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Non-point sources of pollution from cultivated lands in river districts and their contribution to water bodies along the North Han River Basin in Korea

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ABSTRACT

Cultivated lands within the river district are likely non-point sources of pollution that could be directly discharged into rivers and lakes, as well as identified as significantly risky areas for pollutant run-off during floods. In this study, major non-point sources in surface run-offs, from cultivated lands within the river districts, and their effects on the bodies of water in North Han River Basin were examined. It was found that pollutant concentrations in the run-offs from farms appeared to be generally higher than in the run-offs from paddies. Initial concentrations of pollutants during rainy seasons were usually higher than the medians of their concentration ranges, though not necessarily the highest. The unit loads of BOD from cultivated lands within river districts, which were proposed in this study for the first time in Korea, were 4.56, 3.35, and 10.26 $kg/km^2/year$ for paddies, farms, and greenhouses, respectively. Likewise the unit loads of total nitrogen (TN) were proposed as 1.54, 8.11, and 5.59 $kg/km^2/year$ for paddies, farms, and greenhouse, respectively. Meanwhile, the unit loads of Total phosphorus (TP) were 0.71, 2.79, and 1.11 $kg/km^2/year$ for paddies, farms, and greenhouses, respectively. The unit loads for both BOD and TP from paddies and farms in the North Han River basin were higher than those provided by the Ministry of Environment. It was largely attributable to the regional characteristics of the cultivated area, within the river district, that is adjacent to the water system. Three priority standard watersheds, which were believed to contain higher non-point sources of pollution than other standard watersheds, were recommended to undergo restoration. The sum of the discharged total loads per unit area for BOD, TN, and TP from these three standard watersheds (i.e. NHR M2, NHR1, and NHR M) was 71.8, 71.5, and 73.0%, respectively. Restoring cultivated lands within river districts into grasslands could effectively reduce the total load of TP rather than BOD and TN. Therefore, converting cultivated lands within river districts back to grasslands can be an alternative in effectively reducing pollution in bodies of water.

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Keywords: Cultivated lands; River district; Unit loads for BOD; TN and TP; Non-point sources

1. Introduction

Cultivated lands within river districts are considered non-point sources of various pollutants that can be directly discharged into rivers and lakes. They should also be classified as significantly risky areas that could lead to a surface run-off during floods. In the United States alone, about 50% of pollutant loads in rivers are caused by non-point sources. Furthermore, it is estimated that more than 80% of excess nutritious substances are based on non-point sources in the case of closed waters. In Korea, when water management of the four major rivers began, the pollutant load of the non-point sources (based on BOD) accounted for 22–37% of the total loads in some watersheds.

The BOD loads by land use and the level of contribution were 18,097 tons/year (62%) in urban areas, 5,703 tons/year (20%) in forest/resort areas, and 5,285 tons/year (18%) in local paddies and dry fields, respectively, in the Paldang Watershed in Korea. In terms of total nitrogen (TN), the level of contribution of urban areas was more than 60%. Total phosphorus (TP) showed similar levels, regardless of the level of land use. In the meantime, the loads caused by the non-point sources of the total loads accounted for 37.8% (BOD), 38.4% (TN), and 18.5% (TP), respectively [1].

According to the US Environmental Protection Agency, excessive nutrients were the main causes of pollution in the watercourses and rivers throughout the United States. It is also reported that eutrophication, hypoxia, fish mortality, and toxic substances heavily affected the water quality of rivers and watercourses in the Southwestern United States, and the increase in the amount of nutrients introduced into the watercourses led to adverse effects [2]. According to the survey conducted in the Netherlands, agricultural activities contributed about 60% of the total TN load, and about 40–50% of the total TP load, which was mainly attributable to the chemical fertilizers used in farming. At present, political measures to reduce the use of chemical fertilizers are implemented in the Netherlands [3].

The non-point source loads flowing into the main channel from the tributaries of the rivers around Paldang Lake, which is located in the main channels of the Han River, were recently estimated. It was reported that the annual non-point source loads for BOD, TN, and TP accounted for about 61, 81, and 70% of the total loads that were introduced into the mainstream watersheds, respectively [4]. In order to enhance the water quality of the Han River, the South Korean government has invested more than three trillion won to water quality improvement projects since 2000, but has only slightly succeeded. In the study of the effect of financial investment on improving the water quality of the Han River Basin, which was published in 2006 by the Board of Audit and Inspection, state auditors pointed out the lack of consistency in government policies on riparian lands. To cite an example, the Ministry of Environment purchased cultivated lands around the Han River watershed in support of its policy to improve water quality in the region, but the Ministry of Land, Transport, and Maritime Affairs issued an occupancy permit to cultivate publicly owned lands, which ran contrary to the policy of the Ministry of Environment.

The major objectives of this study are to evaluate the content of non-point sources from cultivated lands within river districts and to delineate their contribution to the bodies of water along the North Han River Basin in Korea. Recommended unit loads of BOD, TN, TP, COD, and TSS from cultivated lands within river districts would be proposed for the first time in Korea to evaluate pollution loads that could be directly discharged into water system.

2. Material and methods

2.1. North Han River Basin

As a guide, the schematic diagram of the Han River Basin is shown in Fig. 1, and the general configuration of river districts defined throughout this study is shown in Fig. 2. The area of the North Han River Basin is 10,764.7 $km^{2,}$ with the main channel at 291.3 km long, constituting 41.3% of the entire river Basin area of the Han River that rises in Danbalryeong, which is located further on the upstream. The North Han River flows along many tributaries of Yangguseocheon (YGSC), Geumgangcheon, Suipcheon, Soyang River (SYR), Gapyeongcheon (GPC), and Hongcheon River (HCR), forming the Basin to flow down on the southern part of the river in the vicinity of Yangsuri, Gyeonggido, and flows and merges into Paldang Lake (PDL). Except for some of the flat areas in Gapyeonggun and Chuncheon, most rivers were in mountainous regions. In terms of the distribution of geological features,

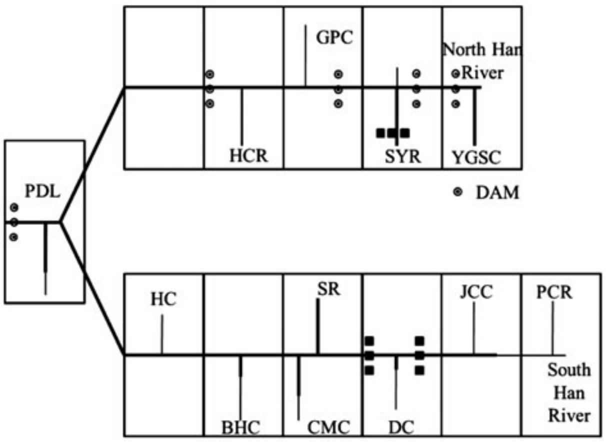

Fig. 1. Schematic diagram of the major tributaries in Han River Basin.

Precambrian gneisses were distributed in the western part of Chuncheon, Gangwondo, while gneiss, quartzite, and limestone were mainly distributed in the vicinity of Chuncheon and Yangsuri through Gapyeong.

YGSC, one of the tributaries of the North Han River is a mid-sized river with a main channel length of 57.9 km, while its watershed area is 600.8 km^2, which constitutes 5.6% of the entire river basin area of the North Han River. The watershed area of the SYR is 2,798.5 km^2, which constitutes 26.01% of the entire area of the North Han River. The SYR is a large river with a main channel length of 158.6 km, which rises in Musan, Injegun, Gangwondo, and flows through the Soyang River Dam, and further flows into the left side of the North Han River located in Chuncheon, Gangwondo.

2.2. Cultivated land DB on the basis of GIS

The distributed area of cultivated lands within the standard watersheds (discussed later in Section 3.1) in the North Han River Basin were calculated through an actual field survey on the cultivated lands by using the river district map of the Han River and the GIS-based DB construction system that was developed in this project.

High-resolution aerial images [5] were extended to a 1:1 scale for 50 cm photos, and were generated in images of larger pixel units. Through the generated image files, geo-referencing was performed, based on the digital map for the construction of a cultivated land DB. Next, screen digitizing was carried out, targeting the boundaries of the cultivated lands through the geo-referenced aerial photos, as shown in (a–c) of Fig. 3. Then, the cultivated land DB was constructed by dividing the targeted area into 37 compartments, ranging from N01 to N37, to facilitate a crop survey on the cultivated lands within the river districts in the mainstream of the North Han River, based on the aerial images using GIS, as shown in (d) of Fig. 3. For the survey on the status of cultivation, the forms of the cultivated lands located in the North Han River area were classified into three types: paddy, farm, and greenhouse.

2.3. Characteristics of conventional pollutants in a surface run-off from cultivated lands

In order to measure and survey the out-flow characteristics of major conventional pollutants in cultivated lands within the river district during rainfall, the research on non-point source pollutants was conducted, targeting the amount of run-off water

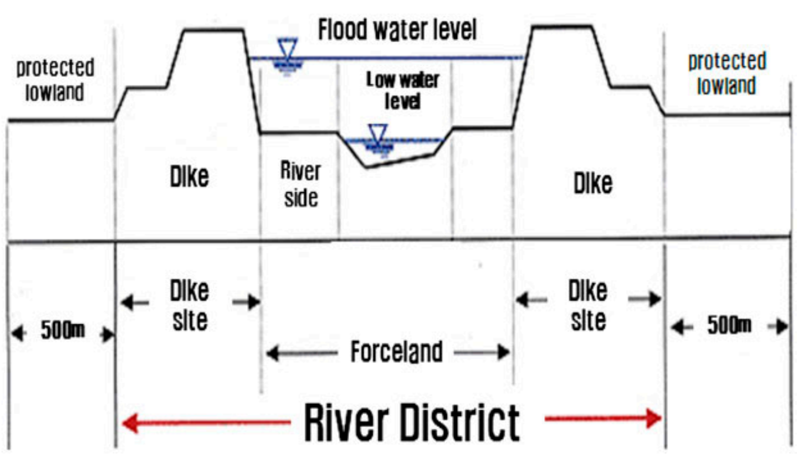

Fig. 2. Schematic diagram of the general river districts.

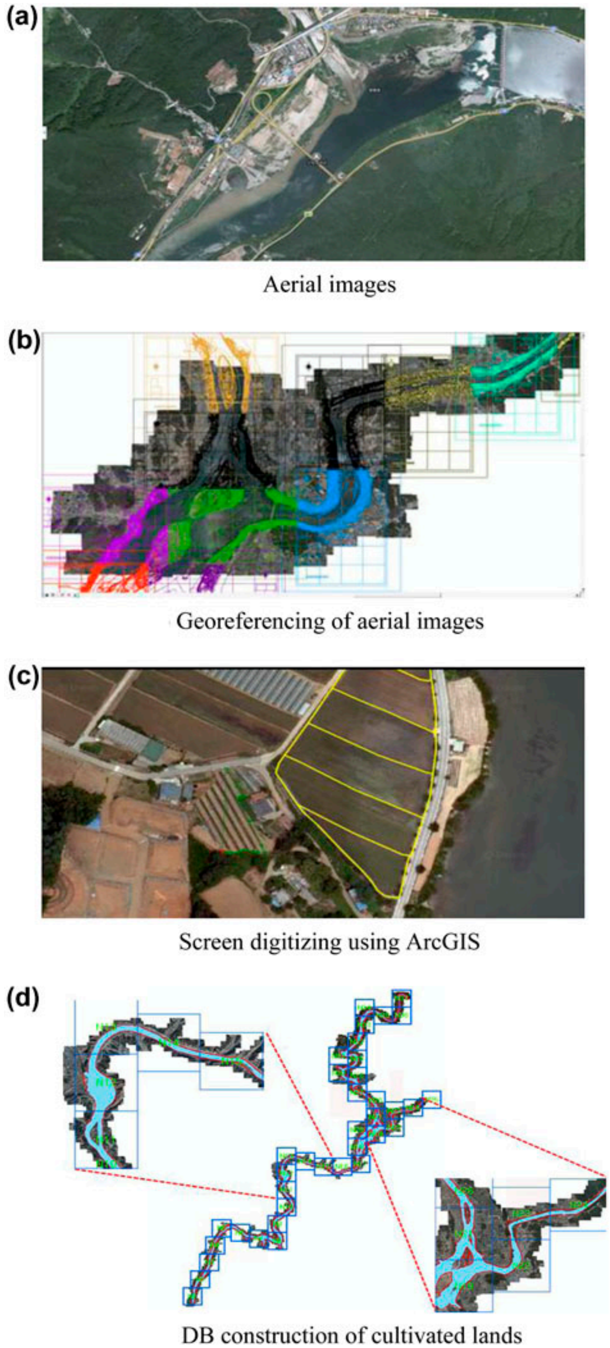

Fig. 3. Configuration of the cultivated land DB based on GIS.

introduced into the water system during rainfall after selecting the representative points by types of cultivation. In addition, precipitation, leakage flow rate, nutrients (TN and TP), organics (BOD and COD), and other constituents (TSS, water temperature, pH, and electrical conductivity) were analyzed to identify the run-off characteristics of the pollutants due to rainfall

Table 1
Location of the research area as representative control points

Location	Cropping	Area (ha)	Crop
N 37, 35´ 44´´	Paddy	0.24	Rice
E 127 20´ 20´´	Field (farm)	0.16	Corn, chili

on cultivated lands and crops. The exact location of the research areas that were selected as representative control points is shown in Table 1.

Two on-site inspections were performed, and four survey sessions regarding the run-off characteristics of the conventional pollutants were conducted in the region. In addition, a comprehensive inspection of the cultivated lands within the river districts was performed six times. Specimens were extracted from the rainfall with a total precipitation of more than 10 mm to ensure that the research target could cause a run-off of the pollutants in the cultivated lands. A sample extraction was performed, targeting a single raindrop of at least 10 times until the end of the rainfall (or run-off) to enhance the reliability of the data analysis in calculating the polluted loads and the event mean concentration (EMC). The sample extraction was performed most frequently in the initial stage of the rainfall run-off so that the first flush of the run-off phenomena could also be analyzed. The specimens were measured 7 times in 10 min intervals of up to one hour from the time of the run-off after the start of the rainfall, two times at 30 min intervals after one hour, two times at one-hour intervals afterward, and two times at two-hour intervals until the end of the run-off. For the sample collection, the run-off water overflowing from the weir was directly extracted.

In this study, the amount of rainfall was measured by using the HOBOs Data Logging Rain Gage Onset Model No. RG2M. This equipment was a tipping bucket rain gage for measuring precipitation by the number of the conduction of the magnetic switch with the weight of the rainfall. Rainfall intensity was calculated in one minute unit, using the software program, BoxCar Pro 4. To measure the flow rate, the right-angled triangular weir was installed in the on-spot measurement point, and the water level was measured through minute average data after obtaining data at 15 s intervals by using the Eijkelkamp's MiniDiver water gage. The value corresponding to the water level was acquired after correcting the atmospheric pressure through an additional installation of the water gage for a more accurate atmospheric pressure calibration. The flow rate was calculated by using the following equation, in accordance with the format of the installed triangular weir, and water level was measured at the representative points.

$$Q = 2.361 \times (0.565 + 0.0087/H^{1/2}) \times H^{5/2} \quad (1)$$

where Q: Flux (m^3/s), H: Water level (m).

2.4. Assessment of unit loads from the cultivated lands within the river districts

The calculation standards for unit loads can be usually divided into the production standard based on the amount produced in the land-use unit within the unit time, the run-off standard based on the discharged load after production, and the transfer rate standard based on the load of the transferred non-point source pollution to specific points. In this study, the unit load was estimated based on the run-off load of the non-point source pollution during rainfall, which was applied to the non-point pollutant unit load. The non-point pollutant unit load is known as the contaminant mass discharged from one unit land area within one unit time in units of mass (kg or ton)/area (ha or km^2)/time (d or year).

In the non-point source model, a variety of equations for unit load that consider land-use characteristics, soil properties, and hydrological information have been suggested. The current calculation methods of unit load involve empirical formulas and an actual measurement of the flow rate and polluted loads in the applicable watersheds for estimation. The unit load (pollutant load per unit area) was calculated by targeting BOD, COD, TSS, TN, and TP, and, by using the calculated unit load, pollutant loads discharged from the cultivated lands within the river district to the mainstream of the Han River were estimated. In addition, a comparative analysis between the actual measurement data and the unit loads by land-use, which was provided by the Ministry of Environment, was also carried out.

In order to determine the concentrations of the discharged pollutants in this study, the pollutant loads and the amount of rainfall run-off by land-use were measured, and to identify the interrelationships, various regression equations, involving flow rate, precipitation, and discharged amount of pollutants, were utilized. However, with no long-term data available, the annual non-point source pollution unit load was estimated, based on the annual rainfall and the amount of run-off using actual measurement data on the precipitation, run-off, and concentrations of pollutants, as shown in Eq. (2) (A Basic Plan for the Optimal Management of Non-point Source Pollution in Paldang Water Supply and a Report on the Feasibility Study, the Ministry of Environment, 2000). The average annual rainfall was obtained from the mean value (1,321 mm) of the total annual rainfall from 2003 to 2008, as measured by the Jinjeop observation station in Namyangju.

$$\text{Unit load (kg/km}^2\text{ year)} = \sum C_t Q_t \Delta t / A \cdot \sum Pi/Pi \quad (2)$$

where C_t: The concentration of the run-off at the time t toward the applicable rainfall (mg/L), Q_t: Run-off flow at the time t toward the applicable rainfall (m^3/min), A: Watershed area (km^2), Δt: Measurement interval (min), $\sum Pi$: Average annual rainfall (mm/year), and Pi: The total rainfall of the applicable rainfall event (mm).

3. Results and discussion

3.1. Agricultural practices in the North Han River Basin

Land use along the river districts in the North Han River Basin was surveyed, based on the distribution of cultivated lands within the river districts, by selecting 22 standard watersheds through the GIS-based DB. The survey showed that forests, such as mixed forests, deciduous forests, and coniferous forests, were mainly distributed in the North Han River Basin, as shown in the left side of Fig. 4. The land-use area had 4,365.91 km^2 of mixed forests, 2,834.31 km^2 of deciduous forests, and 2,470.69 km^2 of coniferous forests, while the total size of the cultivated lands included 318.35 km^2 of paddies and 287.56 km^2 of fields (farms and greenhouses).

The status of the cultivated lands within the river districts of the North Han River Basin is shown in Table 2. The administrative districts within the standard watersheds in the North Han River Basin include Namyangjusi (NYS), Yangpyeonggun (YPG), Gapyeonggun (GPG), Chuncheonsi (CCS), and Hwacheongun (HCG). The total cultivated area within the river districts was 0.4816 km^2; broken down into 0.2558 km^2 (51.3%) of paddies, 0.1794 km^2 (37.3%) of farms, and 0.0464 km^2 (11.4%) of greenhouses. It should be noted that 81% of the total cultivated land in the river district in HCG were paddies, the highest percentage among the five administrative districts.

There were 11 standard watersheds (identification codes: NHR1, NHR M, NHR M1, NHR M2, NHR M3, NHR M15, NHR M16, NHR M19, NHR M20, SYR3, and PMC) with cultivated lands among a total of 22 standard watersheds, as shown in Fig. 6. In the

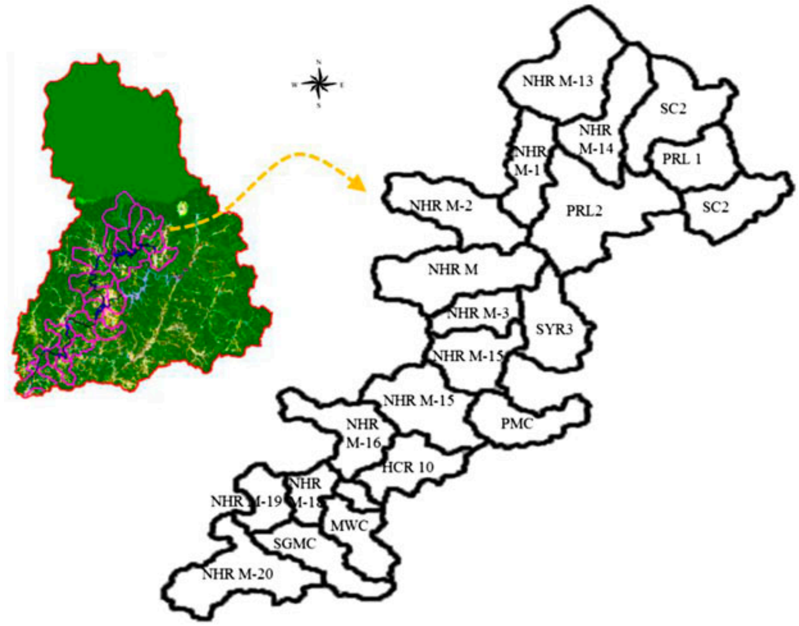

Fig. 4. Location of 22 standard watersheds in the North Han River Basin.

Table 2
The area of cultivated lands within the river districts of the North Han River Basin

Admin. districts	Paddy (km^2)	Field (km^2)		Total (km^2)	%
		Farm	Greenhouse		
NYS	0	0.0005	0	0.0005	0.1
YPG	0.0107	0.0256	0	0.0363	7.5
GPG	0.0040	0.0092	0	0.0132	2.7
CCS	0.0860	0.1313	0.0227	0.2399	49.8
HCG	0.1551	0.0128	0.0237	0.1916	39.8
Total	0.2558	0.1794	0.0464	0.4816	100.0

mainstream of the North Han River 2 (NHR M2), the percentage of the paddies was relatively high, but the percentage of the fields was rather high in the standard watershed of the North Han River 1 (NHR1). The areas of the cultivated lands (i.e. paddies, farms, and greenhouses) within the river districts of the 11 standard watersheds are shown in Fig. 5.

The results of the full survey of cultivated crops in the areas within the river districts show that the most common field crops were corns, bellflowers, potatoes, pepper, and cucumbers. Meanwhile, pepper, watermelons, and cucumbers were cultivated in greenhouses. It is noted in this study that the annual cultivation rotation of the crops were between 3 and 6 months within the river districts.

3.2. Non-point source pollutants in the surface run-off from the cultivated lands within the river district

The characteristics of rainfall based on the field survey conducted on the run-off of the cultivated lands in the North Han River basin are shown in Table 3. Total precipitation ranged from 19.6 to 208.8 mm, while rainfall duration ranged from 1.0 to 14.9 h, and the number of antecedent dry period ranged from 2 to 7 d in this field survey.

The initial concentrations and ranges of the concentrations of the pollutants by incidence of rainfall are shown in Table 4. Generally, pollutant concentrations in the run-offs from the field (farm) appeared to be higher than those in the run-offs from the paddy (see Table 1 for the location). The initial concentrations

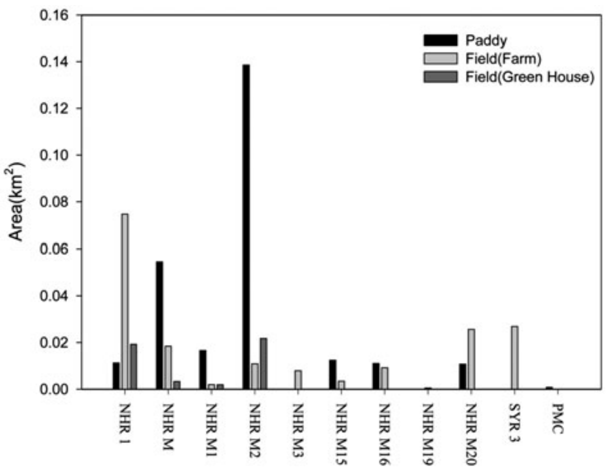

Fig. 5. Area of cultivated lands within the river districts in 11 standard watersheds.

of the pollutants were usually higher than the medians of their concentration ranges, but were not necessarily the highest in their ranges. However, it is noted that the initial concentrations of TP, BOD, COD, and TSS were the highest in their ranges, except the initial concentration of TN on June 9, 2009. The BOD concentrations, when compared to COD concentrations, were relatively low in the 1st and 2nd run-offs.

These low BOD concentrations indicated that the 1st and 2nd run-offs might contain relatively low biodegradable organic matters, but the specific reason for this low BOD would not be clear. It seems necessary but difficult to delineate a proper correlation between pollutant concentrations and rainfall durations (or previous dry weather days) during rainfall with these limited data, which were obtained throughout this study.

Table 3
Characteristics of the rainfall events under investigation

Date	6/9/2009 (1st)	7/9/2009 (2nd)	7/17/2009 (3rd)	8/20/2009 (4th)
Total rainfall (mm)	19.6	208.8	97.0	38.6
Rainfall duration (h)	4.7	14.9	5.5	1.0
Previous dry-weather day (d)	7	6	2	7

Table 4
Concentrations (mg/L) of major conventional pollutants in the run-offs from paddies and fields (farms)

		Paddy		Field (farm)	
Date	Constituents	Concentration range	Initial concentration	Concentration range	Initial concentration
6/9/2009 (1st)	TN	3.0–4.6	3.8	–	–
	TP	1.20–2.83	2.83	–	–
	BOD	1.0–5.0	5.0	–	–
	COD	10.5–16.7	16.7	–	–
	TSS	9.5–14.7	14.7	–	–
7/9/2009 (2nd)	TN	1.0–3.6	3.0	20.2–93.0	36.2
	TP	0.30–3.75	3.75	11.9–29.4	11.9
	BOD	–	–	0.1–5.2	2.9
	COD	4.2–15.3	14.7	32.6–39.8	35.6
	TSS	6.4–155.0	155.0	331.0–2,137.0	1,174.5
7/17/2009 (3rd)	TN	0.6–4.7	1.9	7.0–32.5	15.5
	TP	0.35–2.50	1.65	1.20–14.10	11.10
	BOD	0.40–6.80	2.3	2.4–7.3	6.0
	COD	6.2–12.0	9.8	29.8–76.7	69.3
	TSS	11.0–96.6	67.0	313.0–2,917.0	2,077.0
8/20/2009 (4th)	TN	0.8–2.4	2.4	5.5	5.5
	TP	0.23–0.35	0.30	2.36–2.48	2.36
	BOD	5.8–9.8	7.6	15.5–16.6	15.5
	COD	8.7–13.7	12.6	66.3–67.0	67.0
	TSS	65.0–223.0	223.0	2,119.5–2,333.0	2,119.5

3.3. Estimation of unit loads from cultivated lands within the river districts

The unit loads were estimated based on the EMC formulated in the field survey. Table 5 shows the estimated unit loads in this study (indicated as Unit loads within river district in Table 5), together with the unit loads provided by the Ministry of Environment, which show those unit loads according to the classification of land use (Guidelines for establishment of plans for the polluted load management of the Han River Basin, Revised plan, the Ministry of Environment, February 2009). Any unit load for paddy, farm, and greenhouse within the river districts has neither been studied systematically nor been proposed in Korea prior to this study. The proposed unit loads, which can be used exclusively to estimate total loads from the cultivated lands within river districts, appeared to be the landmarks for watershed management in the future. It should be noted that the total loads estimated on the basis of these unit loads were apparently the total loads which assumed that 100% of the generated loads would be introduced into the bodies of water. It may be known that the unit loads provided by the Ministry of Environment can be applicable in generally estimating the total load. However, the unit loads shown in this study can be used only for the total load estimation from cultivated lands within river districts. As shown in the table below, the unit loads for BOD and TP from paddies and farms in the North Han River Basin were higher than those provided by the Ministry of Environment because of the regional characteristics of the cultivated area within the river district adjacent to the water system.

3.4. Assessment of total loads per unit area for standard watersheds

The 11 standard watersheds, which have cultivated lands within the river districts, were initially considered in this study in order to select the priority standard watersheds to manage the total loads in the North Han River basin. The total load for each constituent from the cultivated lands within the river districts in the standard watershed was initially calculated by multiplying each area of the paddy, farm, and greenhouse by the proposed unit loads, as shown in Table 5. The total load for each constituent in the cultivated lands flowing out of the river districts in the standard watershed were also calculated by multiplying each area of the paddy, farm, and greenhouse by the unit loads provided by the Ministry of Environment, also shown in Table 5. Then, the total loads per unit area of BOD, TN, and TP were calculated for each standard watershed by dividing the sum of the two total loads by the entire area of each standard watershed. The results of the assessment of the total loads per unit area for BOD, TN, and TP, as mentioned above, are shown in Fig. 6.

As indicated in Fig. 6, the highest total loads per unit area of BOD in descending order were 1.2449, 0.7867, and 0.4202 kg/km^2/year for the mainstream of the North Han River 2 (NHR M2), the North Han River 1 (NHR1), and North Han River (NHR M), respectively. The highest total loads per unit area of TN in descending order were 4.2891, 4.0843, and 1.4760 kg/km^2/year for NHR1, MHR M2, and NHR M, respectively. The total loads per unit area of TP in descending order were 0.3100, 0.1313, and 0.1009 kg/km^2/year for NHR M2, NHR 1, and NHR, respectively.

In Fig. 6, the sum of the discharged total loads per unit area for BOD, TN, and TP from these three standard watersheds (i.e. NHR M2, NHR1, and NHR M) accounted for 71.8, 71.5, and 73.0% of the sum of the discharged total loads per unit area from the 11 standard watersheds under this study, respectively. The total loads of the standard watersheds, namely, NHR M2, NHR1, and NHR M, appeared to be the major

Table 5
Assessment of the unit loads from the cultivated lands

	Unit loads within river district[1] (kg/km^2 d)			Unit loads for status of land use[2] (kg/km^2 d)		
Constituents	Paddy	Field (Farm)	Field (Greenhouse)	Paddy	Field (Farm)	Field (Greenhouse)
TSS	53.67	572.45	54.8	–	–	–
BOD	4.56	3.35	10.26	2.30	1.60	–
COD	7.84	23.94	16.00	–	–	–
TN	1.54	8.11	5.59	6.56	9.44	–
TP	0.71	2.79	1.11	0.61	0.24	–

[1]Unit loads only for typical cultivated lands within river districts.
[2]Provided by the Ministry of Environment (February 2009).

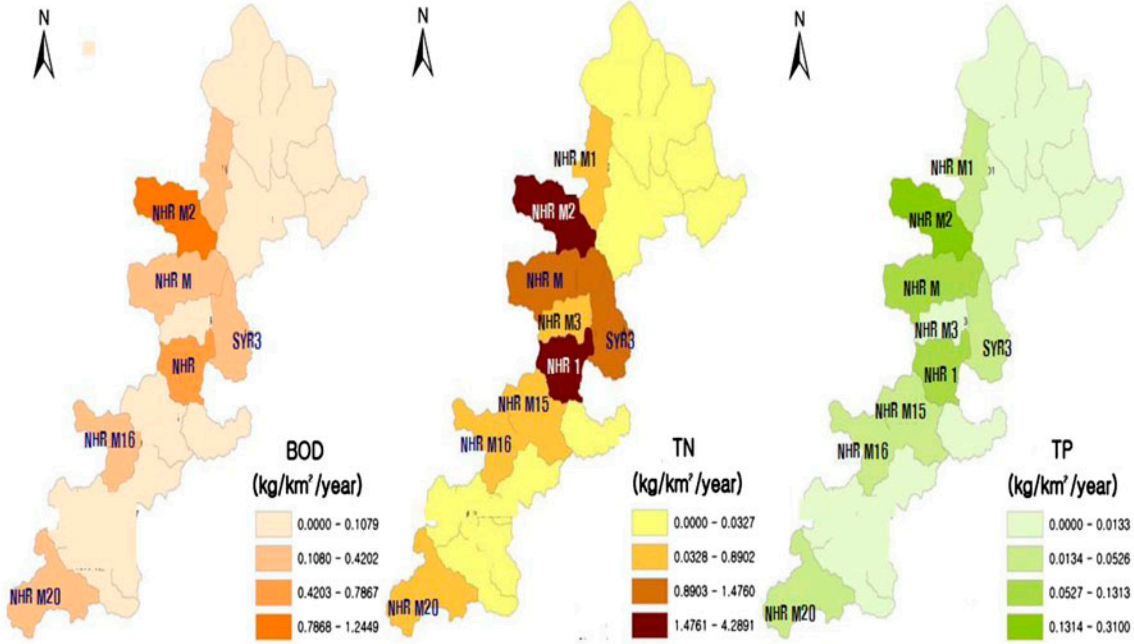

Fig. 6. Total loads per unit area for BOD, TN, and TP in the 11 standard watersheds.

non-point sources in the North Han River basin, which apparently were adjacent to the mainstream of the North Han River.

3.5. Assessment of total loads in the standard watersheds

The total loads from the cultivated lands (A) within the river districts in the 11 standard watersheds were estimated as shown in Table 6, on the basis of the unit loads (Table 5) proposed in this study. The total loads from the entire cultivated lands (B) in the 22 standard watersheds near the mainstream of the North Han River were also estimated, as shown in Table 6, using the land-use data of the standard watersheds in the North Han River and the unit loads described in the Water Pollution Load Management Guidelines (Ministry of Environment, 2008). The total loads for BOD, TN, and TP are shown in Table 6. There was a big difference in the total loads in units of kg/year between the total loads from cultivated lands within the river districts in the 11 standard watersheds and the total loads from cultivated lands in the 22 standard watersheds. This was primarily due to the areas of concern (0.4816 km^2 for A and 1,882 km^2 for B), as shown in Table 6. The total loads of BOD, TN, and TP from the paddy, farm, and greenhouse are also shown in detail in Table 7, which will be discussed later. The total loads of BOD and TN per unit area (1,700 and 1,598 $kg/km^2/year$) from cultivated lands within the river districts were about 40.8 and 44.0% higher than the cultivated lands from a total of 22 standard watersheds (1,207 and 1,110 $kg/km^2/year$), respectively.

Table 6
Total loads and total loads per unit area from Area A and B

Area classification	Area (km^2)	Constituents	Total loads (kg/year)	Total load per unit area ($kg/km^2/year$)
A	0.4816	BOD	818.8	1700
		TN	796.5	1598
		TP	267.8	556
B	1882	BOD	2270900	1207
		TN	2088970	1110
		TP	151290	80.4

Note: A: cultivated lands only within the river districts in the 11 standard watersheds; and B: cultivated lands in the 22 standard watersheds.

Table 7
Total loads from the cultivated lands within river districts and their reduction through restoration to grasslands

			Cultivated lands		Grasslands after restoration	
Constituent	Land use	Area (km^2)	Total load per unit area (kg/km^2/year)	Total load (kg/year)	Total load (kg/year)	Reduction (%)
BOD	Paddy	0.2558	1,664	425.8	84.0	80.3
	Field (Farm)	0.1794	1,223	219.4	58.9	73.2
	Field (Greenhouse)	0.0464	3,745	173.6	15.2	91.2
	Total	0.4816	1,700	818.8	158.1	80.7
TN	Paddy	0.2558	562	143.8	70.9	50.7
	Field (Farm)	0.1794	2,960	531.1	49.7	90.6
	Field (Greenhouse)	0.0464	2041	94.6	12.8	86.4
	Total	0.4816	1,598	769.5	133.4	82.7
TP	Paddy	0.2558	259	66.3	2.5	96.2
	Field (Farm)	0.1794	1,018	182.7	1.8	99.0
	Field (Greenhouse)	0.0464	406	18.8	0.5	97.3
	Total	0.4816	556	267.8	4.8	98.2

However, the total load of TP per unit area (556 kg/km^2/year) from cultivated lands within the river districts were about 7 times higher than that (80.4 kg/km^2/year) from cultivated lands in the total of 22 standard watersheds. The reason for this very high total load of TP per unit area was unclear, and might be due to agricultural practices in the region. It should be further investigated.

3.6. Reduction of total loads by restoring cultivated lands to grasslands

In the agricultural river watershed, the transport of non-point source pollution is mainly caused by the outflow of the run-off and sedimentation [6]. The transport and deposition phenomena of various pollutants, eroded materials, dissolved and attached substances lead to serious damage in the agricultural soil and water environment, such as soil, erosion, and eutrophication [7,8]. Generally, these phenomena have intensified through changes in land use, such as cultivation of forest resources to arable land. Various programs have been widely used to manage watersheds. These programs include conservation tillage practice, conservation reserve program practices, such as grass filter strips and riparian buffers, and the so-called "Converting Cropland to Forest Land Program" [9–11]. Once these programs are found suitable to local conditions, they can be utilized to attain sustainable agricultural management and conservation, as well as reduce sediment and pollutant loss in agricultural areas [12].

In this study, the total loads of BOD, TN, and TP from cultivated lands within the river districts were estimated again to see if the cultivated lands can possibly be converted and restored to grasslands. The unit loads according to the classification of land use (Guidelines for the establishment of plans for the polluted load management of the Han River basin, Revised plan, the Ministry of Environment, February 2009) were again applied for this estimation: 0.96 kg/km^2/d for BOD, 0.759 kg/km^2/d for TN, and 0.027 kg/km^2/d for TP. As shown in Table 7, the total loads of BOD of 818.8 kg/year could be reduced to 158.1 kg/year, indicating a reduction of 80.7%. The total loads of TN of 769.5 kg/year could be also reduced to 133.4 kg/year, or a reduction of 82.7%. The total loads of TP of 267.8 kg/year could be also reduced to 4.8 kg/year, or a reduction of 98.2%. The restoration of the cultivated lands within river districts to grasslands could effectively reduce the total load of TP, compared to those of BOD and TN. Therefore, the conversion of cultivated lands within river districts back to grasslands can be an alternative to effectively reduce water pollution.

4. Conclusions

Major non-point sources of pollution in the surface run-offs from cultivated lands within the river districts and their contribution to the bodies of water in the North Han River Basin were the focus of this study. After careful analysis, it was found that pollutant concentrations in the run-offs from the field (farm) were generally higher than those in the run-offs from the paddy. Furthermore, initial concentrations of pollutants during incidences of rainfall were usually higher than the medians of their concentration ranges, though they were not necessarily the highest in their ranges. The unit loads of BOD from cultivated lands within river districts, as proposed in this study for the first time in Korea, were 4.56, 3.35, and 10.26 kg/km^2/year for paddies, farms, and greenhouses, respectively, while the unit loads of TN were 1.54, 8.11, and 5.59 kg/km^2/year for paddies, farms, and greenhouses, respectively, and the unit loads of TP were 0.71, 2.79, and 1.11 kg/km^2/year for paddies, farms, and greenhouses, respectively. It should be noted that the unit loads for BOD and TP from the paddies and farms in the North Han River Basin were higher than those provided by the Ministry of Environment due to regional characteristics of the cultivated area within the river district adjacent to the water system. Three priority standard watersheds, which supposed to contain higher non-point sources than other standard watersheds, were proposed for restoration. The sum of the discharged total loads per unit area for BOD, TN, and TP from these three standard watersheds (i.e. NHR M2, NHR1, and NHR M) accounted for 71.8, 71.5, and 73.0% of the standard watersheds under this study, respectively. Upon the assessment of the total load reduction that the restoration of cultivated lands within river districts to grasslands could effectively reduce the total load of TP rather than those of BOD and TN, such restoration or conversion can be a viable alternative to reduce the pollution load to the bodies of water along the North Han River Basin.

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