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# Improvement of the estimation method for non-point source pollution load reduction in Korean total maximum daily load management system

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**ABSTRACT**

This study focused on improving the regression equations for the cumulative rainfall ratio (CRR), cumulative pollutant load ratio (CPR), and average pollutant load reduction efficiency of non-point source (NPS) pollution load reduction facilities to facilitate the calculation of NPS pollution load cutback used in South Korea's technical guidelines for the total maximum daily load. The recently updated hourly rainfall data from the Korea Meteorological Administration and NPS pollution load monitoring data from the Ministry of Environment (MOE) were used. Furthermore, the updated rainfall patterns and data together with the existing regression equation were used to formulate an improved regression equation for the CRR, which was used to calculate the CRR. Additionally, the improved regression equation for the CPR was used to determine the area type weighted CRR based on (i) CRR of land cover and (ii) public data provided by the MOE for 2008–2014. Also, the pollutant load reduction efficiency of the NPS pollution reduction facilities was updated using data of the inflow and outflow monitoring of NPS pollution reduction facilities obtained from various pilot projects or research on NPS pollution load by the MOE and by adding efficiency data of previously excluded low impact development techniques.

*Keywords:* Cumulative rainfall ratio; Cumulative pollutant load ratio; Pollutant load reduction efficiency; Non-point source pollution; Total maximum daily load

## 1. Introduction

Owing to the limitations of the existing methods for improving the quality of river water by strengthening water quality standards for pollutant emission facilities, South Korea's Ministry of Environment (MOE) has introduced the total maximum daily load (TMDL) system [1]. The TMDL system allows management of pollutant load with respect to both water quality and amount of effluent flow [2–6].

The special act on the four main rivers has made implementation of the TMDL system mandatory for the four main river water systems [2–5]. Additionally, based on the Water Environment Conservation Act [6], the TMDL system has been operational via consultation in the Jinwicheon and Sapgyocheon water systems among the various water systems connected to the sea.

The procedure of the TMDL system from planning to execution is as follows. First, the MOE determines the water quality target for cities and provinces. The governor of each city or province then develops a basic plan to determine the water quality target. The effluent pollutant load is allocated by unit basin to achieve the devised water quality target. Second, municipality heads within each city or province establish an enforcement plan including the yearly pollutant reduction plan to achieve the water quality target and the allocated load from this basic plan. Once the enforcement plan is established, the municipal heads perform annual performance evaluations of the plan to check whether the allocated load has been achieved [7,8].

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According to the TMDL system, the amount of point and non-point source (NPS) pollution must be quantitatively calculated. The amount of reduction can be scientifically determined based on the technical guidelines for TMDL [9] developed by the MOE [10], which is available to all the people who need such data to establish the plan.

According to the technical guidelines for TMDL [9], NPS pollutant load reduction is first calculated by deriving the cumulative rainfall ratio (CRR) using the designed rainfall data for the non-point reduction facility and then by calculating the cumulative pollutant load based on the CRR and cumulative pollutant load ratio (CPR). The result is subsequently multiplied with the pollutant load occurred from the catchment area of the NPS pollution reduction facility to determine the NPS pollutant load in the designed rainfall. Finally, the NPS pollutant load is multiplied with the average pollutant load reduction efficiency of the NPS pollution reduction facilities to determine the final NPS pollutant load reduction.

The regression equations used to derive the CRR and CPR were devised based on rainfall data of 10 y ago and the inflow/water quality monitoring data from some NPS pollution reduction facilities. Therefore, calculating the NPS pollution load reduction based on the effluent characteristics by load cover based on more recent rainfall patterns is difficult.

In addition, the average pollutant load reduction ratio does not consider the fact that neither do NPS pollution reduction facilities implement low impact development (LID) techniques nor have LID techniques been sufficiently subdivided. Therefore, the reduction efficiency in the technical guidelines for TMDL [9] need to be updated by adding data obtained from monitoring NPS pollution reduction facilities under various rainfall situations.

The aim of this study is to improve the various regression equations used to calculate the NPS pollution load reduction and the average NPS pollution load reduction efficiency in the technical guidelines for TMDL [9] using the most up-to-date hourly rainfall data and NPS-based monitoring data from the MOE. This will facilitate more accurate determination of NPS pollution load reduction in the TMDL system in the near future.

## 2. Materials and methods

### 2.1. Estimation method for NPS pollution load reduction in the TMDL system

The technical guideline [9] for the TMDL system of the MOE in South Korea provides equations for calculating the amount of NPS pollution load reduction. In this guideline, the amount of NPS pollution load is calculated using unit load of each landcover type (Table 1, Eq. (1)), and then, the amount of load flow into the NPS pollution reduction facility is calculated by multiplying the NPS pollution load and the specific ratio (CRR and CPR).

$$\text{Generated NPS pollution load} = \text{landcover area} \times \text{unit load} \quad (1)$$

where the landcover area is the catchment area (km$^2$), and the unit load is average amount of nonpoint source pollution each landcover by area (kg/km$^2$/d, Table 1).

Table 1
Average unit load by landcover and water quality (kg/km$^2$/d)

| Landcover | BOD | TN | TP |
|---|---|---|---|
| Agricultural land | 1.59 | 9.44 | 0.24 |
| Paddy | 2.30 | 6.56 | 0.61 |
| Forest | 0.93 | 2.20 | 0.14 |
| Impervious area | 85.90 | 13.69 | 2.10 |
| Others | 0.960 | 0.759 | 0.027 |

The CRR and the cumulative pollution load ratio can be calculated using Eqs. (2) and (3) in the technical guideline [9]. The equations are suggested based on the design storm ranges in the technical guideline.

$$\text{Cumulative rainfall ratio} = a \times \ln(P) + b \quad (2)$$

where $a$ is 0.2716 if the CRR is based on the rainfall or 0.2445 if it is based on the rainfall intensity; $b$ is −0.2425 if the CRR is based on rainfall or 0.3174 if it is based on the rainfall intensity; and $P$ is the design rainfall (mm) if the CRR is based on rainfall or the design rainfall intensity (mm/h) if it is based on the rainfall intensity.

$$\text{Cumulative pollutant load ratio} = e^{\left[a \times \{\ln(\text{Cumulative rainfall})\}^2 + b \times \ln(\text{Cumulative rainfall ratio})\right]} \quad (3)$$

where $a$ and $b$ are determined based on the water quality items listed in Table 2.

Finally, the amount of NPS pollution reduction load is calculated by multiplying the NPS pollution load in the NPS pollution reduction facility by the reduction efficiency (Table 3).

### 2.2. Improvement of the CRR estimation

The CRR is a coefficient that determines how much cumulative rainfall flows into the NPS pollution reduction facility considering the design storm. This CRR is calculated through the regression equation (Eq. (2)) according to the technical guideline [9]. This regression equation was derived from the daily weather data of four representative weather stations in South Korea. The process of deriving this CRR regression equation is as follows. First, the accumulated rainfall is calculated in units of 1 mm from the rainfall data for 10 y, and this accumulated amount of rainfall is divided by the total amount of rainfall for 10 y in each weather station. Finally, the relation between the

Table 2
Constants $a$ and $b$ in Eq. (3)

| Constant | BOD | TN | TP |
|---|---|---|---|
| $a$ | −0.0184 | −0.0030 | −0.0018 |
| $b$ | 0.6922 | 0.7509 | 0.7931 |

Table 3
Reduction efficiency of NPS pollution load reduction facilities

| Category | | BOD | TN | TP |
|---|---|---|---|---|
| Retention type | Pond | 34 | 28 | 36 |
| | Underground retention facility | 25 | 24 | 20 |
| | Constructed wetland | 53 | 37 | 60 |
| Infiltration type | Porous pavement | 75 | 83 | 65 |
| | Porous retention facility | 69 | 58 | 69 |
| | Infiltration trench | 77 | 62 | 73 |
| | Dry well | | | |
| | Porous tube | 53 | 72 | 46 |
| | Infiltration gutter | | | |
| Filter type | Vegetated filter strip | 44 | 42 | 42 |
| | Vegetated swale | 34 | 45 | 51 |
| | Sand-based filtering facility<br>Manufacturing filter system | 50 | 46 | 54 |
| Bio-retention type | Porous pot | 75 | 73 | 72 |
| | Rain garden<br>Passage garden<br>Tree-based filter box | 54 | 49 | 65 |
| Whirlpool-based filtering system | | 16 | 11 | 22 |
| Screen-based facility | | 15 | 9 | 19 |
| Facility type (ultra-speed coagulation and sedimentation) | | 80 | 20 | 85 |

calculated CRR and the daily rainfall amount is analyzed, and the regression equation is developed (Eq. (1), Fig. 1) [11].

However, because this regression equation is not based on data from all weather stations in South Korea, it does not consider recent changes in rainfall patterns since 2008 due to climate change. Furthermore, it uses the daily cumulative rainfall and does not consider continuous rainfall events that exceed 1 d, leading to a less accurate CRR.

To solve these issues, this study considers the hourly rainfall and rainfall intensity data [12] for the last 30 y obtained from 64 weather stations and the appropriate retention time (24 h) in a constructed wetland, recommended by the MOE [13], to derive the regression equation through a correlative analysis of the cumulative rainfall and CRR at each weather station. Finally, the regression equation obtained from all weather stations was averaged to develop a regression equation for the representative CRR estimation.

### 2.3. Improvement of the CPR estimation

The cumulative pollution load ratio is a coefficient that is used to determine how much of the NPS pollution load amount flows into the NPS pollution reduction facility in rainfall events. This coefficient is calculated using the regression equation derived by analyzing the relation between the rainfall-runoff monitoring data of the 83 NPS pollution reduction facilities installed by the MOE in South Korea and the CRR as calculated above (Figs. 2 and 3).

However, this single regression equation was developed using effluent rainfall monitoring data obtained from 83 NPS pollution load reduction facilities mostly installed in impervious catchment areas. Thus, estimating the CPR based on the NPS runoff characteristics of other regions with a different impervious ratio is a challenging task.

To circumvent this issue, the long-term NPS runoff monitoring data [14–17] from each of the 16 landcover types

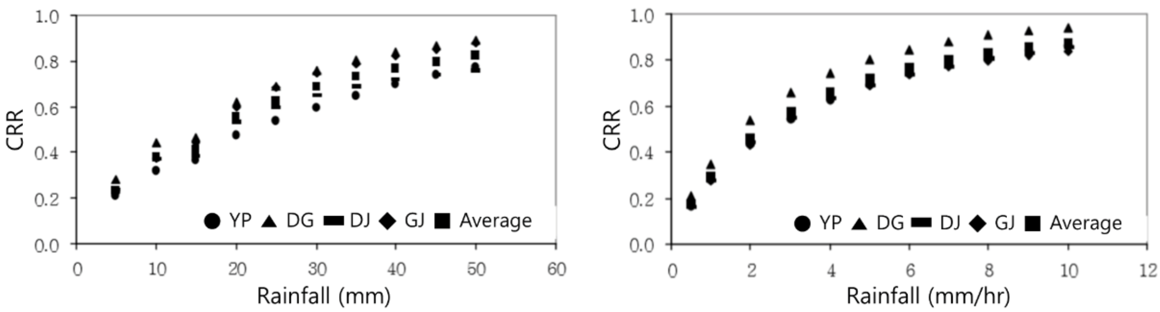



Fig. 1. Relation between CRR and rainfall (mm).

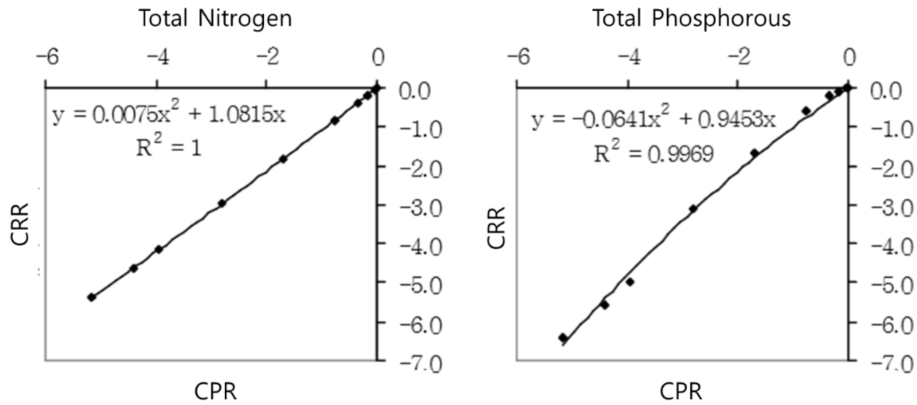



Fig. 2. Relation between the CRR and CPR of TN and TP in a constructed wetland [11].

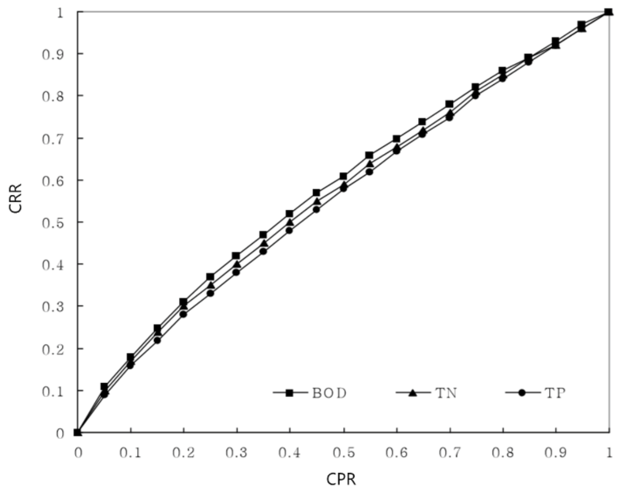



Fig. 3. Relation between the CRR and CPR of BOD, TN, and TP [11].

provided by the MOE were used to analyze the cumulative flow ratio and the CPR of BOD, TN, TP, and SS. Thus, a regression equation was derived for the cumulative load ratio estimation by landcover. To derive the regression equation, the current single regression equation (Eq. (3)) was maintained, whereas the landcover was varied, and the monitoring data with the rainfall (about 80 mm) corresponding to 75% of the CRR analyzed using the CRR estimation were utilized.

Post data selection, the cumulative rainfall (mm) and cumulative pollutant load (g) of the monitoring data based on each rainfall event were calculated, and the results were sorted in descending order. The results were then divided by the maximum cumulative rainfall and the maximum cumulative pollutant load to derive the CPR. From the CRR and CPR, 1n was reduced to derive the regression equation for estimating the cumulative pollutant load. The regression equation by rainfall events was averaged to derive the final regression equation for the CPR estimation by landcover (Fig. 4).

Furthermore, the CPR in the final catchment area was determined using the area weighting by landcover.

### *2.4. Estimation of the average NPS pollution load reduction efficiency*

The average NPS pollution load reduction efficiency of the NPS pollution reduction facility in the TMDL Guidelines [9] was devised based on monitoring data of several NPS pollution reduction facilities. However, the MOE continuously monitored the data until 2018, and these data need to be updated. Furthermore, while some NPS pollution reduction efficiency of LID has been included in the TMDL guidelines [9], they are not subdivided, and newer LID technique recommended in MOE, such as "green roofs" have been excluded in the TMDL guidelines [9], thus requiring revisions.

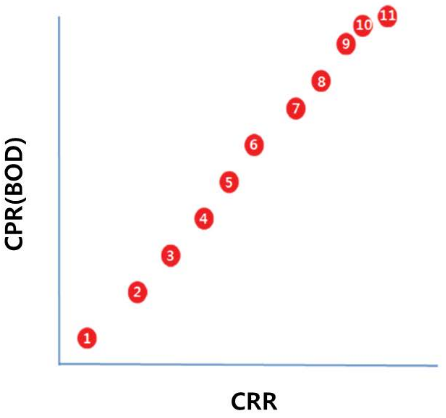
In this study, all NPS pollution monitoring data from key MOE studies on NPS pollution load reduction facilities were surveyed and analyzed, including the NPS pollution Reduction Facility Implementation Pilot Projects in four main river water systems (2008–2014), Zero Rainwater Run-out Pilot Project (2015–2018), monitoring the effects of government-subsidized NPS pollution load reduction facilities (2016–2017), and effective NPS Pollution Load Management Techniques Development Project [18]. This study aimed to include NPS pollution reduction efficiency of LID that had neither been updated nor existed prior to 2014. In addition, the newly integrated NPS pollution reduction efficiency of LID were subdivided.

To determine the average NPS pollution load reduction efficiency of NPS pollution load reduction facilities in an objective manner, the summation of loads, which is used to calculate the reduction efficiency by summing the inflow and outflow pollutant load based on rainfall events, was used. The efficiency was summarized using the criteria developed by reduction facilities in the NPS pollution load facility installation and management operation manual provided by the MOE [13].

## 3. Results and discussion

### *3.1. Improvement of the CRR estimation*

Fig. 5 shows the correlation between the cumulative rainfall and CRR by weather stations. When the CRR converges to 1, the cumulative rainfall is approximately 450 mm.




| Time | Cumulative Rainfall(mm) | Cumulative Pollutant Loads(BOD,g) | CRR | CPR | |
|---|---|---|---|---|---|
| 2014-09-09 21:25 PM | 0.8 | 8 | 0.005 | 0.001 | ① |
| 2014-09-09 21:35 PM | 1.8 | 20 | 0.011 | 0.001 | ② |
| 2014-09-09 22:25 PM | 5.8 | 264 | 0.034 | 0.019 | ③ |
| 2014-09-10 6:25PM | 11.8 | 705 | 0.069 | 0.051 | ④ |
| 2014-09-10 9:55PM | 15 | 1,263 | 0.088 | 0.091 | ⑤ |
| 2014-09-10 12:25PM | 19.2 | 1,990 | 0.113 | 0.143 | ⑥ |
| 2014-09-10 17:25PM | 31.6 | 2,852 | 0.186 | 0.205 | ⑦ |
| 2014-09-10 19:25PM | 60.2 | 3,942 | 0.354 | 0.283 | ⑧ |
| 2014-09-10 21:25PM | 71.6 | 5,458 | 0.421 | 0.392 | ⑨ |
| 2014-09-11 5:55PM | 141.8 | 9,491 | 0.833 | 0.682 | ⑩ |
| 2014-09-11 12:35PM | 170.2 | 13,918 | 1.000 | 1.000 | ⑪ |

Fig. 4. Example of the determination of the regression equation for the CPR.

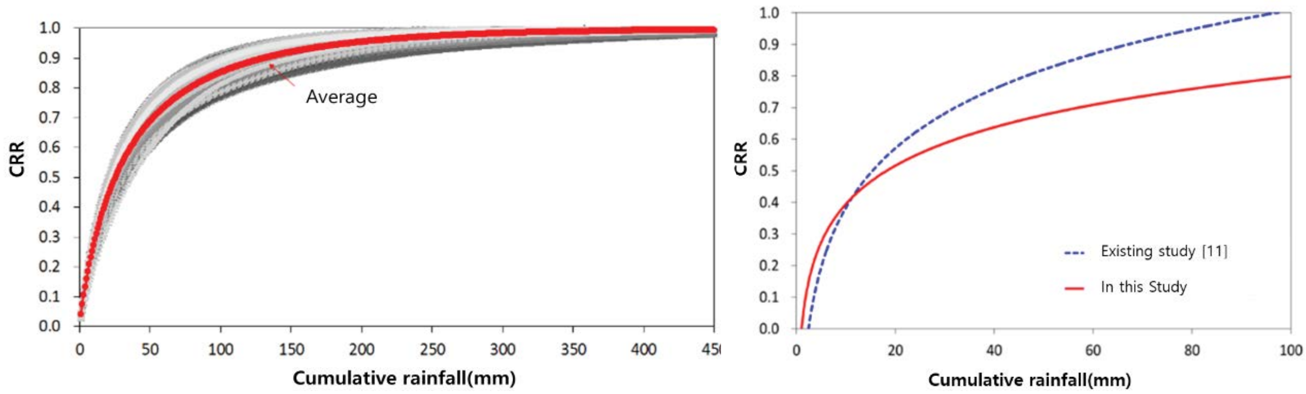



Fig. 5. Correlation between the cumulative rainfall and CRR using the hourly rainfall data for the last 30 y.

Both the cumulative rainfall and CRR show a high correlation with $R^2 > 0.9$. In addition, the regression equation and regression constant by weather stations in the form of Eq. (1) were derived, as shown in Table 4.

In addition, Fig. 5 shows the graphs comparing the relation between the CRR and cumulative rainfall in the existing study [11] together with the results derived from this study. With cumulative rainfall at or below 10 mm, the CRR in the existing study is lower, whereas under high rainfall conditions, the CRR obtained in the existing studies is higher than that obtained in the present study. In addition, the CRR in the existing study converged to 1 with rainfall of approximately 100 mm, whereas it needed to reach about 450 mm in the present study. These changes are likely due to the consideration of hourly rainfall events in this study, which was not accounted for in the existing study.

Fig. 6 shows the correlation between the cumulative rainfall intensity and CRR using the weather stations rainfall data. When the CRR converges to 1, the cumulative rainfall intensity is approximately 40 mm/h. The cumulative rainfall intensity and CRR showed a high correlation with $R^2 > 0.90$.

Based on the correlation analysis, the regression constants by weather stations for regression Eq. (1) and the average constant were determined as shown in Table 5. Similar to the rainfall analysis, some differences from the existing results [11] were observed owing to the additional rainfall intensity characteristics considered in this study.

Thus, calculating the NPS pollution reduction load using the CRR provided in the technical guideline [9] indicates that the amount of the NPS pollution reduction load was underestimated when the rainfall intensity was below 10 mm/d or 2.5 mm/h.

### 3.2. Results of the improvement of the CPR estimation

The regression equation for estimating the CPR was applied to analyze 16 items based on the landcover characteristics (including orchard, upland, green house, other plantations, paddy, coniferous, broadleaf, mixed forest, public, industrial, transportation, cultural and educational, commercial, residential, artificial meadow, and other bare land), which were then divided into five large categories for the TMDL (agricultural land, paddy, forest, impervious area, and others). Fig. 7a shows the CPR based on the CRR by land category per TMDL. In the existing study [11], 76% of data used in the analysis were the rainfall-runoff survey data obtained from impervious areas, such as roads and parking lots. Therefore, the load ratio by pollutant based on the CRR is believed to be higher than the results obtained in the present study.

Table 4
CRR regression constants by weather stations

| No. | Station no. | Name | CRR regression constant | | | No. | Station no. | Name | CRR regression constant | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *a* | *b* | $R^2$ | | | | *a* | *b* | $R^2$ |
| 1 | 90 | Sokcho | 0.1991 | −0.1213 | 0.9673 | 33 | 201 | Ganghwa | 0.1630 | −0.0003 | 0.9371 |
| 2 | 100 | Daegwallyeong | 0.1761 | −0.0745 | 0.9609 | 34 | 202 | Yangpyeong | 0.1899 | −0.1203 | 0.9757 |
| 3 | 101 | Chuncheon | 0.1740 | −0.0457 | 0.9672 | 35 | 203 | Icheon | 0.1837 | −0.0653 | 0.9607 |
| 4 | 105 | Gangneung | 0.1536 | 0.0611 | 0.9015 | 36 | 211 | Inje | 0.1632 | 0.0311 | 0.9459 |
| 5 | 108 | Seoul | 0.1723 | −0.0533 | 0.9649 | 37 | 212 | Hongcheong | 0.1626 | 0.0080 | 0.9363 |
| 6 | 112 | Incheon | 0.1845 | −0.0661 | 0.9663 | 38 | 216 | Taebaek | 0.1711 | 0.0087 | 0.9410 |
| 7 | 114 | Wonju | 0.1814 | −0.0570 | 0.9694 | 39 | 221 | Jecheon | 0.1782 | −0.0461 | 0.9604 |
| 8 | 115 | Woolleungdo | 0.1672 | 0.0720 | 0.8968 | 40 | 226 | Boeun | 0.1859 | −0.0397 | 0.9537 |
| 9 | 119 | Suwon | 0.1921 | −0.1052 | 0.9743 | 41 | 232 | Cheonan | 0.1960 | −0.0860 | 0.9748 |
| 10 | 127 | Chungju | 0.1885 | −0.0606 | 0.9703 | 42 | 235 | Boryeong | 0.1588 | 0.0769 | 0.9081 |
| 11 | 129 | Seosan | 0.1806 | −0.0287 | 0.9484 | 43 | 236 | Buyeo | 0.1928 | −0.0768 | 0.9593 |
| 12 | 130 | Uljin | 0.1809 | −0.0082 | 0.9444 | 44 | 238 | Geumsan | 0.1820 | −0.0260 | 0.9613 |
| 13 | 131 | Cjeongju | 0.1939 | −0.0638 | 0.9630 | 45 | 243 | Buan | 0.1784 | 0.0088 | 0.9413 |
| 14 | 133 | Daejeon | 0.1819 | −0.0408 | 0.9563 | 46 | 244 | Ilsil | 0.1898 | −0.0482 | 0.9595 |
| 15 | 135 | Chupungnyeung | 0.1966 | −0.0703 | 0.9765 | 47 | 245 | Jeongeup | 0.1870 | −0.0256 | 0.9512 |
| 16 | 136 | Andong | 0.1998 | −0.0486 | 0.9601 | 48 | 247 | Namwon | 0.1888 | −0.0556 | 0.9593 |
| 17 | 138 | Pohang | 0.1673 | 0.0499 | 0.9120 | 49 | 260 | Jangheung | 0.2145 | −0.1692 | 0.9767 |
| 18 | 140 | Gunsan | 0.1626 | 0.0648 | 0.9108 | 50 | 261 | Haenam | 0.2095 | −0.1144 | 0.9709 |
| 19 | 143 | Daegu | 0.1748 | 0.0295 | 0.9349 | 51 | 262 | Goheung | 0.1960 | −0.0913 | 0.9462 |
| 20 | 146 | Jeonju | 0.1912 | −0.0552 | 0.9711 | 52 | 272 | Yeongju | 0.1875 | −0.0596 | 0.9474 |
| 21 | 152 | Ulsan | 0.1744 | 0.0170 | 0.9198 | 53 | 273 | Mungyeong | 0.2040 | −0.1088 | 0.9632 |
| 22 | 155 | Masan | 0.1914 | −0.0965 | 0.9420 | 54 | 277 | Yeongdeok | 0.2018 | −0.0678 | 0.9560 |
| 23 | 156 | Gwangju | 0.1997 | −0.0927 | 0.9684 | 55 | 278 | Euiseong | 0.1717 | 0.0502 | 0.9258 |
| 24 | 159 | Busan | 0.1898 | −0.0846 | 0.9387 | 56 | 279 | Gumi | 0.1942 | −0.0517 | 0.9665 |
| 25 | 162 | Tongnyeong | 0.1985 | −0.0998 | 0.9413 | 57 | 281 | Yeongcheon | 0.2000 | −0.0584 | 0.9638 |
| 26 | 165 | Mokpo | 0.2115 | −0.0881 | 0.9663 | 58 | 284 | Geochang | 0.1877 | −0.0637 | 0.9550 |
| 27 | 168 | Yeosu | 0.2112 | −0.1465 | 0.9578 | 59 | 285 | Hapcheon | 0.2050 | −0.1314 | 0.9730 |
| 28 | 170 | Wando | 0.2084 | −0.1401 | 0.9547 | 60 | 288 | Millyang | 0.1802 | −0.0029 | 0.9253 |
| 29 | 184 | Jeju | 0.1829 | −0.0404 | 0.9589 | 61 | 289 | Sancheong | 0.1990 | −0.1555 | 0.9754 |
| 30 | 188 | Seongsan | 0.1970 | −0.1231 | 0.9477 | 62 | 294 | Geoje | 0.1853 | −0.0940 | 0.9255 |
| 31 | 189 | Seoguipo | 0.1755 | −0.0462 | 0.9158 | 63 | 295 | Namhae | 0.2156 | −0.2291 | 0.9628 |
| 32 | 192 | Jinju | 0.2046 | −0.1453 | 0.9617 | Average | | | 0.1752 | −0.0089 | 0.9369 |

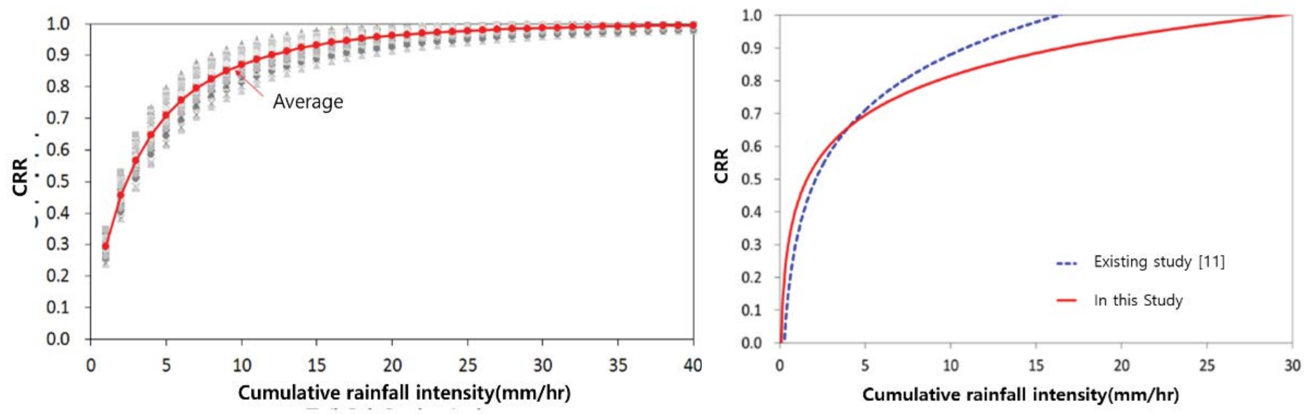



Fig. 6. Correlation between the cumulative rainfall intensity and CRR using the hourly rainfall data for the last 30 y.

Table 5
CRR regression constants by weather stations based on rainfall intensity

| No. | Station no. | Name | CRR regression constant | | | No. | Station no. | Name | CRR regression constant | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *a* | *b* | $R^2$ | | | | *a* | *b* | $R^2$ |
| 1 | 90 | Sokcho | 0.1813 | 0.4392 | 0.9127 | 33 | 201 | Ganghwa | 0.1523 | 0.4177 | 0.8976 |
| 2 | 100 | Daegwallyeong | 0.1704 | 0.4650 | 0.8968 | 34 | 202 | Yangpyeong | 0.1868 | 0.3592 | 0.9505 |
| 3 | 101 | Chuncheon | 0.1860 | 0.3898 | 0.9377 | 35 | 203 | Icheon | 0.1774 | 0.3985 | 0.9269 |
| 4 | 105 | Gangneung | 0.1440 | 0.5074 | 0.8436 | 36 | 211 | Inje | 0.1723 | 0.4351 | 0.9187 |
| 5 | 108 | Seoul | 0.1714 | 0.3830 | 0.9350 | 37 | 212 | Hongcheong | 0.1845 | 0.3822 | 0.9352 |
| 6 | 112 | Incheon | 0.1707 | 0.4014 | 0.9281 | 38 | 216 | Taebaek | 0.1728 | 0.4683 | 0.9145 |
| 7 | 114 | Wonju | 0.1768 | 0.4057 | 0.9363 | 39 | 221 | Jecheon | 0.1800 | 0.4006 | 0.9357 |
| 8 | 115 | Woolleungdo | 0.1828 | 0.4437 | 0.9198 | 40 | 226 | Boeun | 0.1671 | 0.4334 | 0.9124 |
| 9 | 119 | Suwon | 0.1720 | 0.3961 | 0.9305 | 41 | 232 | Cheonan | 0.1841 | 0.3848 | 0.9448 |
| 10 | 127 | Chungju | 0.1746 | 0.4149 | 0.9316 | 42 | 235 | Boryeong | 0.1654 | 0.4131 | 0.9223 |
| 11 | 129 | Seosan | 0.1664 | 0.4143 | 0.9127 | 43 | 236 | Buyeo | 0.1738 | 0.4007 | 0.9242 |
| 12 | 130 | Uljin | 0.1961 | 0.4379 | 0.9284 | 44 | 238 | Geumsan | 0.1815 | 0.4123 | 0.9297 |
| 13 | 131 | Cjeongju | 0.1627 | 0.4402 | 0.9104 | 45 | 243 | Buan | 0.1810 | 0.4026 | 0.9347 |
| 14 | 133 | Daejeon | 0.1752 | 0.4051 | 0.9285 | 46 | 244 | Ilsil | 0.1799 | 0.4098 | 0.9366 |
| 15 | 135 | Chupungnyeung | 0.1815 | 0.4448 | 0.9277 | 47 | 245 | Jeongeup | 0.1623 | 0.4359 | 0.9069 |
| 16 | 136 | Andong | 0.1791 | 0.4543 | 0.9176 | 48 | 247 | Namwon | 0.1814 | 0.3968 | 0.9322 |
| 17 | 138 | Pohang | 0.1417 | 0.5166 | 0.8385 | 49 | 260 | Jangheung | 0.1899 | 0.3550 | 0.9481 |
| 18 | 140 | Gunsan | 0.1681 | 0.4287 | 0.9149 | 50 | 261 | Haenam | 0.1822 | 0.3828 | 0.9435 |
| 19 | 143 | Daegu | 0.1678 | 0.4617 | 0.9034 | 51 | 262 | Goheung | 0.1581 | 0.4203 | 0.8927 |
| 20 | 146 | Jeonju | 0.1723 | 0.4233 | 0.9287 | 52 | 272 | Yeongju | 0.1944 | 0.3986 | 0.9347 |
| 21 | 152 | Ulsan | 0.1754 | 0.4295 | 0.9176 | 53 | 273 | Mungyeong | 0.1840 | 0.4221 | 0.9193 |
| 22 | 155 | Masan | 0.1702 | 0.3988 | 0.9074 | 54 | 277 | Yeongdeok | 0.1876 | 0.4439 | 0.9157 |
| 23 | 156 | Gwangju | 0.1716 | 0.4037 | 0.9358 | 55 | 278 | Euiseong | 0.1808 | 0.4413 | 0.9255 |
| 24 | 159 | Busan | 0.1617 | 0.4116 | 0.9000 | 56 | 279 | Gumi | 0.1801 | 0.4387 | 0.9210 |
| 25 | 162 | Tongnyeong | 0.1784 | 0.3911 | 0.9183 | 57 | 281 | Yeongcheon | 0.1819 | 0.4345 | 0.9229 |
| 26 | 165 | Mokpo | 0.1845 | 0.4088 | 0.9418 | 58 | 284 | Geochang | 0.1855 | 0.4131 | 0.9207 |
| 27 | 168 | Yeosu | 0.1893 | 0.3677 | 0.9412 | 59 | 285 | Hapcheon | 0.1775 | 0.4103 | 0.9255 |
| 28 | 170 | Wando | 0.1939 | 0.3471 | 0.9464 | 60 | 288 | Millyang | 0.1797 | 0.4171 | 0.9158 |
| 29 | 184 | Jeju | 0.1684 | 0.4214 | 0.9247 | 61 | 289 | Sancheong | 0.1847 | 0.3782 | 0.9302 |
| 30 | 188 | Seongsan | 0.1683 | 0.3627 | 0.9299 | 62 | 294 | Geoje | 0.1900 | 0.3317 | 0.9411 |
| 31 | 189 | Seoguipo | 0.1828 | 0.3407 | 0.9386 | 63 | 295 | Namhae | 0.1921 | 0.3255 | 0.9393 |
| 32 | 192 | Jinju | 0.1842 | 0.3851 | 0.9268 | Average | | | 0.1720 | 0.4187 | 0.9188 |

The results derived by land category show that "agricultural land" includes orchard, upland, green houses, and other plantations, and in all landcover excluding green houses, the CPR gradually increased after the CRR reached 0.5. It is believed that during rain, rainfall permeates on the surface (soil), and as the soil becomes saturated, rainfall runoffs occur.

Compared with the other landcover categories, the CPR by pollutant in green houses rapidly increased in a lower CRR. This might have occurred because rainfall runoffs in green houses did not permeate to the surface and were quickly discharged through the vinyl surface (Fig. 7b).

Fig. 7c shows that in paddies, the CPR by pollutant gradually when the CRR reached over 0.4. Such a trend was observed for all land categories, excluding green houses. Fig. 7d shows that in the forest category including coniferous forests, broadleaf forests, and mixed forests, the pollutant concentration caused by rainfall runoffs is very low. The cumulative pollution load ratio by pollutant based on the CRR gradually increases in forests, similar to the results observed for agricultural land and paddy categories. Fig. 7e shows the impervious area category divided into public, industrial, transportation, cultural and educational, commercial, and residential regions; here, compared with the other land categories, the CPR based on the cumulative rapidly increased. Additionally, impervious regions with high non-permeability (transportation, commercial, and industrial regions) exhibited a similar trend to the results of the existing study [11].

Public, cultural and educational, and residential regions included in the impervious area category have a higher ratio of permeable areas, such as landscaping and green spaces, than the transportation, commercial, and industrial regions. Thus, the cumulative load ratio by pollutant based on the CRR gradually increased.

Fig. 6f shows that the other land category includes artificial bare lands and artificial meadows. Similar to the

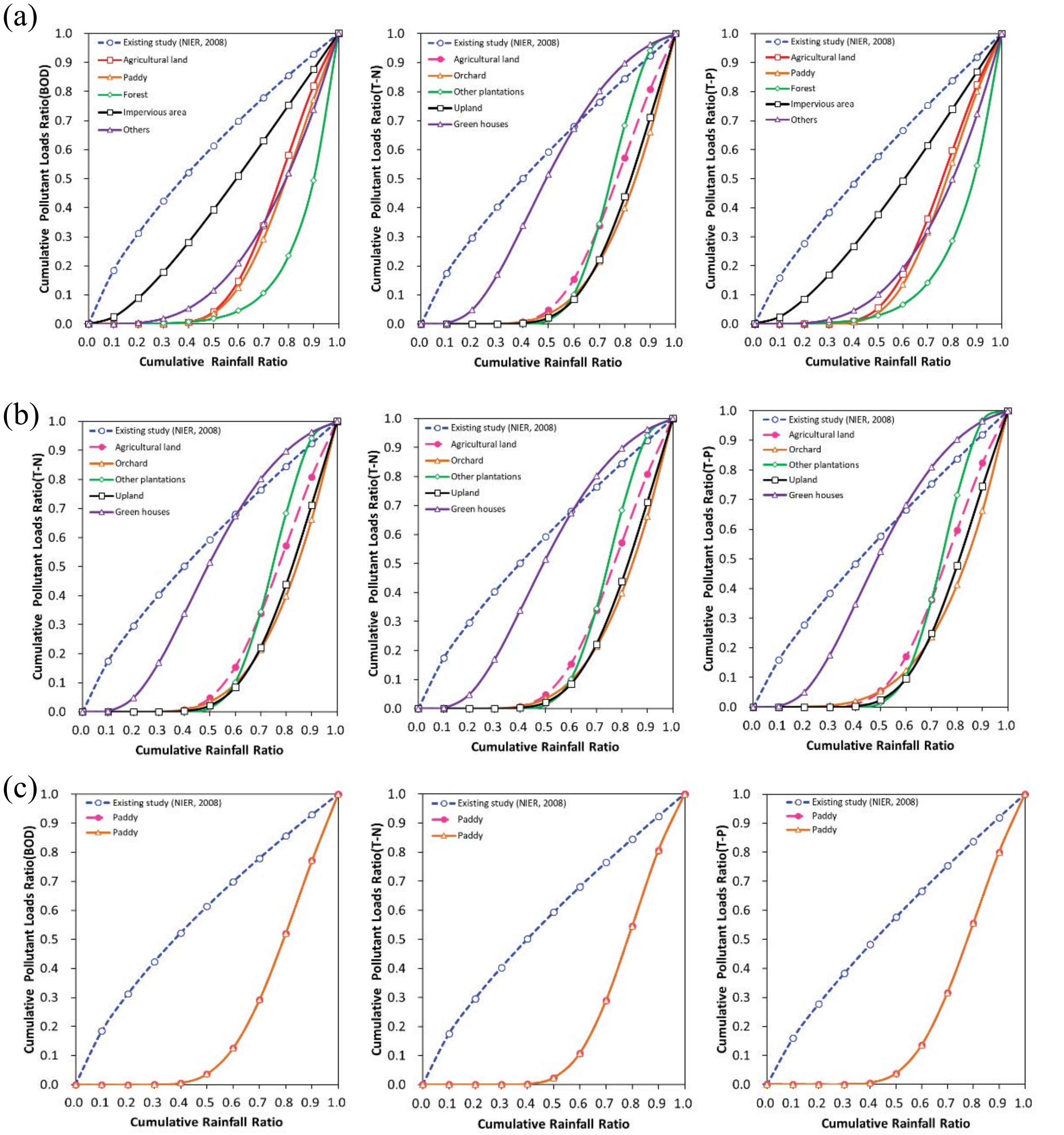



Fig. 7. Correlation between the CRR and CPR each landcover type: (a) TMDL land category, (b) "Agricultural land" category, and (c) "Paddy" land category.

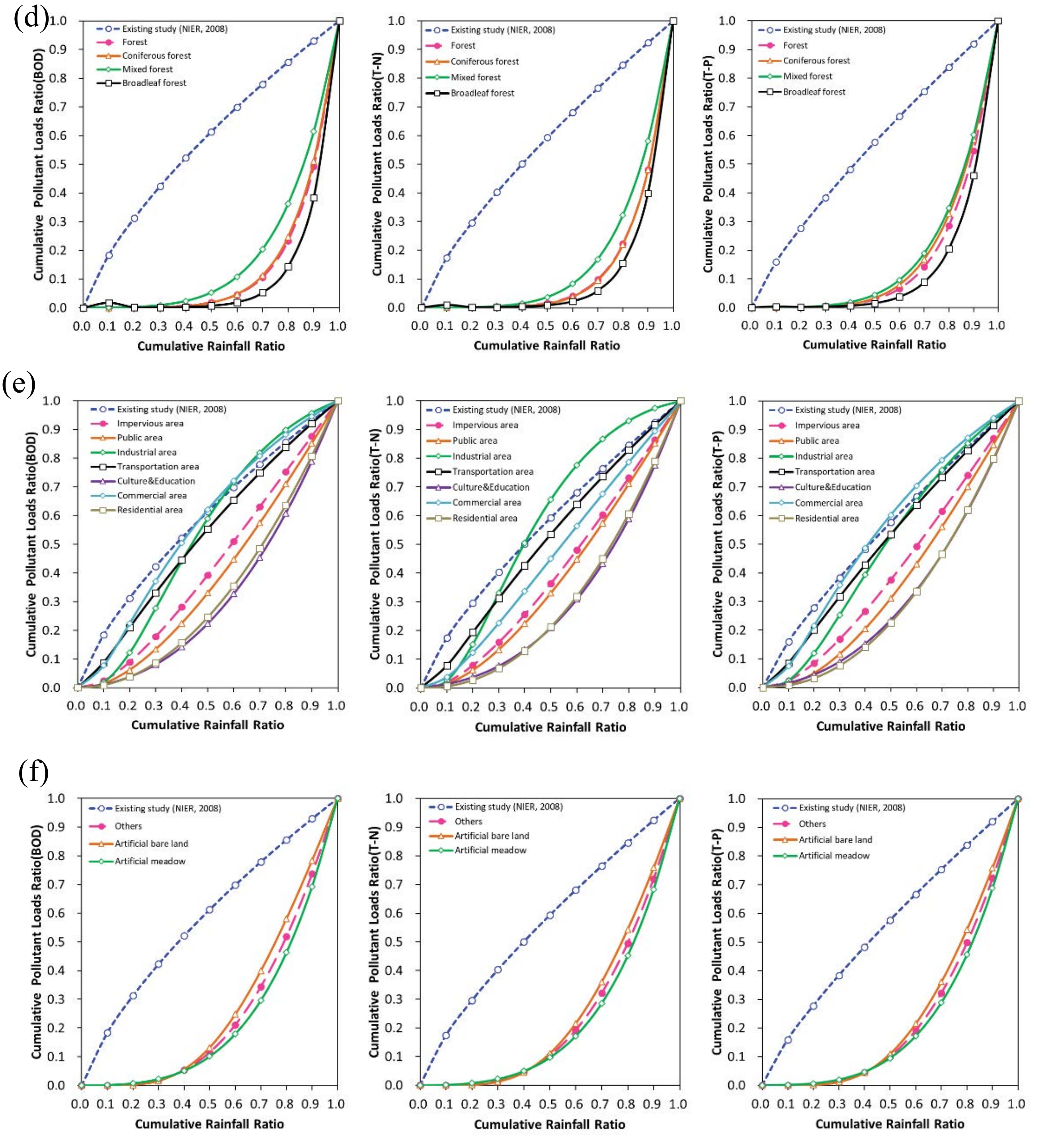



Fig. 7. Correlation between the CRR and CPR each landcover type: (d) "Forest" land category, (e) "Impervious area" category, and (f) "Other" land category.

agricultural land, paddy, and forest categories, the CPR gradually increased according to the increase in the CRR. Table 6 shows the regression constants of the regression equation for the CPR estimation together with the land categories derived from Fig. 7.

Therefore, the cumulative pollution load ratio can vary greatly depending on the landcover characteristics. In particular, when calculating the NPS pollution reduction load in the NPS pollution reduction facilities in the pervious-dominant area, the load can be overestimated with the technical guideline [9].

Furthermore, the existing CPR can be calculated using a simple equation that does not consider the runoff characteristics by landcover, whereas the improved CPR calculated in this study incorporates the runoff characteristics by landcover. The proposed regression constant by land category aims to determine the NPS pollutant load in a more concrete manner using the weighted-area averaging method (Fig. 8).

The method developed in this study can improve the limitations of the single regression equation provided in the existing study [11] and can be applied to estimate the efficient CPR based on the runoff characteristics by various landcovers.

### 3.3. Results of the average pollutant load reduction efficiency

The efficiency of the NPS pollution reduction facility installed by the NPS pollution load reduction pilot project and R&D project of MOE was maximum for the planter box, an LID technique, for BOD and TN and was maximum for porous pavements for TP (Table 7). The efficiency by pollutant was 30%–89% for BOD, 37%–89% for TN, and 34%–98% for TP.

Compared with the TMDL guideline [9], the results from this study added to the average pollutant load reduction efficiency and provided additional efficiency data, such as the efficiency of green roofs and other facilities (such as infiltration trench, infiltration gutter, tree box filter, and bio-retention basin) that were evaluated to determine their reduction efficiency. Furthermore, result of calculation of reduction efficiency in the NPS pollution reduction facilities using the various domestic rain event monitoring data, In most facilities, the efficiency increased (from 82% to 410%) compared with that of the existing TMDL guideline [9] (Fig. 9).

The differences in the results of the existing and present studies stem from the addition of monitoring data from NPS pollution load reduction facilities under various rainfall event conditions. Furthermore, continuous efficiency monitoring would be required after the present study.

## 4. Conclusions and recommendations

The results of this study can be incorporated in official analyses to estimate the reduction in cumulative rainfall more accurately. Our results improved the estimation

Table 6
Regression constants of the CPR

| Land category | | Regression constant for the CPR | | | | | |
|---|---|---|---|---|---|---|---|
| | | BOD | | TN | | TP | |
| | | *a* | *b* | *a* | *b* | *a* | *b* |
| '08 study result | | –0.0184 | 0.6922 | –0.0030 | 0.7509 | –0.0018 | 0.7931 |
| Agricultural land | Orchard | –2.9830 | 3.2688 | –1.5614 | 3.7618 | –0.5032 | 3.8480 |
| | Other plantations | –10.3645 | –0.6599 | –9.6385 | –0.4468 | –10.0605 | –0.7442 |
| | Upland | –4.1392 | 2.5185 | –3.9167 | 2.8202 | –4.3704 | 2.3405 |
| | Green house | –0.8446 | 0.4872 | –1.0054 | 0.2606 | –1.0061 | 0.2337 |
| | Average | –4.5828 | 1.4037 | –4.0305 | 1.5990 | –3.9850 | 1.4195 |
| Paddy | Paddy | –3.9208 | 2.0492 | –5.7049 | 1.4400 | –4.4162 | 1.6479 |
| Forest | Coniferous forest | 0.9419 | 6.4648 | 1.3633 | 7.0971 | 0.3241 | 5.0864 |
| | Mixed forest | 0.6647 | 4.6977 | 0.6685 | 5.2218 | 0.5763 | 4.8721 |
| | Broadleaf forest | 3.3427 | 9.4516 | 3.0458 | 9.0344 | 2.2254 | 7.5938 |
| | Average | 1.6498 | 6.8714 | 1.6925 | 7.1178 | 1.0419 | 5.8508 |
| Impervious area | Public region | –0.1319 | 1.5063 | –0.1397 | 1.4994 | –0.1967 | 1.5465 |
| | Industrial region | –0.5958 | 0.3484 | –0.6128 | 0.1826 | –0.4333 | 0.6198 |
| | Transportation region | –0.1241 | 0.7673 | –0.1289 | 0.8105 | –0.1030 | 0.8306 |
| | Cultural and education | 0.1449 | 2.2588 | 0.2451 | 2.4242 | 0.1672 | 2.2010 |
| | Commercial region | –0.2631 | 0.5058 | –0.1626 | 1.0380 | –0.2433 | 0.5624 |
| | Residential region | –0.0001 | 2.0244 | 0.0074 | 2.2381 | 0.0004 | 2.1426 |
| | Average | –0.1617 | 1.2352 | –0.1319 | 1.3655 | –0.1348 | 1.3172 |
| Others | Artificial bare land | –1.0322 | 2.2032 | –0.9285 | 2.5286 | –0.9612 | 2.5171 |
| | Artificial meadow | 0.3054 | 3.5138 | 0.4109 | 3.6538 | 0.2502 | 3.5747 |
| | Average | –0.3634 | 2.8585 | –0.2588 | 3.0912 | –0.3555 | 3.0459 |

<<Original >>

$$e^{[a\times\{\ln(Cumulative\ rainfall)\}^2+b\times\ln(Cumulative\ rainfall\ ratio)]}$$

▷

<< Improved method >>

$$\sum_{i=1}^{n}\frac{\left(e^{[a\times\{\ln(Cumulative\ rainfall_i)\}^2+b\times\ln(Cumulative\ rainfall\ ratio_i)]}\right)\times land\ area_i}{Total\ area}$$

Fig. 8. Comparison between the this study and the TMDL guideline for the estimation method for CPR.

Table 7
Results of the average pollutant load reduction efficiency

| Category | Type | BOD | TN | TP |
|---|---|---|---|---|
| Retention type | Pond | 51 | 45 | 46 |
| | Underground retention facility | 80 | 70 | 75 |
| Constructed wetland | Constructed wetland | 64 | 56 | 67 |
| Infiltration type | Porous pavement | 81 | 82 | 98 |
| | Porous retention facility | 66 | 58 | 62 |
| | Infiltration trench | 87 | 84 | 85 |
| | Dry well | 88 | 89 | 88 |
| | Porous tube | 88 | 89 | 88 |
| | Infiltration gutter | 72 | 72 | 74 |
| Bio-retention type | Vegetated filter strip | 61 | 67 | 64 |
| | Vegetated swale | 80 | 75 | 79 |
| | Tree box filter | 79 | 75 | 72 |
| | Planter box | 89 | 89 | 88 |
| | Bio-retention basin | 83 | 84 | 82 |
| | Green roof | 86 | 89 | 62 |
| Filter-type facility | | 48 | 42 | 49 |
| Whirlpool-based filtering system | | 30 | 24 | 34 |
| Screen-based facility | | 40 | 37 | 37 |
| Coagulation and sedimentation-type facility | | 71 | 42 | 70 |

of the NPS load reduction while reflecting the existing TMDL system plan in South Korea using hourly rainfall data and monitoring data related to various MOE NPS for reflecting up-to-date rainfall patterns and runoff characteristics by landcover.

Calculating the accurate amount of NPS pollution reduction load in the TMDL system is important because the amount of the reduction load can be used as pollutant load allocated for regional development. It was difficult to calculate the accurate amount of NPS pollution reduction load as the equations for calculating this amount suggested in the existing technical guidelines for the TMDL system were derived using meteorological data and rainfall-runoff monitoring data of the NPS pollution reduction facility at least 15 y ago.

Therefore, this study devised a new calculation method of the NPS pollution reduction in the technical guidelines for the TMDL system by utilizing the hourly rainfall data obtained from 64 weather stations and the rainfall-runoff data obtained by monitoring various points with different landcover and NPS pollution reduction facilities.

Through this improved method of considering the characteristics of rainfall-runoff each landcover, the overestimated NPS pollution reduction load in pervious areas can be calculated more realistically, and it has become possible to calculate the NPS pollution reduction load underestimated below in a specific amount of rainfall more appropriately. In addition, the NPS pollution reduction efficiency calculated from the rainfall-runoff data of long-term monitored NPS pollution reduction facilities under various rainfall conditions can be helpful for more accurate NPS pollution reduction load calculation in the TMDL system.

However, the ripple effect of the improved method should be analyzed for the TMDL system for further research because, although there is no significant difference between the two methods when comparing the existing method and the improved method for the calculation of the NPS pollution reduction load at the NPS facilities at the urban area, in the case of NPS pollution reduction facilities at the permeable areas, the amount of NPS pollution reduction load calculated by the improved method can be significantly reduced compared with the existing method.

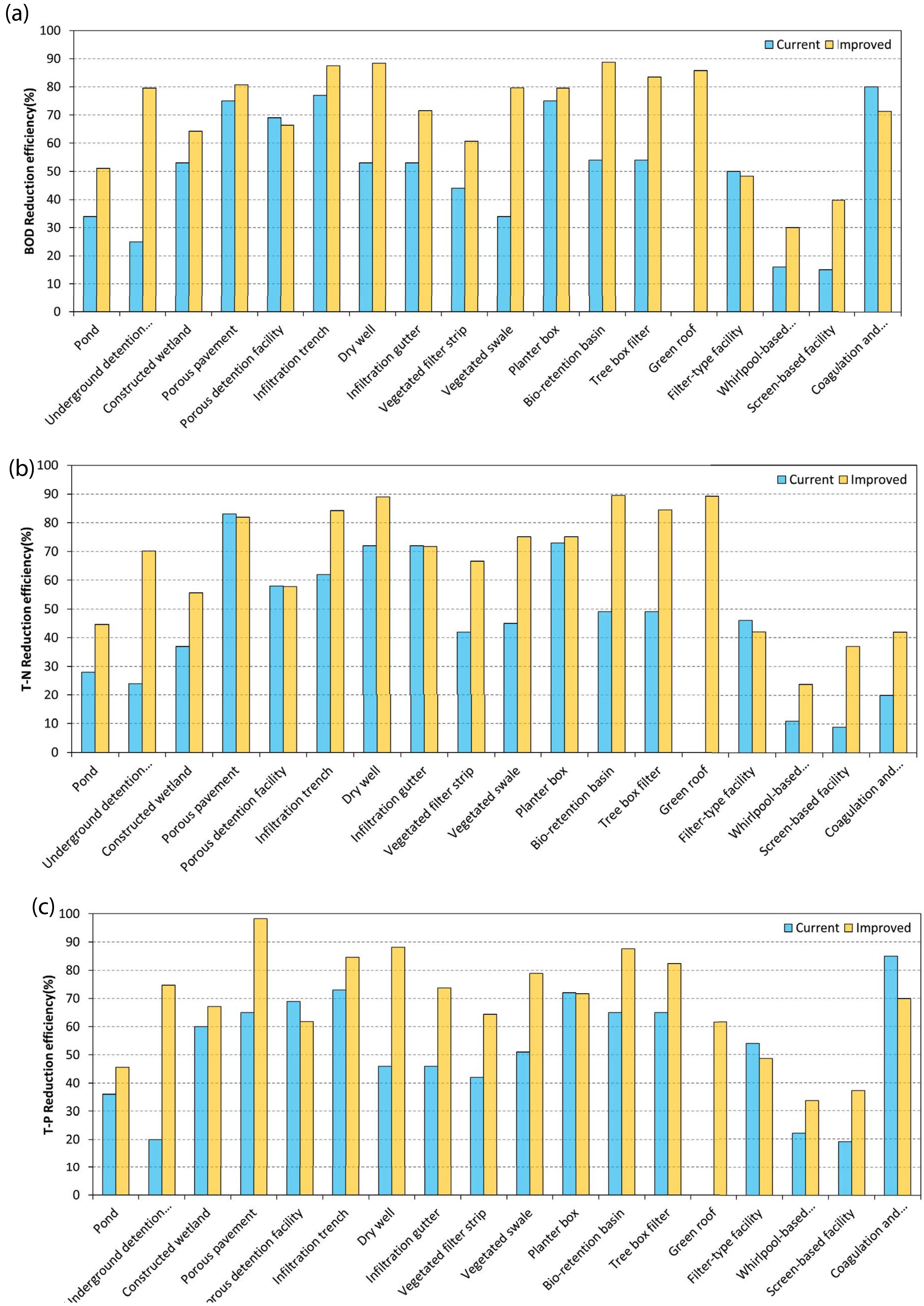



Fig. 9. Comparison between the present study and the TMDL guideline for the estimation method for the average pollutant load reduction efficiency: (a) BOD, (b) TN, and (c) TP.

In addition, since the some reduction efficiency in the NPS pollution reduction facilities derived in this study were rapidly increases compared with reduction efficiency recommended in the TMDL guideline, It may be necessary to apply the safety rate (10%~20%) to the reduction efficiency for stable operation of the TMDL system.

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