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Developing delivery ratio duration curve (DRDC) based on SWAT modeling in Nakdong river basin

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ABSTRACT

As a river basin pollution runoff quality indicator, delivery ratio is an important factor in river basin management but the lack of empirical data and absence of practical application method as well as increase in non-point pollution source make assessment of delivery ratio for flow duration difficult. Therefore, this research puts into consideration the river basin of Nakdong river's water system with water quality and flow data secured by real time auto monitoring that takes place at the area of subject of research. This survey on the spot and water basin model law provides practical assessment of individual case of flow duration and river basin delivery ratio and is applied on the area of research. By careful consideration of land use types in Nakdong river's water system, mountainous, agricultural land, and urban property area is governed and an adequate area that represents the characteristics of river basin delivery ratio is chosen by use of real time monitoring based on land use. Through the SWAT results obtained by monitoring results, flow duration curve (FDC) and loads duration curve (LDC) of three property areas over the three year between 2000–2007 have been written along with a final delivery rate duration curve (DRDC). Monitoring data by land use and FDC, LDC, DRDC as basis, polluted substance runoff characteristics and polluted substance delivery characteristics have been analyzed according to regional land use for overall analysis of individual river basin runoff and delivery characteristics. Urban property area has shown high delivery and agricultural property area has shown low delivery. Legibility in the statement of different delivery ratio has been obtained by checking the difference in delivery ratio that proved each river basin to have differing delivery ratio according to its topographic characteristics.

Keywords: Delivery ratio duration curve (DRDC); Non-point source pollutant loads; SWAT

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1. Introduction

Although delivery ratio is an important factor as pollution runoff quality indicator for river basin, lack of real time data and weak application method available make it difficult to assess delivery ratio. Unlike point pollution source, non-point pollution source has weaknesses in management of treatment facilities and since it is closely related to rainwater runoff 80% of non-point pollution substance is leaked between May and September due to climate characteristics of Korea with approximately 20% of runoff in the dry season between October and April [1]. Moreover, due to the rainy season, daily and seasonal difference in discharge is substantial and also changes according to river basin and regional characteristics such as climate, topography, land use form, and soil. Therefore, in order to accurately measure polluted substance, real time data for water quality and flow during rainfall is needed. Consequently, the thesis for assessment method of delivery ratio for flow duration is in dire need of a more scientific and acceptable assessment in allotment loading amount. Moreover, in the long term the percentage of total management in non-point pollution source is predicted to gradually increase and putting this into consideration, there needs to be a research plan for a river basin model that can be applied to overall pollution management.

For the conduct investigation regarding delivery load of the amount of polluted substance runoff and the destination point of river, flow and water quality needs real time assessment on the spot in times of perspiration or rainfall in order to obtain accurate data. However, facilities for real time assessment of water quality and delivery loads data is lacking and requires much cost and labor and is inefficient; therefore, it is advised that revision and inspection of river basin model for using polluted substance runoff interpretation is from repeated real time assessment [2]. The river basin model and its daily polluted substance runoff amount can be tested by applying the water basin's topographic characteristics as well as pollution source's spatial distribution. Also, climate or soil use or even river basin management status can change model variables or coefficients. The problem in the assessment in delivery ratio due to lack of actual measurement can be supplemented and a more scientific river basin management can be implemented through an overall river basin and linked management by integrating the river and lake water quality model. For this, predicted water quality must be foreseen and an important part of this water quality modeling process is assessment of delivery load amount – this delivery load amount is decided by delivery ratio and gives this research its significance.

This research has put into consideration the water system of Nakdong river and its characteristics of the surrounding area, gaining data on water quality and delivery loads through real time monitoring. By real time assessment method and river basin model method, reasonable calculation of delivery ratio has been put forward by case of water flow and river basin characteristics and applied on the area of research.

2. Materials and methods

2.1. Study scopes

This study has its significance in the largest water source region of Yongnam in Korea but the threat of eutrophication and other water pollution accidents on water usage has allowed for the Nakdong river basin to be chosen as subject of research. Accordingly, comparison and analysis had been carried out for problem solving and improvements in the method assessment in flow, river basin characteristics, and delivery ratio by pollutants. And then, after selecting a representative river basin region, real time auto monitoring of water quality and delivery ratio was operated. The results were used as a basis for investigating and analyzing delivery characteristics and pollutants discharge of the Nakdong river to present a reasonable delivery ratio assessment method according to river basin and water flow. The application of this is then determined and the river basin model, with possible application solution on gross weight control discharge load ratio, is presented.

For this purpose, eight days interval data on flow and water quality acquired from Ministry of Environment have been extended and tested to a daily flow and water quality data by using river basin model and statistical method. Also, FDC and LDC as well as DRDC were written and analyzed to show change in delivery ratio that followed flow duration.

2.2. Traditional method for delivery ratio

Estimating the delivery ratio is classified according to the methods such as using the ratio of erosion soil, using improved method of discharge coefficient or statistical formula and monitoring data. Above all, the method of using on-site monitoring data is the best way to estimate the delivery, but it wasn't able to estimate delivery ratio on unmeasured basins. On the other hands, the intensive study based on watershed modeling method has been conducted well because of its advantages such as considering regional and hydraulic characteristics and applying spatial distribution characteristics of pollutant or discharge structure of non-point pollutant source [3–6]. However, this method also has disadvantages as for the fact that it requires exclusive knowledge in hydrological modeling and limits of input data. To overcome the limits of above methods, some researchers suggest alternative method, estimating reduction factor of pollution load by Monte Carlo Simulation. This method is specifically computed river shape factor first to conduct quantitative analysis of pollutant runoff characteristics according to landuses. The river shape factor is useful to definite relation with pollutant load so that estimations of runoff pollutant load and concentration is possible in unmeasured watersheds as well [7]. But this method is inappropriate to analyze the change of pollutant delivery load according to change of whole discharge because of considering unit discharge

Recently, the researches for estimating the delivery ratio using SWAT model have been activated [8–10]. Also the researches using HSPF model [11] and using TANK model have been activated [12]. Therefore, this study adapted watershed modeling method using SWAT which considers regional and hydraulic characteristics well.

On the basis of actual measurement of delivery ratio assessment, delivery ratio is a measurement of reach to a specific point in a number field of polluted substance discharged from pollution source and assessed by subwatershed or pollution source. According to base year, the calculated monthly or daily discharge load ratio (also known as daily average discharge load ratio) by discharge ratio assessment and the investigation of water system environment data at the corresponding time is obtained by calculated delivery load. When actual measurement data exists, delivery load ratio and discharge load ratio are divided and calculated on the basis of water quality and water flow data of water quality observation point. Eq. (1) is shown:

$$\mathrm{K} = \frac{P_M}{P_T} \tag{1}$$

where, K is delivery load ratio, P_M is actual measurement pollutant load, P_T is total emission pollutant load in the basin. When actual measurement data doesn't exist, standard flow of subwatershed without actual measurement data applies delivery ratio measurement data that exists in subwater shed's monthly calculated delivery ratio through water flow surface area ratio relation regressed into index figure and deducted by functional formula as shown in Eq. (2):

$$\text{Delivery ratio} = \mathrm{a}\left(\frac{flow}{area}\right)^{\mathrm{b}} \quad \text{(a and b are constant)} \tag{2}$$

The characteristics in delivery ratio assessment based on actual measurement is highly practicable yet cannot show the effect of weather elements on delivery properties nor the river basin's physical delivery properties. In addition, it cannot include background concentration of nitrogen (occurring above 1 in delivery ratio) and when applied on river basin of unmeasured water quality it does not reflect the self-purification capability with hydrological and hydraulic properties of the basin.

Other measurements of delivery ratio are USLE method, ASCE method, rational method, and statistical method. The USLE method is difficult to apply in determining the delivery ratio in the delivery of polluted substance within the water system as it depends largely on the relative amount of absorption or desorption of polluted substance in the components of the soil. The ASCE method only considers the geographic characteristics of the river basin and therefore has the weaknesses of being unable to possess the other elements such as those related to soil erosion.

The rational method is the use of a runoff variable as approximate indicator to measure the delivery effect of polluted substances into water systems. According to Yu [13], delivery ratio can be measured by using rational method, which is often used for measuring amount of water flow due to rainfall in small scale drainage area. However, the principle in using the rational method only considers the quantity of water and so there exists uncertainty in measured delivery ratio. Yet, it provides for an approximate indicator in measuring delivery effect. In addition, delivery ratio of polluted substance doesn't necessarily go in accord with delivery ratio of erosion amount and depends on whether the polluted substance contains soil.

Choi [14] used regression method on river basin of Juamho to measure delivery ratio according to inflow. According to Joo [15], the use of statistical method assesses delivery ratio by deduction in multiple regression analysis of the linear relation of population and basin surface area, and its general delivery ratio ranges between 0.017–0.070. However, the regression equation doesn't adequately explain the exactness of data in the regression analysis or the rationality of the considered independent variable. It shows a great range of disparity in the value of actual measurement and proves inefficient in this aspect.

2.3. Method for constructing delivery rate duration curve (DRDC)

Currently, the target of TMDL management is BOD and the standard flow is shown to be an average 10 y of low-flow [16]. However, although the role of regulation standard to meet the goal of water quality in the load and management of river basin is satisfied by setting specific flux of low-flow to standard flux, there still lacks the means of management in the role of water environment improvement in the river basin [17]. To solve these problems, overall change in flux following the change in delivery load amount must be able to be realized by a measurement in water flow delivery ratio [17,18].

Accordingly, Jung et al. [19] used the 8 d interval data on changing amount and water quality from the Ministry of Environment to assess flow delivery load amount and delivery ratio of BOD and TP. With the assessed delivery load amount, an application of empirical regression equation was examined and later used to assess delivery ratio.

In this study, eight days interval monitoring data of water quality and flow of subwatersheds considering land use, eight days interval delivery load amount was produced, and by TANK model or Rating Curve, a flow duration curve (FDC) was drawn up through the production of the daily water flow. Moreover, by using the relation curve between flow duration curve and water flow and delivery load amount, a loads duration curve was written and by applying the respective river basin discharge load amount and loads duration curve(LDC), delivery rate duration curve(DRDC) invented by Ferguson [20] was measured.

3. Results

3.1. Characteristics of study watersheds

Representative subwatersheds were chosen as agricultural subwatershed, mountainous subwatershed, urban subwatershed by landuse. Also monitoring points were chosen considering easiness of observation and applicable use of existing data. The final points of monitoring chosen were Shingigyo for agricultural subwatershed, Daerisuwipyo for mountainous subwatershed and Jeonhagyo for urban subwatershed.

An analysis of basin characteristics for urban, mountainous, and agricultural subwatershed was carried out. The geographic characteristic variables for the respective subwatershed were area, average slope, length, runoff curve index shown in Table 1 and the subject basin is like that of Fig. 1. The value of basin area, average slope, average length, and average runoff curve index of the subwatershed showed a quality of 47.88 km^2, 0.0455 (m/m), 11.79 km, 74.22.

Discharge load amount of the subwatershed were according to the regulations of two level water system pollution total control technology guide and the assessed standard by Daegu Kyungbuk Development Research Center for subwatershed discharge load amount of year 2006, as it is shown in Table 2.

Table 1
Characteristics of research watersheds by land use

Watershed	Area (km^2)	Slope (m/m)	Length (km)	CN number
Urban watershed	17.66	0.0150	7.61	83.20
Agricultural watershed	49.36	0.0615	11.69	75.71
Mountainous watershed	76.62	0.0570	16.07	63.75

3.2. Monitoring for watersheds

The basic aim of the subwatershed monitoring lies in collecting, analyzing, and putting forward data for delivery ratio based on both existing research data and survey. In addition, flow, water quality, and precipitation data produced by monitoring are basic contents for revision and examination of river basin model.

The points for monitoring are Shingigyo, Daerisuwipyo, and Jeonhagyo that were chosen from the three land types. For the agricultural subwatershed of Shingigyo, area is 49.36 km^2, land use of agricultural 33%, mountainous 64%, urban 1%. For the urban subwatershed of Jeonhagyo, area is 17.66 km^2, land use of agricultural 15%, mountainous 50%, urban 35%. For the mountainous subwatershed of Daerisuwipyo, area is 76.62 km^2, land use of agricultural 6%, mountainous 93%, urban 1%.

Monitoring was carried out automatically and manually. The common measurement factors for hydraulic and hydrology monitoring were water level and precipitation. Especially in the case where river basin hydrology cycle and flow needed to be identified real time, rainfall and water level were necessary elements and for this purpose monitoring systems that helped to acquire rainfall and water level data were set up in the three subwatershed areas. For manual water flow and water quality monitoring, measurement took place in eight days interval to reflect the change in hydrology and hydraulics within the water system according to the water quality pollution official test method. Also, in assessing statistically similar flow duration curve and load duration curve, measurement took place 15 times and to identify non-point pollutant runoff characteristics, monitoring was carried out twice in times of rainfall for urban and agricultural basin are with the exception of mountainous.

3.3. SWAT modeling process

The structuring process of the SWAT model using GIS database data of the river basin can be categorized into two, the structure process and basin runoff process. Specific processes in structuring are, first; appointing

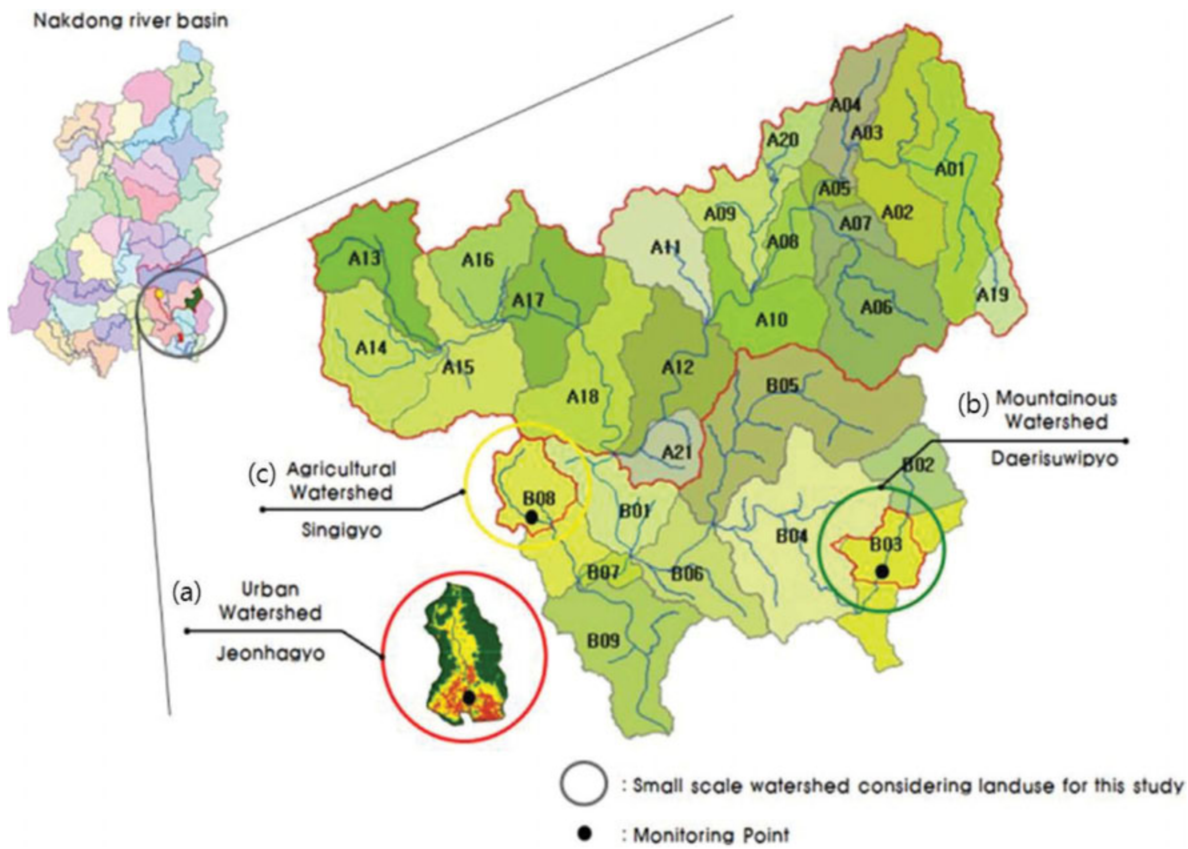

Fig. 1. The location map of research watershed for (a) urban, (b) mountainous, and (c) agricultural at Nakdong river basin.

Table 2
Daily waste loads for research watersheds

Watershed	Area (km^2)	BOD (kg/d)	TN (kg/d)	TP (kg/d)
Urban watershed	17.66	119.955	29.711	3.736
Agricultural watershed	49.36	549.506	323.833	29.148
Mountainous watershed	76.62	181.208	184.603	14.048

an outlet then by making a basin division and stream network, land use, soil map, rainfall observation center coordinates and rainfall data input, retention facilities location and specification input, hydraulic reaction unit(HRU) production process, finally the model is calibrated and verified by using the monitoring data.

Examination of subwatershed flow revision in the three areas of agricultural (Shingigyo), mountainous (Daerisuwipyo), and urban (Jeonhagyo) were carried out by data derived from 15 times of observation. Four areas of subwatershed showed overall satisfactory results and the observation data that was taken from the eight days interval were revised by data from below average rainfall to make it more credible in the case of uncertainty in assessment for examination of flooded season model. Agricultural, mountainous, and urban point's correlation coefficient were 0.81, 0.82, and 0.78 respectively. In the case of agricultural and mountainous there was a bit of overvalue and in the urban case there was a bit of undervalue, yet the model value and actual measurement value showed a tendency to be similar. Revision of water flow through modeled flux amount data were used as input in assessing load duration curve.

Calibration of water quality in subwatershed points for agricultural (Shingigyo), mountainous (Daerisupyo), and urban (Jeonhagyo) through water flow calibration and minimum variance and unbiased estimation method produced pollutant load duration curve, and using the model was implemented. Three areas of subwatershed obtained satisfactory results and as it was done with flow calibration, below average data on rainfall were used for credible calibration. Agricultural, mountainous, and urban subwatersheds had a correlation coefficient of 0.88, 0.42, 0.82 for BOD, 0.82, 0.55, 0.76 for TN, and 0.81, 0.40, 0.69 for TP, showing a tendency of a bit of overvalue for agricultural and urban and a bit of undervalue for mountainous. Nevertheless, the results of the model value and actual measurement value were closely matching. The reasons for these slight variations are judged to be the result of lack in water quality data and handling of runoff in polluted substance followed by soil erosion.

3.4. Delivery ratio estimation based on observation data

After deciding on a subwatershed on soil usage and delivery ratio by soil usage characteristics were assessed by monitoring. In the case of delivery ratio, there were a bit of differences according to the geographical structures but overall the polluted substance went in the order of TN, TP, and BOD respectively by order of highest delivery properties. However, the difference between TP and BOD is negligible. In the case of TN, change in delivery ratio is significant compared to pollution source and this is assumed to be because of the existing pollution load amount measurement method that cannot calculate the polluted substance in the background concentration irrespective of the high rise in geyser nitrogen content from underground water. Also, source load unit of TN cannot adequately show natural environment.

In delivery by soil usage, delivery properties are shown from the highest in the order of urban, mountainous, and agricultural. This is judged to be the change in basin water flow according to soil usage of polluted substances, and from this the changes in the transportation and resurfacing of riverbed nutrient substances as well as the non-point pollution substance and natural nutrient substances are leaked into the basin (Table 3).

3.5. Delivery ratio estimation based on SWAT modeling

By using SWAT model results through monitoring results, FDC of three subwatershed over three year (2005–2007) were measured. FDC of the three subwatershed over three years are as shown in Figs. 2 and 3.

Table 3
Estimation delivery ratio based on observation data

Watershed	BOD	TN	TP
Urban watershed	0.240	0.468	0.286
Agricultural watershed	0.030	0.122	0.032
Mountainous watershed	0.203	0.332	0.177

By use of SWAT load amount model results and discharge load amount data obtained from monitoring results, DRDC of three subwatershed over three year have been calculated. Fig. 4 shows the DRDC of three subwatersheds over three year.

Delivery load amount data produced by SWAT and discharge load amount data have been used to measure pollutant flow duration delivery ratio of three subwatersheds. According to each basin's geographic properties, the tendency of delivery ratio shows a bit of difference but overall delivery ratio increased in times of rainfall when non-point pollution substance is

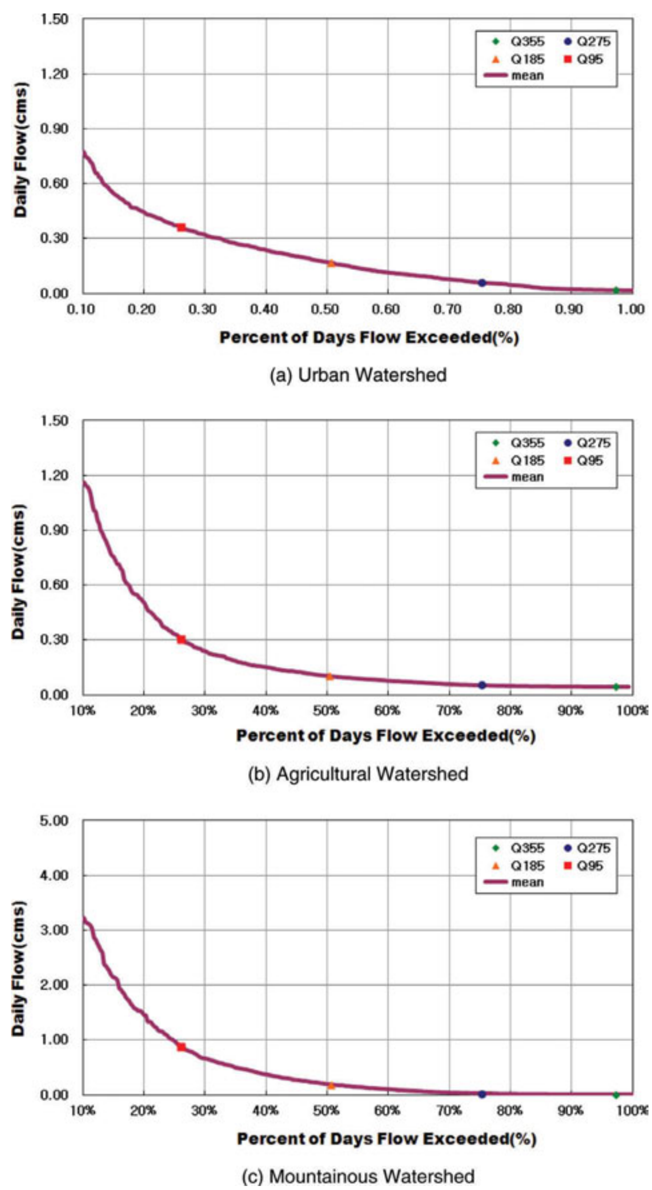

Fig. 2. Flow duration curve (FDC) based on SWAT model: 3 y average (2005–2007) for three watersheds.

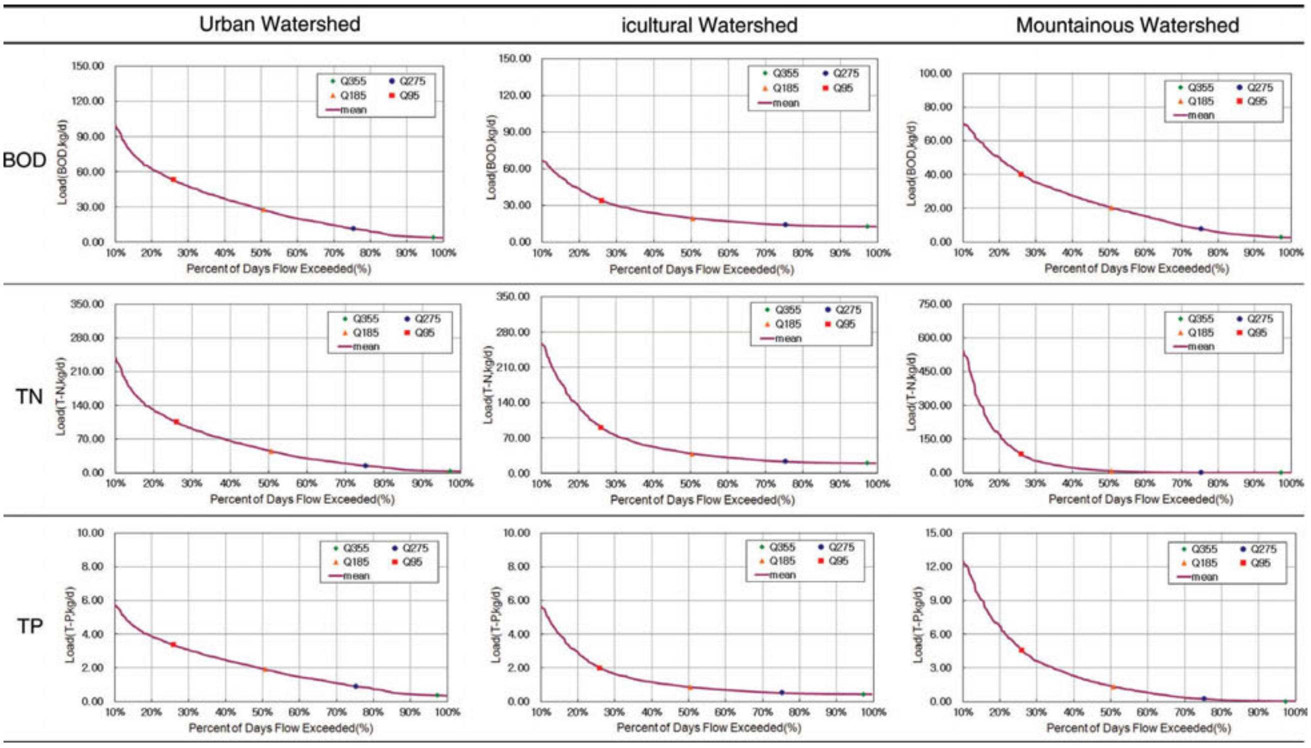

Fig. 3. Load duration curve (LDC) based on SWAT: 3 y average (2005–2007) for three watersheds.

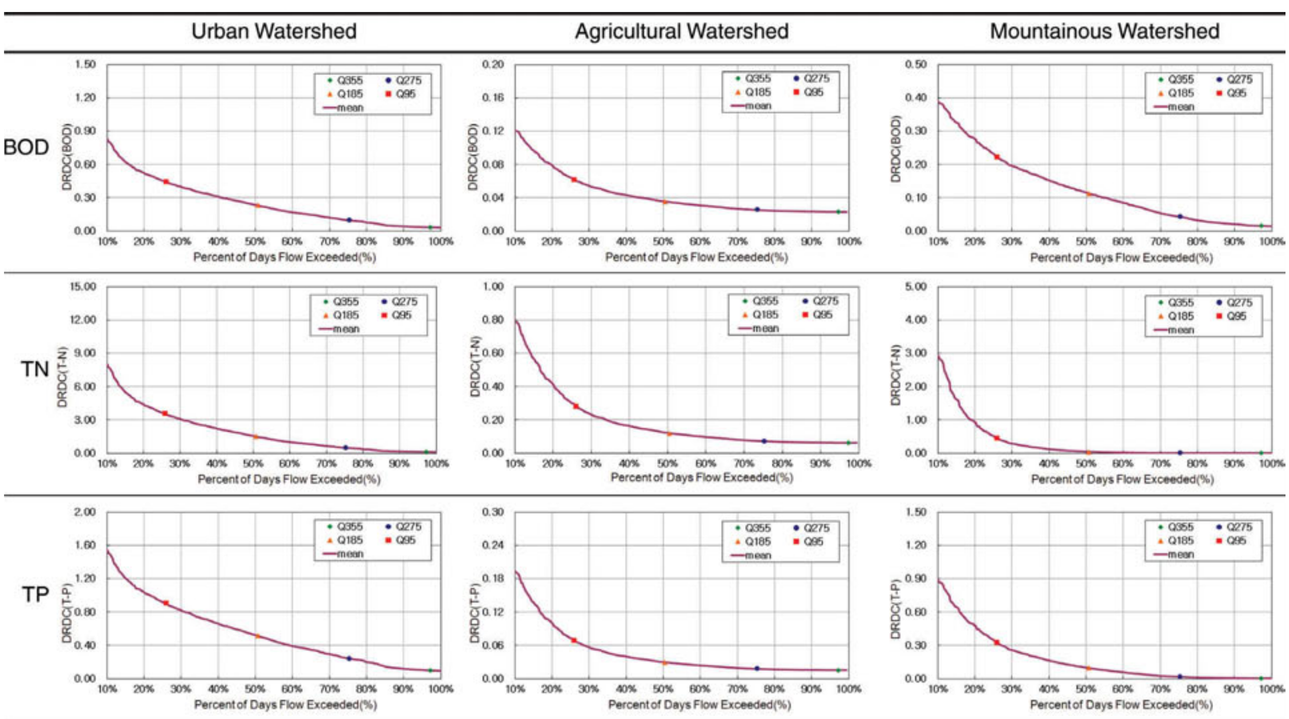

Fig. 4. Delivery rate curve (DRDC): based on watershed model: 3 y average (2005–2007) for three watersheds.

leaked. Amongst the model results, the delivery ratio for the amount of $\mathbf{Q}_{95}$, $\mathbf{Q}_{185}$, $\mathbf{Q}_{275}$, $\mathbf{Q}_{355}$, of urban subwatershed BOD have shown the results 0.44, 0.23, 0.10, 0.03, proving that delivery ratio decreases with the decrease of flux. Such results have proved to show the same results for TN and TP, and possess the same properties in other subwatersheds as well.

In the case of model based delivery ratio, although a bit of difference is shown in delivery ratio depending on geographic properties, overall pollutants showed delivery characteristics in the ascending order of TN, TP, and BOD. In the case of TP and BOD, the difference is negligible. For TN, a significant change ratio is shown compared to other pollution sources. This is because existing method of measurement for pollution load amount doesn't consider the background concentration of polluted substance despite the high background concentration of nitrogen originating from underground water and geyser efflux. Moreover, it is due to the fact that basic unit of source load is considered to be unable to adequately reflect the natural environment.

When observing delivery characteristics of landuse, high delivery properties are shown in the case of BOD in the order of urban, mountainous, and agricultural subwatershed. For the case of TN, the subwatershed excluding the urban are more or less similar in delivery properties and in the case of TP, delivery characteristics are shown in the order of urban, mountainous, and agricultural. Overall, urban subwatershed showed highest delivery properties while agricultural area showed the lowest. It is assumed that this is due to the characteristics in soil usage and change in flux of drainage system which causes change in the basin flux which in turn causes an increase in polluted substance delivery, resurfacing of nutrient on the riverbed, and an influx of non-point pollution substance and natural nutrient substance into the basin in rainfall season.

According to FDC and LDC assessment results, modeled flow and delivery load amount's daily volatility is shown to be significant. This makes it difficult to estimate the subject basin area delivery ratio that is based on single unit flow and delivery load amount. Moreover, the results show that there is a need to consider the overall change in water flow and quality.

4. Discussions

According to this study, estimated delivery ratio of flow duration according to land uses is as shown in Table 4. The delivery ratio for $\mathbf{Q}_{95}$ of BOD, TN, TP on all watersheds have shown the results 0.44, 3.55, 0.90 that is the highest than other flow durations, $\mathbf{Q}_{185}$, $\mathbf{Q}_{275}$ and $\mathbf{Q}_{355}$. Moreover, urban watershed has shown the highest delivery ratio than agriculture or mountainous watershed.

Table 4
Estimated delivery ratio by DRDC for each land use and pollutant

	Flow duration	Urban watershed	Agriculture watershed	Mountainous watershed
BOD	Q95	0.44	0.06	0.22
	Q185	0.23	0.04	0.11
	Q275	0.10	0.03	0.04
	Q355	0.03	0.02	0.02
TN	Q95	3.55	0.28	0.44
	Q185	1.52	0.12	0.05
	Q275	0.48	0.07	0.00
	Q355	0.12	0.06	0.00
TP	Q95	0.90	0.07	0.32
	Q185	0.52	0.03	0.10
	Q275	0.24	0.02	0.02
	Q355	0.10	0.02	0.00

By using actual measurement data in Fig. 5, delivery ratio was compared on the basis of the delivery ratio and flow model as urban area. When comparing delivery ratio estimated by modeling and that obtained from observation data, urban subwatershed showed delivery ratio similar to that of $\mathbf{Q}_{275}$. In the case of agricultural subwatershed, delivery ratio of $\mathbf{Q}_{275}$ was shown in BOD. For the case of TN and TP, delivery ratio showed similarity to that of $\mathbf{Q}_{185}$ yet with a slight overvalue. Mountainous subwatershed showed similarity to the delivery ratio of $\mathbf{Q}_{95}$ yet each category showed similar value in water flow between flooded season and high water season.

BOD delivery ratio at lower reach in Keum river watershed (Gap stream) estimated by research by Son et al. [21] showed the value of 0.7. This value was similar to the observation data of urban watershed. It seems that Gap stream has urban watetshed feature as passing Daejeon city. Also BOD delivery ratio at Hwasungho obtained by research by Woo et al. [22] showed the value of 0.021 which was similar to the delivery ratio of the observation data of subwatershed in urban and mountainous areas. Also, delivery ratio of TN showed 0.058 for agricultural subwatershed delivery ratio while TP delivery ratio showed 0.045, proving the similarity in agricultural subwatershed delivery ratio. When considering the river basin Hwasungho to be one with a mixture of agricultural and mountainous, mountainous subwatershed and agricultural subwatershed showed similar delivery ratio. This proved that delivery ratio assessed in this research have similar tendency to that of other researches.

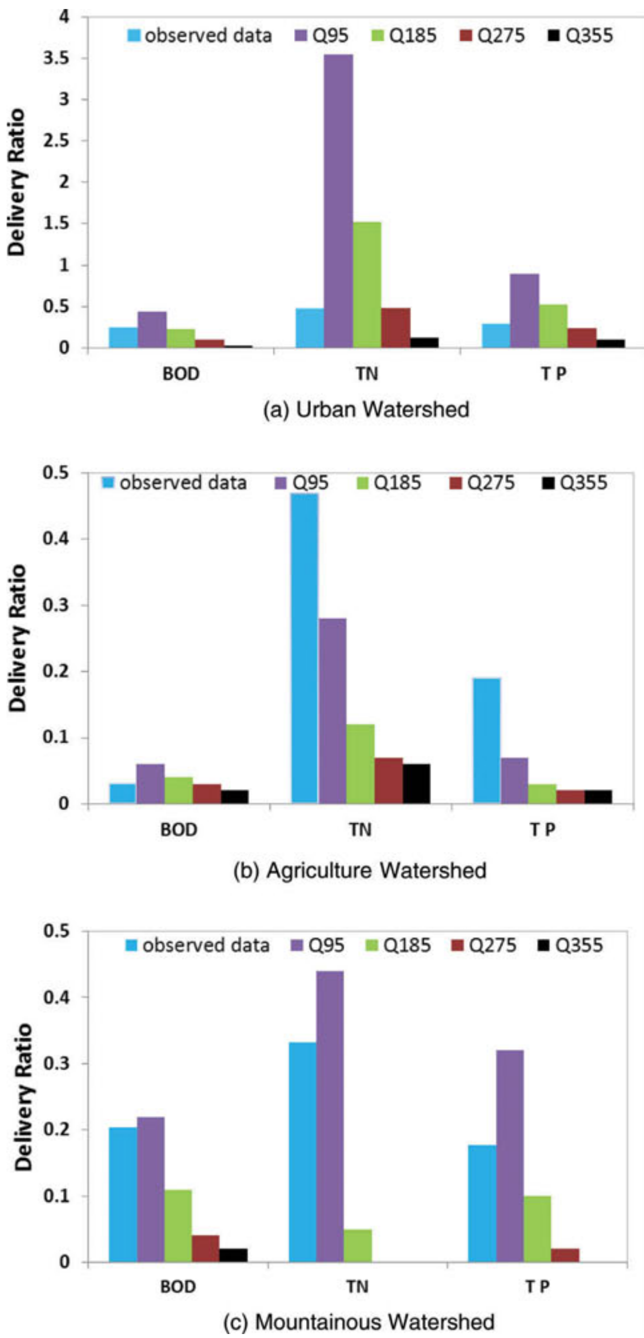

Fig. 5. Comparison of estimated delivery ratio between observed data and estimated data by SWAT and DRDC method.

5. Conclusions

In this research, problems are identified through comparison and analysis in assessment method of river basin properties and delivery ratio by pollutant. Also, delivery ratio assessment method based on actual measurement and modeling was established to deduct an improved solution to delivery ratio measurement. In order to implement delivery ratio measurement method, three areas of small scale river basin in urban (Jeonhagyo), agricultural (Shingigyo), and mountainous (Daerisupyo) were chosen and monitored to obtain actual measurement data. In addition, SWAT model was used to structure a total hydrology model which in turn was used to research and analyze pollutant runoff and changing properties by landuse. In the end, DRDC method was introduced and applied to submit reasonable delivery ratio measurement method according to flow duration and basin properties.

By using data from monitoring and modeling of basin by landuse, pollutant runoff properties and delivery properties according to landuse within the area had been analyzed. Depending on geographic characteristics, delivery properties have slight difference in tendency but in the case of pollutant high delivery properties were shown for TN, TP, and BOD. Yet, TP and BOD had negligible differences. When observing delivery properties by landuse, high delivery properties had been shown in the order of urban, mountainous, and agricultural area. Overall, urban subwatershed showed high delivery properties while agricultural subwatershed showed low delivery properties. It is assumed that this is due to the characteristics in landuse and change in flow of drainage system which causes change in the basin runoff which in turn causes an increase in pollutant delivery, resurfacing of nutrient on the riverbed, and an influx of non-point pollution substance and natural nutrient substance into the basin in rainfall season.

The results of this study are believed to be important data to be submitted for the theoretical and technical basis of water environment management in Nakdong River, and improvement policies on the subject river.

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