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Characteristics of non-point source pollutants on a railway bridges

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ABSTRACT

The railway industry is receiving more attention these days in accordance with the high technologies being introduced into the industry. However, the research on the railway facilities has been inadequate. The interest on non-point source pollution is increasing in an effort to protect the quality of the water system. In this study, the data of the concrete road-beds on railway bridges, the runoff characteristics, event mean concentration (EMC), and pollutant load per unit area were assessed. The railway bridge concrete road-bed areas typically show the first-flush effect, whereas the railway bridge gravel road-bed areas show a two-peak effect on the runoff characteristics of non-point source pollution. The pollutant unit load and EMC in the concrete road-bed areas have also been found to be higher than those in gravel road-bed areas. The pollutant load per unit area around railway facilities shows more non-point source pollutants than other areas. The values of heavy metals and oil and grease (O&G) pollutants more washed out than heavy metals and O&G pollutants in the pavement and urban areas. The non-point source pollutants are the main type of the pollutants around the railway facilities. In order words, it is necessary to control non-point source pollution in the railway-bridge gravel road-bed areas.

Keywords: Non-point source pollution; Railway; Concrete road-bed; Gravel road-bed; Heavy metal; Oil and grease

1. Introduction

The railway industry in South Korea has received much attention due to its high-tech transportation and its ability to make effective use of a limited land area. With continues government support and private investment, development of railway industry is rapidly increasing. The status of railways, serving as an excellent means of mass transport that is also stable, economic, energy efficient and eco-friendly, is improving compared to other forms of transportation such as automobiles and air travel [1,2]. But railway of eco-friendly transportation system is not considering about that effect of non-point source pollution from railway facilities. In case of Seoul in South Korea, total 20 railway bridges were located. Most of railway bridges in the Seoul were pass through or nearby located the Han-river. In addition, nearby the Pal-dang dam area, most of railway bridges were located near the water system. In railway bridges, commonly located near rivers, non-point source pollutants are washed out directly into the water system.

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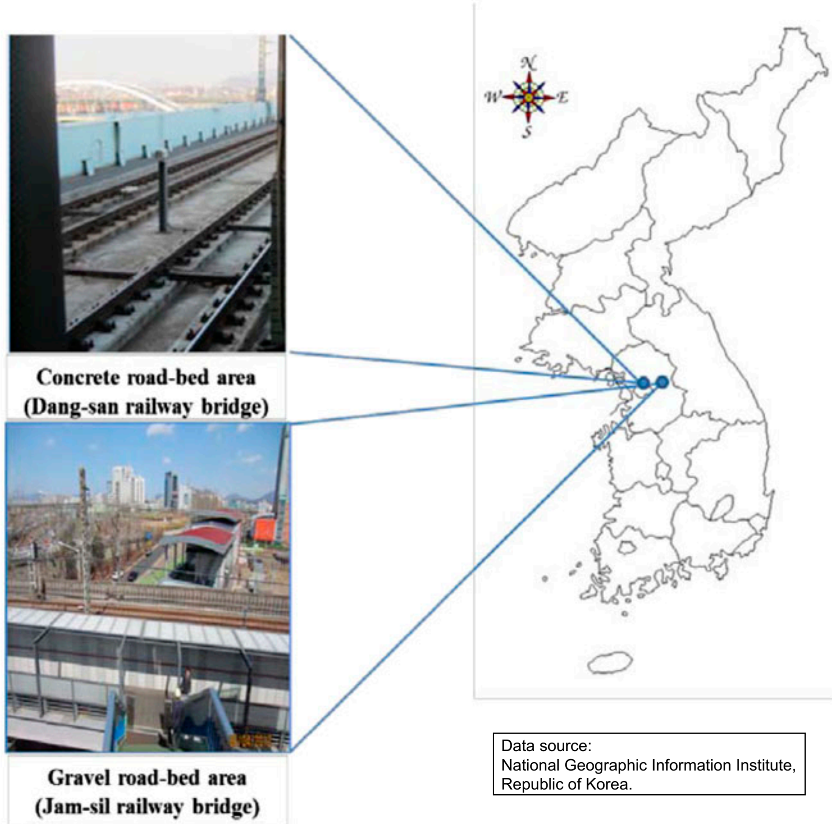

Fig. 1. Map showing the monitoring sites (source of a blank map of Korea: http://www.ngii.go.kr/child/contents/contentsView.do?rbsIdx=33).

Point source management is achieved by continued interest and effort related to the management of water system and the quality of water. However, in spite of these efforts, research continues on the water quality of lakes and rivers [3–5]. Because our comprehension and thus management of non-point source pollution are immature, non-point source pollution is allowed to flow into water systems [6–8].

Non-point source pollution has attracted widespread attention in the important field of management of water systems and water quality. Non-point source pollution washes out into the water system through undefined routes, in direct contrast to point source types of pollution. Therefore, the causes of this type of pollution are difficult to calculate and determine, as are the generated amounts [9–11]. Most non-point source pollution reportedly flows into the water system with rainfall runoff. In a 2005 announcement in South Korea, the pollution load caused by non-point source pollution at Pal-Dang lake is 44.5%, whereas at the Guem River and the Sumjin River the amounts were 36.8 and 48.5%, respectively. As a result, social interest in the study and management of non-point source pollution is increasing rapidly, as it accounts for 40–70% of water system and water pollution [12].

The necessity for research on the environment is becoming more emphasized with the increasing growth in the railway industry. However, researches on railway environments have been limited to related fields, i.e. noise and vibration, safety, and conformability. Therefore, interest in the surrounding environment is

Table 1
Characteristics of the monitoring sites

Characteristics of concrete road-bed area	
Location	Dang-san dong, Yeongdeungpo gu, Seoul, South Korea (Dang-san railway bridge)
Size (m^2)	306 m^2
Land-use	Concrete and reinforced
Characteristics of gravel road-bed area	
Location	Shin-chun dong, Songpa gu, Seoul, South Korea (Jam-sil railway bridge)
Size (m^2)	168 m^2
Land-use	Gravel, concrete and reinforced

Table 2
Event table for monitored events

No.	Event date (yy/mm/dd)	ADD (d)	Total rainfall (mm)	Duration time (h)	Average rainfall intensity (mm/h)
1	2012/04/21	9	56.5	36	1.6
2	2012/05/15	10	6.5	6	1.1
3	2012/06/29	20	89.5	15	5.9
4	2012/07/05	2	174.5	38	4.6
5	2012/09/13	4	15.5	10	1.6
6	2012/10/27	4	44.0	14	3.1
7	2013/05/18	5	34.0	17	2.0
8	2012/05/27	7	68.0	31	2.2
9	2013/06/17	4	12.5	24	0.5
10	2013/07/02	3	43.5	13	3.3
11	2013/07/27	2	14.7	19	0.77

increasing rapidly in an effort to improve the living standards of people. Some research results have discussed to occur pollutants when repairing railway lines and railway vehicles such as organic carbon, nutrient, heavy metals, and oils [13,14]. These pollutants have high possibility about washed out to water system during rainfall event. But these pollutants (non-point source pollutants) aren't considering in railway environment. Because, researches non-point source pollution in railway bridges have not been fully conducted.

In this research, rainfall monitoring was performed in a railway bridge area. Based on the result, the characteristics of non-point source pollutants, event mean concentration (EMC) the pollutant load per unit area and unit pollutant load are analyzed. Also, the

Table 3
Event table of the runoff characteristics

	Concrete road-bed runoff type (event number)				
Parameter	(a)	(b)	(c)	(d)	(e)
COD	1,2,3,4,5,6,7,8,9,10,11				
BOD	1,2,3,4,5,6,7,8,9,10,11				
TN	1,2,3,4,5,6,7,8,9,10,11				
TP	1,2,3,4,5,6,7,8,9,10,11				
Cu	4,5,10	3,6,7		1,2,8,9,11	
Cd	1,2,3,4,5,6,7			8,9,10,11	
Pb	1,2,3,4,5,6,7			8,9,10,11	
O&G	1,2,3,4,5,6,7,10			8,9,11	
Total	69	3		16	
	Gravel road-bed runoff type (event number)				
Parameter	(a)	(b)	(c)	(d)	(e)
COD	5	6			1,2,3,4,7,8,9,10,11
BOD	2,5,6,7,8				1,3,4,9,10,11
TN	2,6,7,8	5			1,3,4,9,10,11
TP	6,7,8				1,2,3,4,5,9,10,11
Cu	5,11	2,6		4	1,3,7,8,9,10
Cd				1,2,4,5,6	3,7,8,9,10,11
Pb	1,2,9,10		4,5	3,6	7,8,11
O&G	4,5,6	1,3,7,8		2,9,10	11
Total	22	8	2	11	45

characteristics of the railway bridge area were analyzed in terms of the pollutant load per unit area compared to that in other areas in which were checked in earlier research.

2. Experimental methods

2.1. Monitoring sites and method

The monitoring sites in this study are shown in Fig. 1 and the characteristics of the monitoring sites are shown in Table 1. The water discharge areas are a concrete road-bed area in Dang-san dong, Yeongdeungpo gu, Seoul, South Korea (Dang-san railway bridge) and a gravel road-bed area in Shin-chun dong, Songpa gu, Seoul, South Korea (Jam-sil railway bridge). The site sizes are 306 m^2 (concrete road-bed area) and 168 m^2 in the gravel road-bed area. Sampling and sampling intervals were determined by turbidity concentrations [15,16]. To measure the flow rates, a direct measuring method was used. Monitored samples were immediately moved to a laboratory after a rainfall event. All pollutants were analyzed according to Standard Methods [17].

2.2. Calculation of the rainfall EMC and pollutant unit load

The EMC is calculated by dividing the total amount of the pollutant mass during a total rainfall runoff time by the total amount of runoff volume during the total rainfall runoff time. The EMC can be expressed by Eq. (1). The pollutant unit load is important when calculating the pollutant load. The pollutant unit load can be expressed by Eq. (2). The calculation of the pollutant unit load uses the average EMC (calculated by Eq. (1)), the effective rainfall and the size of the area.

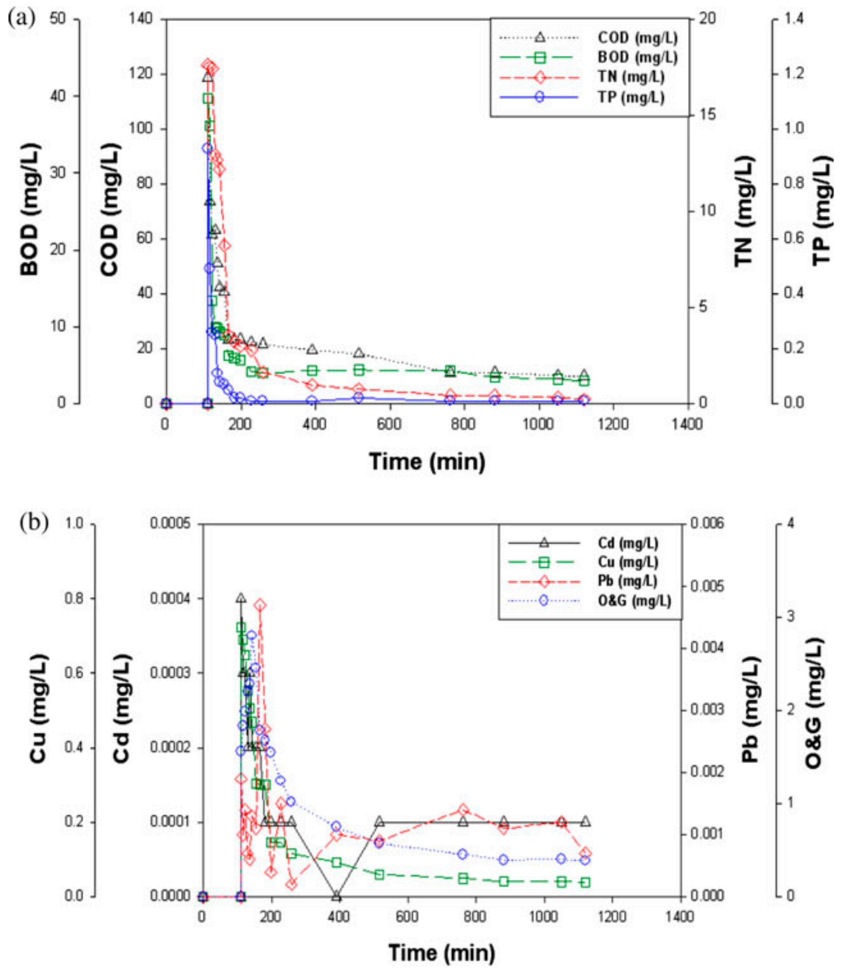

Fig. 2. Polluto-graphs of monitored event seven in the concrete road-bed area (a): COD, BOD_5, TN and TP, (b): Cd, Cu, Pb and O&G.

$$\text{EMC (mg/L)} = \frac{\text{Discharged mass during an event}}{\text{Discharged volume}}$$

$$= \frac{\int_0^t c(t) \times q(t)\mathrm{d}t}{\int_0^t q(t)\mathrm{d}t} \tag{1}$$

$$\text{Pollutant Unit Load (kg/km}^2 - \text{year)} = \frac{\text{EMC} \times \text{ Total yearly effective rainfall}}{\text{Area of catch basin}} \tag{2}$$

3. Results and discussion

3.1. The results of monitored rainfall events

A total of 11 rainfall events were monitored during two years, from 2012 to 2013. The results of these events are shown in Table 2. Antecedent dry days (ADD) range from 2 to 20 d, the total rainfall amount is 6.5–174.5 mm, the runoff duration time is 6.0–38.0 h, and the average rainfall intensity is 0.5–5.9 mm/h.

3.2. Runoff characteristics of NPS

A polluto graph representing the characteristics of the concrete road-bed area is shown in Fig. 2. This polluto graph is for rainfall event seven (18 May 2013), clearly showing the runoff characteristics of the concrete road-bed area (the Dang-san railway bridge). Shown in Fig. 2(a) shows the organic component of the COD and BOD and the TN and TP nutrient amounts; and (b) shows the density shift depending on the rainfall time for Cd, Cu, Pb and O&G. The parameters of analyzed substances (Cd, Cu, Pb and O&G) show that the outflow contained the highest concentrations upon the initial rainfall. The concentrations in rainfall effluent then decrease in subsequent rainfall events. This indicates that the pollutant concentrations decrease after the highest initial pollutant concentration. The non-point source pollutant runoff

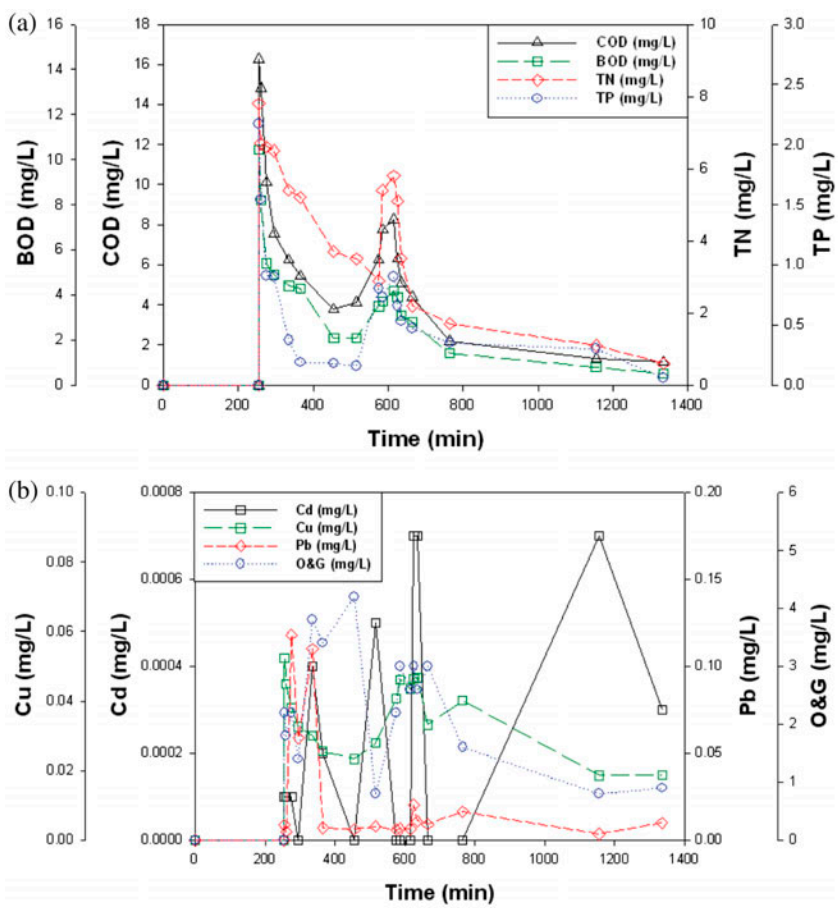

Fig. 3. Polluto-graphs of monitored event seven in the gravel road-bed area (a): COD, BOD_5, TN and TP, (b): Cd, Cu, Pb and O&G.

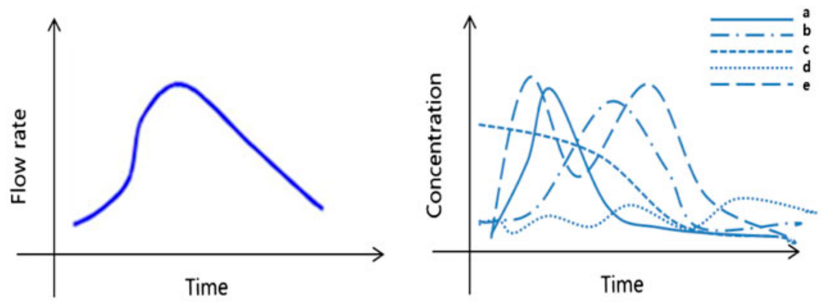

Fig. 4. Graph of the runoff characteristics.

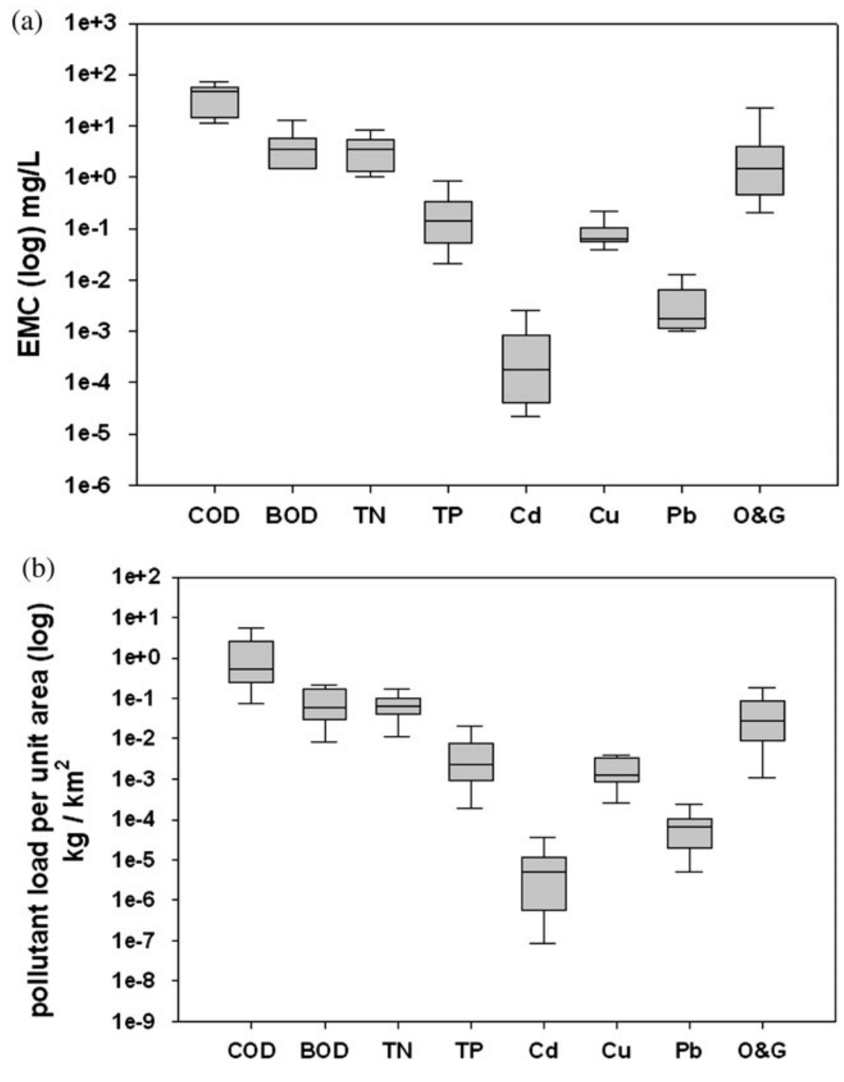

Fig. 5. EMC and pollutant load per unit area in the concrete road-bed area (a): EMC, (b): Pollutant load per unit area.

shows the first-flush effect on the concrete road-bed area. Generally, the first-flush effect is known to be associated with the relative coefficient of the discharge occurring around buildings, pavement areas and roads. The target area in this research is a concrete road-bed, and it shows the first-flush effect due to its concrete and reinforced land-use characteristics. The concentration range of pollutants was as follows: COD

10–118 mg/L, BOD 3–39.7 mg/L, TN 0.21–17.6 mg/L, TP 0.1–0.93 mg/L, Cd 0.0007–0.0047 mg/L, Cu 0.04–0.7 mg/L, Pb 0.1–0.4 mg/L and O&G 0.1–2.3 mg/L.

Fig. 3 depicts a polluto graph of the gravel road-bed area (Jam-sil railway bridge) examined in this study. This polluto graph refers to rainfall event seven (18 May 2013), precisely showing the runoff characteristics of the gravel road-bed area (in the Jam-sil area). Fig. 3(a) shows the organic components of COD and BOD and the nutrients of TN and TP; and Fig. 3(b) shows the density shift depending on the rainfall duration time for Cd, Cu, Pb and O&G. The analysis parameters (COD, BOD, TN and TP) show high concentrations at the initial rainfall time but decreasing concentrations with subsequent rainfall events. Next, the concentrations were checked as to whether they were high when the flux increased. However, this examination showed a random pattern in which no relationship exists between the rainfall time and the flux of the pollutants for Cd. The following concentration ranges of pollutants were noted: COD 1.1–16.25 mg/L, BOD 0.9–10.4 mg/L, TN 0.6–7.8 mg/L, TP 0.06–2.17 mg/L, Cd 0.0001–0.0007 mg/L, Cu 0.022–0.055 mg/L, Pb 0.003–0.1 mg/L and O&G 0.8–4.2 mg/L.

Generally, the runoff tendency for non-point source pollutants has four parts, as shown in Fig. 4. Each type is as follows:

(1) A type: The first-flush effect.
(2) B type: Runoff characteristics related to the flow rate.
(3) C type: Effects of dilution.
(4) D type: Random runoff.
(5) E type: Two peaks.

However, the railway bridge gravel road-bed area, which is the target area of this study, shows a two-peak runoff characteristic, as depicted by e in Fig. 4, showing a mixing of the A and B types. The two-peak type indicates higher detected concentrations upon the initial rainfall as well as increasing flow rate times. In the railway bridge gravel road-bed area, the reasons behind this characteristic runoff type are the small size of the area and the different land-use types, i.e. gravel, concrete and reinforced areas. The runoff characteristics of monitored rainfall events are analysis in Table 3.

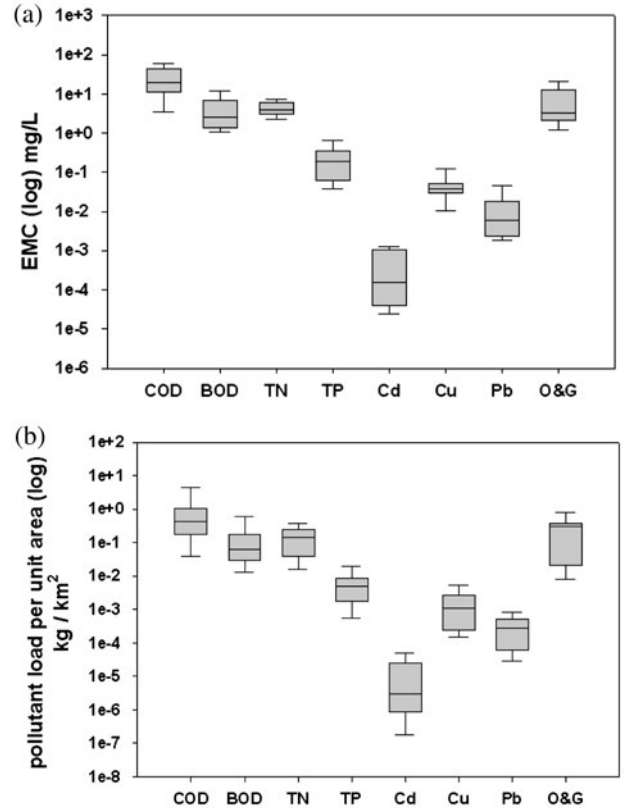

Fig. 6. EMC and pollutant load per unit area in the gravel road-bed area (a): EMC, (b): Pollutant load per unit area.

Table 4
EMC and pollutant load per unit area in concrete road-bed area and gravel road-bed area

	Concrete road-bed		Gravel road-bed	
Parameter	EMC (mg/L)	Pollutant load per unit area (kg/km^2)	EMC (mg/L)	Pollutant load per unit area (kg/km^2)
COD	41.2	1.57	26.2	1.2
BOD	4.9	0.09	4.4	0.16
TN	3.8	0.08	4.6	0.15
TP	0.26	0.006	0.26	0.007
Cu	0.0007	0.00001	0.0005	0.00001
Cd	0.09	0.002	0.05	0.002
Pb	0.004	0.00008	0.01	0.0003
O&G	5.2	0.06	7.64	0.29

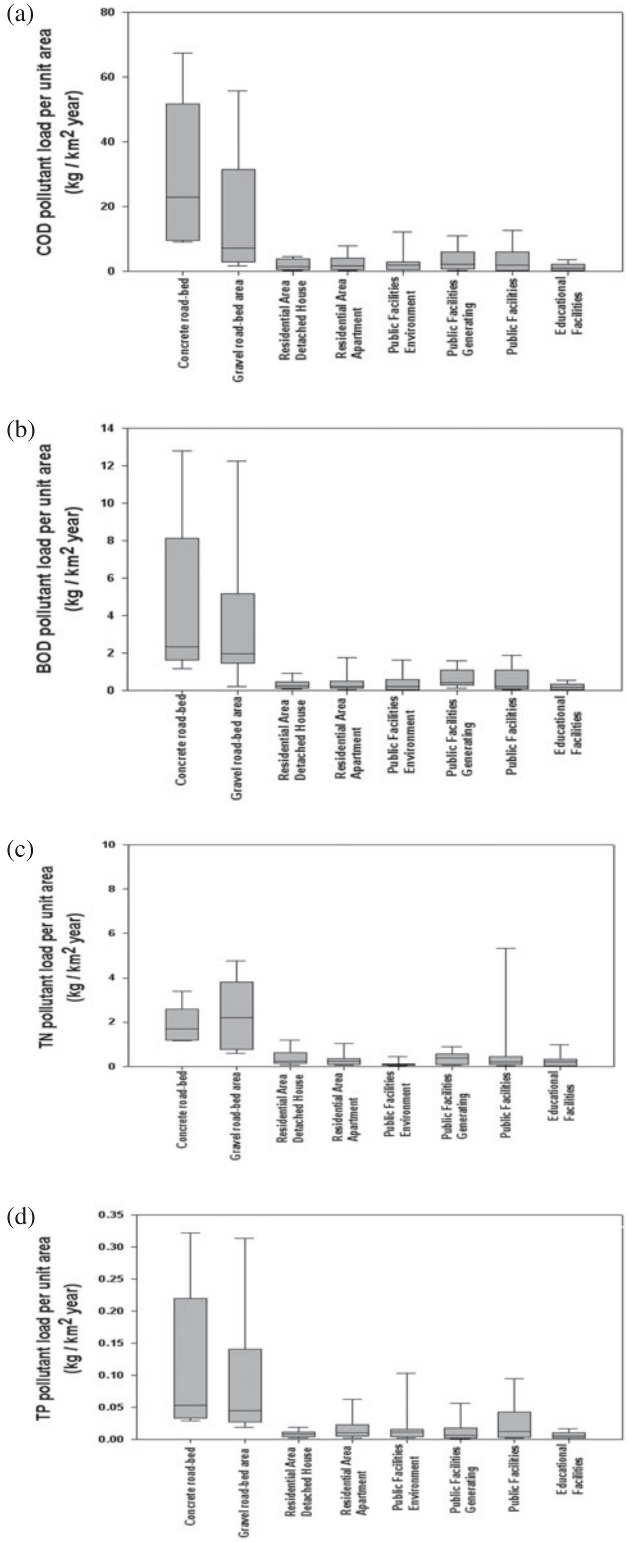

Fig. 7. Analysis of the pollutant load per unit area (COD, BOD, TN and TP) (a): COD, (b): BOD, (c): TN, (d): TP.

3.3. EMC and pollutant load per unit area

Figs. 5 and 6 show a comparison of pollution load per unit area values in the concrete road-bed area and the gravel road-bed area. For the analysis of EMC and pollutant load per unit area in railway bridge areas, various pollutants were used such as organic matter (COD, BOD), nutrient (TN and TP), heavy metals (Cd, Cu and Pb) and O&G. Generally, the EMC and pollutant load per unit area values were higher in the concrete road-bed area than in the gravel road-bed area. The reason of this result was land-use characteristics such as concrete and gravel. Some of non-point source pollutants were adsorbed gravel surface during initial rainfall and low rainfall intensity. So, EMC and pollutant load per unit area in gravel road-bed area were shown lower values than concrete road-bed area.

In Table 4, the EMC and pollutant load per unit area values are shown in each field.

3.4. Analysis of the pollutant unit load

Fig. 7 shows a comparison of the COD, BOD, TN and TP pollutant unit load values in the concrete road-bed area, the gravel road-bed area, and residential and public facilities areas. As a result of the analysis, the pollutant unit load from the railway bridge areas was found to be high. In case of organic matter, concrete road-bed area was shown the higher value (20 times over) than other areas based on COD. In case of nitrogen, gravel road-bed area was shown the higher value (five times over) than other areas. And phosphorus concrete road-bed area was shown the higher value (three times over) than other areas. This result means that non-point source pollutants from railway bridge areas were occurred about amount of pollutant loads than residential and public facilities areas. In railway bridge area, commonly located near rivers and lakes, non-point source pollutants are washed out into the water system. Therefore, non-point source pollutant management methods are required around railway bridge areas.

Fig. 8 shows a comparison of the pollutant unit load values (Cu, Pb and O&G) in various land-use areas. The results for the concrete road-bed area and the gravel road-bed area are the results from this study, and the results for the pavement and urban areas are results from existing research. The values for the railway bridge area pollutant unit loads are higher than the pavement and urban area values for all compared pollutant parameters. In the railway bridge area, the Pb pollutant unit load showed similar values for each area. However, the values for the

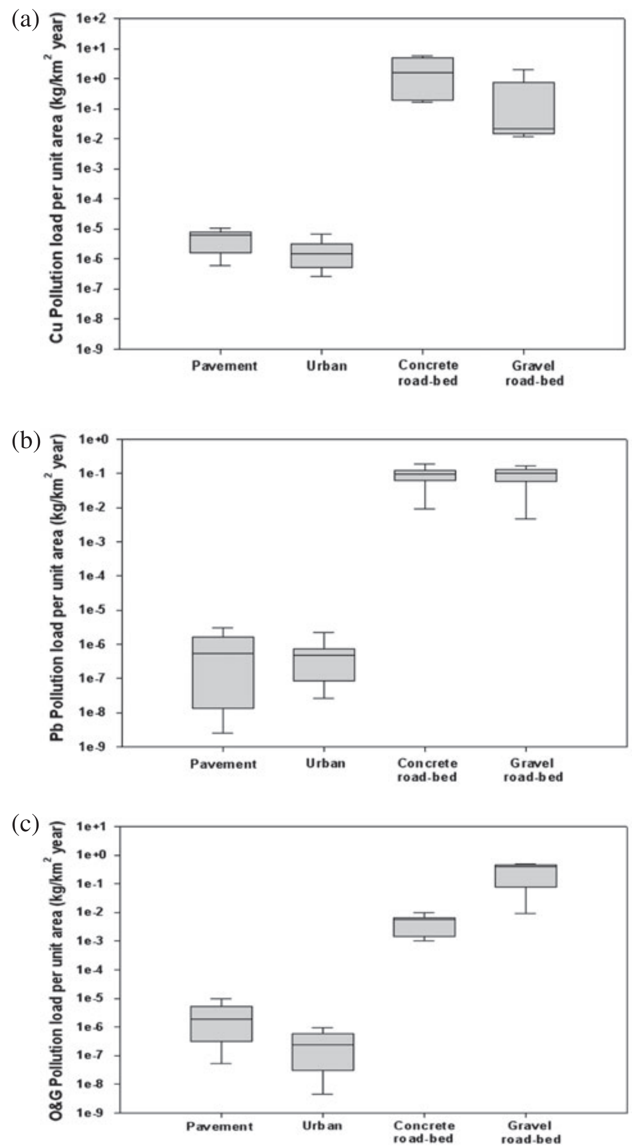

Fig. 8. Analysis of the pollutant load per unit area (Cu, Pb and O&G) (a): Cu, (b): Pb, (c): O&G.

Cu and O&G pollutant unit load differed. The Cu pollutant unit load value is higher in the concrete road-bed area, and the O&G pollutant unit load value is higher in the gravel road-bed area. This was considered to results from the two-peak runoff trend in the gravel road-bed area. With the initial rainfall and the increase in the flux, pollutants of high concentrations were found in the runoff, and these influenced the calculation of the pollutant load per unit area. Therefore, the calculation of the pollutant unit load was too high. The pollutant unit load values are higher than those of pavement and urban areas, indicating that much of the heavy metal and O&G mass occurred during the rainfall events. This influences the pollutant amounts which occur in the railway bridge area studied here.

4. Conclusions

At the railway bridge area focused on here, rainfall monitoring was done to analyze the characteristics of non-point source pollution. The characteristics of non-point source pollution outlined below are derived from the results of this analysis.

(1) The runoff characteristics at the railway bridge concrete road-bed area tend to show the first-flush effect and are similar to the runoff characteristics in paved areas. This result is effect of the land-use characteristics, in which concrete and reinforced materials dominate. The non-point source pollutant runoff characteristics at the railway bridge show two peaks, during the initial rainfall and when the flow rate increases. This finding differs from the existing runoff characteristics. These runoff characteristics appear to be due to the small size of the area and the different land-use types, in this case gravel, concrete and reinforced areas.

(2) The pollutant unit load for organic matter and nutrients upon the initial rainfall at the railway bridge concrete road-bed area showed the following results: COD 20.3 kg/km^2y, BOD 2.05 kg/km^2y, TN 1.5 kg/km^2y and TP 0.05 kg/km^2y. The pollutant unit load for organic matter and nutrients upon the initial rainfall at the railway bridge gravel road-bed area showed the following results: COD 6.4 kg/km^2y, BOD 1.7 kg/km^2y, TN 2.0 kg/km^2y and TP 0.04 kg/km^2y.

(3) The pollutant unit load of heavy metal and O&G at the railway bridge concrete road-bed area showed the following results: Cd 0.006 kg/km^2y, Cu 1.56 kg/km^2y, Pb 0.09 kg/km^2y and O&G 0.006 kg/km^2y. The pollutant unit load of heavy metal and O&G at the railway bridge gravel road-bed area showed the following results: Cd 0.02 kg/km^2y, Cu 0.1 kg/km^2y, Pb 0.099 kg/km^2y and O&G 0.38 kg/km^2y. The values for the heavy metal and O&G pollutant load per unit area are higher than those of the pavement and urban areas.

(4) Railway bridge areas have higher pollutant unit load values than other areas, such as residential areas (with detached houses), other residential areas (apartments), public facilities (outdoor environment), other public facilities (generating

facilities) and education facilities. This result shows that the problem of non-point source pollution from the railway bridge areas are more serious compared with other areas. Thus, non-point source pollutant management methods at railway bridge areas are necessary.

(5) For management of non-point source pollution in railway bridge areas, higher pollutant loads have to consider. Especially, Heavy metals and O&G were serious problem in railway bridge areas. When design of BMPs in railway bridge areas, management of heavy metals and O&G should have to establish with considering about runoff characteristics.

Railway bridge areas are mostly located around lakes or rivers. Accordingly, rainfall effluent can directly flow into the water system with amount of pollutants during rainfall event. The results of this research show that non-point source pollutants from railway bridge areas can be higher than in other areas. And management of railway bridges non-point source pollution is urgent. This research results can be considered as important raw data for management of non-point source pollution in railway bridge areas. Because, researches non-point source pollution in railway bridges have not been fully conducted. In the future, more non-point source pollution researches must be conduct and accumulate data in railway facilities area.

Acknowledgments

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