibrate and verify the model, a ten year long term rainfall data of yearly BOD, TN and TP pollution loading amount (kg/y) of the four land uses were estimated and along with the yearly rainfall data that was used, a graph was drawn out. Through an optimized SWMM model, the estimated non-point pollutant load amount (kg/y) of residential region, commercial region, industrial region, and green zone area is shown in Fig. 3.

It was simulated for a decade of data from 1998 to 2007 and calculated the various water quality indicators for each type of region. The district with the highest yearly average load of all basins was Dong Stream in the business district, which showed 202.965 kg/y of BOD, 58.113 kg/y of T-N, and 6664 kg/y of T-P. On the contrary, the lowest numbers were held by Dongbak Stream in the greens, with 22,280 kg/y of BOD, 7367 kg/y of T-N, and 1729 kg/y of T-P. It is now clear that how the

Table 6
Rainfall, geomorphic and climate data for SWMM to compute non-point source pollutant loads and unit load in residential area (Oncheon stream and Guje stream) in Busan

Applied model	SWMM (storm water management model)				
Selected event	July 20th, Oct 22nd and 23rd in 2008				
Geomorphic input data	Stream	Area (ha)	Width (m)	Impervious area (%)	Average slope (m/m)
	Oncheon	0.4021	600	58	0.22
	Guje	0.0983	300	71	0.21
Climate input data	Evapotranspiration (mm), Infiltration rate (%)				
Rainfall input data	Event	Starting date	End date	Total rainfall (mm)	
	1	2008-07-20 (06:20)	2008-07-20 (22:30)	16	
	2	2008-10-23 (06:00)	2008-10-23 (23:50)	50	

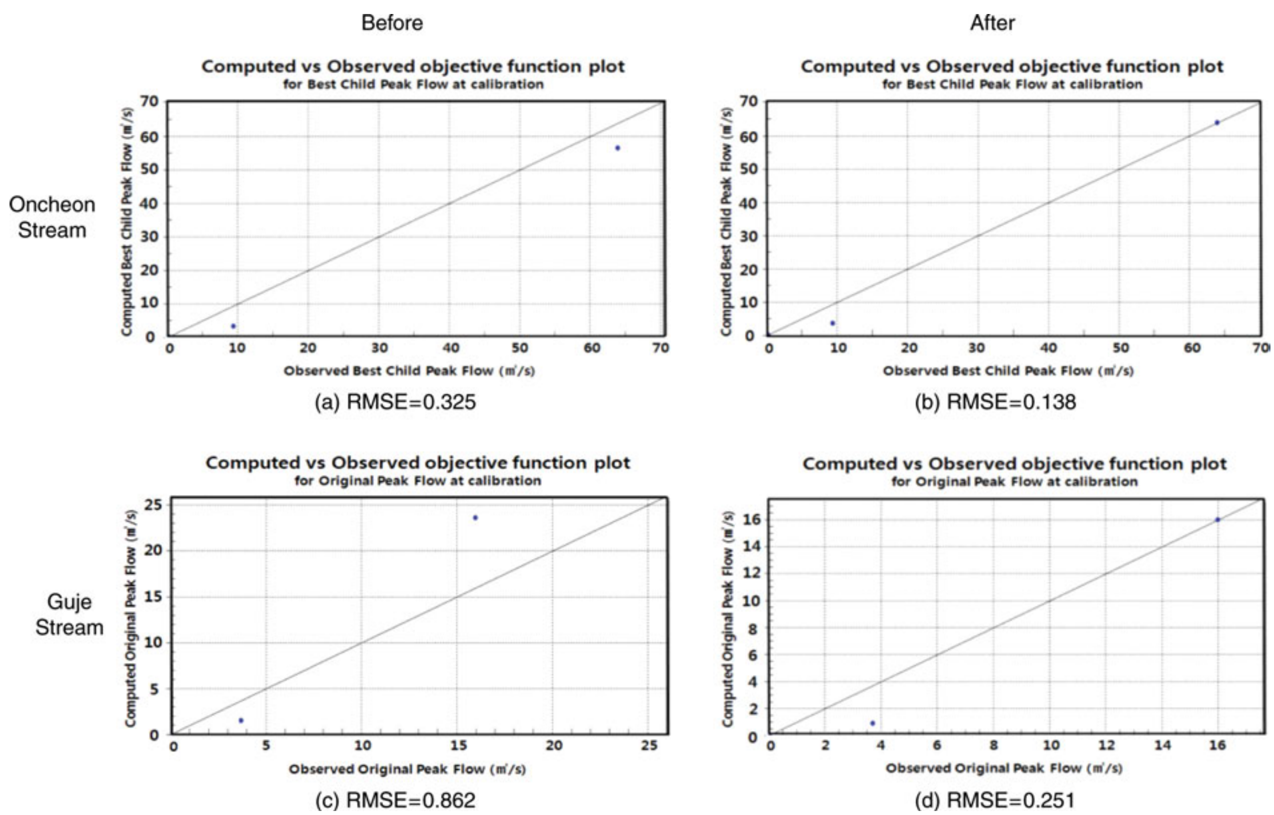

Fig. 2. Result of SWMM calibration and verification for Oncheon stream and Guje stream.

land is used greatly affects the amount of pollutant load, and it is obvious that a single principle cannot regulate the two radically different cases, which leads to the conclusion that while estimating the pollutant load in an urban area, the use of land must be considered together.

Based on the area, BOD and T-N were remarkably high in the residential Oncheon Stream, but T-P was the greatest in Dongbak Stream, which is in greens. As T-P mainly increases by excreta, synthetic detergent, factory waste, and fertilizer, while T-N is normally in excreta and factory waste [7], the exceptional T-P from Dongbak Stream can be explained by the farmlands in the greens emitting fertilizers and pesticides which contain T-P that leaked during rainfalls. The average pollution load for the decade for each type of land is presented in Table 8.

Table 7
Results of runoff discharge considering selected rainfall events in Oncheon stream and Guje stream

			Peak discharge (m^3/s)	Average discharge (m^3/s)	Base time (min)
Residential	Oncheon stream	Event 1	3.585	2.665	390
		Event 2	63.630	23.960	540
	Guje stream	Event 1	0.872	0.578	390
		Event 2	15.990	5.136	540

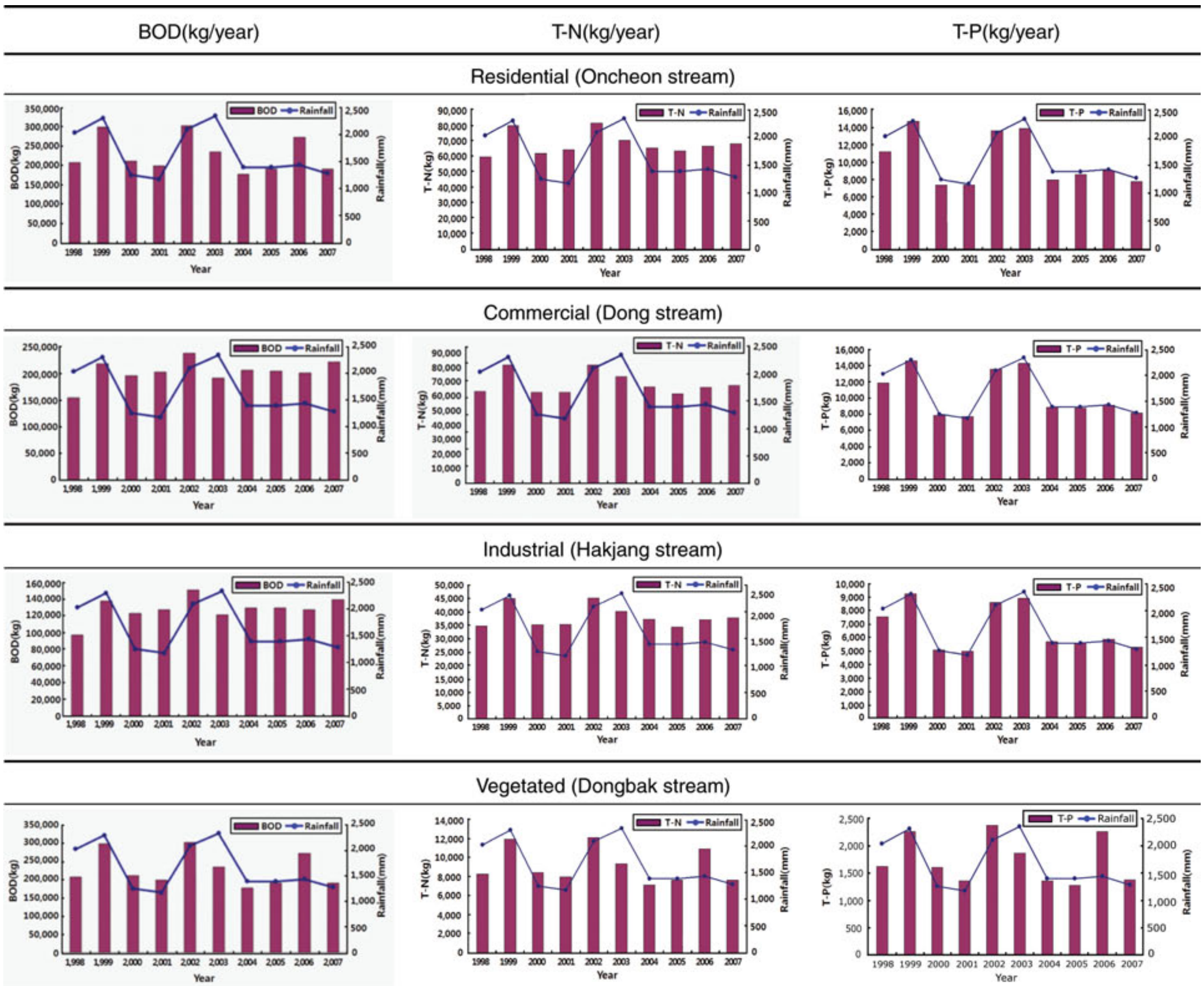

Fig. 3. Results of annual NPS loads by SWMM Modeling during 1998 to 2007.

To further clarify the significance of this research and its applicability, existing researches were analyzed, and it became apparent that from 2002 to 2004 was the period in which the dominant numbers of researches have been done to non-point pollutant sources load estimation with the rainfall data. Among the rainfall data of ten years, the ones from 2002 to 2004 were therefore used to apply the existing method and calculate the average, and it was then compared to the results of the former research. The former research [8] estimated the load by picking a single representative area, being unsuitable to be used for the model. Especially, this representative watershed has over 60% of vegetated features such as paddy, field and forest. The Dongbak Stream, a green district that has a similar land use to the representative area of the former research, presented 68.91 kg/ha/y

Table 8
Results of BOD, T-N and T-P on 10 y average load(kg/y) by SWMM

Land uses	Stream	BOD	T-N	T-P
		kg/y		
Residential	Oncheon	280,382.80	76,946.68	9,720.80
Commercial	Dong	1,537,999.99	326100.00	26490.00
Industrial	Hakjang	128,217.32	38,061.57	6,664.48
Vegetated	Dongbak	22,852.079	7,369.187	1,730.234

of BOD that was second highest, with 20.95 kg/ha/y of T-N and 3.97 kg/ha/y of T-P that were the highest. This seems to be due to the high proportion of farmland that discharges fertilizer and pesticide than other urban watershed which has high proportion of urban landuse. In addition, the highest BOD unit load appeared in industrial area and the highest T-N, T-P unit load appeared in Residential area. Our result is less than precedent one because of watershed conditions such as geomorphic factors (slope etc.), infiltration, soil properties. This comparison result would be useful to show that unit load can be estimated differently in each land uses rather than numerical analysis. The comparison of two unit loads, each from and the former research are shown in Table 9.

To compare the result from SWMM with the existing unit load method—the de facto standard of field practice to estimate the non-point pollutant load—both of them are applied to the target area, and the differences are shown in percentages. The existing method, for instance, when applied to Oncheon Stream, requires the proportion of each type of land and simply multiplies them with the average load generation of each type in the NIER's 2007 Guideline. The results were, in case of the residential Oncheon Stream, that all entries showed greater number with the existing method, while in case of Dong Stream the opposite was observed—the SWMM's result had higher values. In case of Hakjang Stream, water purity values such as T-N and T-P, except BOD, were greater in the SWMM, showing that the existing method underestimates the load, while Dongbak Stream had an even further difference where the SWMM's numbers were greater in all entries. Dong Stream showed the most radical remainder in BOD, T-N, and T-P. On the contrary, with the least difference was the industrial Hakjang Stream. BOD was overestimated in both residential and industrial districts. It seems to be a drawback of the existing method that is unable to reflect the fast leakage of non-point pollutants during rainfalls, thereby neglecting the pollutant "washoff" unlike the SWMM. Therefore, it is truthfully proven that the SWMM shall contribute to more credible load estimation by taking the flow into account based on the raining-flowing correlation (Table 10).

Table 9
Results of NPS unit loads in Kimhae city by SWMM

Category	Land uses	Stream	BOD	T-N	T-P
			kg/ha/y		
Precedent research	Mixed	Representative watershed	110.70	74.00	13.10
This study	Residential	Oncheon	69.79	22.98	5.44
	Commercial	Dong	69.12	20.40	4.00
	Industrial	Hakjang	75.10	19.11	2.26
	Vegetated	Dongbak	68.91	20.95	3.97

Table 10
Comparison BOD, T-N and T-P loads between SWMM method or conventional method for urban areas

Land uses	Stream	BOD (kg/d)		T-N (kg/d)		T-P (kg/d)	
		SWMM[1]	Conventional unit load method[2]	SWMM[1]	Conventional unit load method[2]	SWMM[1]	Conventional unit load method[2]
Residential	Oncheon	768.2 (–104.3%)	1,569.2	210.8 (–32.9%)	280.1	26.6 (–49.8%)	39.9
Commercial	Dong	4,213.7 (76.8%)	976.8	893.4 (76.9%)	206.7	72.6 (60.5%)	28.7
Industrial	Hakjang	351.3 (–42.0%)	498.9	104.3 (4.2%)	99.9	18.3 (27.8%)	13.2
Vegetated	Dongbak	62.6 (68.2%)	19.9	20.2 (39.5%)	12.2	4.7 (77.8%)	1.1

[1]Non-point pollutant source computation method using SWMM which reflected rainfall-runoff characteristics well.
[2]Non-point pollutant source computation method based on technical guideline from National Institute of Environmental Research in Korea.
[3]The percentages mean percent change computed as equation, {(SWMM method result-conventional unit load method result)/SWMM method result}×100.

4. Conclusions

The research was to substantiate a method to estimate the Non-point source pollutant loads by segmenting the urban area by its land uses. Developing a model that is able to reflect the raining-flowing traits of the city and each area's characteristics shall facilitate the estimation of load and unit load.

By a comparative analysis to the result of SWMM with the former researches based on the existing unit load estimation method, the conclusion is that the pollution load, obtained through SWMM that is optimized and corrected by field-measured data, showed greater correlation to rainfall than other factors. Also it showed that the existing unit load method overestimates the result in comparison to the model's estimation, which is conjectured to be due to the water flow not reflected in the existing unit load method. While the researches that designated the terminals to be the representative spot and monitored it to estimate the load could go no further than analyzing the non-point pollutant source of the entire target area, the new method is expected to generate a quantified analysis and an efficient abatement plan through a more credible load and unit load estimation by reflecting the characteristics of each area. It is also anticipated to establish the Busan City's basic plan of non-point pollutant source management, feasibility study of abatement facilities, contribution, cut rate, and predicting the prediction of future non-point pollutant source load.

For the model to be effectively practiced, the condition of the target region has to be carefully examined and applied, as even in a same land use the actual environmental consequences are largely affected by each area's identity such as the population density, construction density, and the type of industry. One drawback to the model is that regional differences are not fully appreciated as there are only four types of segments and the factors are limited to impermeability or land use. A more thorough model will be possible in future research that also takes into account of topographical variables such as gradient, CN value, and infiltration rate as well as the climatic variables such as rainfall intensity that influences the non-point pollutant leakage.

Acknowledgements

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