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Comparison of physico-chemical characteristics of sediments from different land use types

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ABSTRACT

Non-point source (NPS) pollutants are generated and washed off from various land uses during storm events. Different pollutants and soil particles can be discharged to stream and lakes. In this study, three different land use types such as urban, agricultural, and livestock areas were selected to determine the physico-chemical characteristics of the discharged sediments. The results showed that sediment generated from urban areas consists of large particle sizes such as sand. Moreover, sediments from agricultural and livestock areas mainly consisted of silt and sand particles. The sediment from urban areas showed the highest content of non-biodegradable organic matters, which was mainly composed of hydrocarbons caused by vehicular activities, compared to other land use types. On the other hand, the livestock area showed high-nitrogen content concentration caused by livestock wastewater. Comparing the metal concentration in sediments coming from different land use types showed that the generated metal pollution was below the Korean soil standard. This implied that these sediments can be recycled. However, the results also showed that establishment of best management practices are necessary to mitigate water pollution. Furthermore, management practice from pollution source sites to river entrance should be practiced.

Keywords: Agricultural; Land use types; Livestock; Sediments; Urban

1. Introduction

Various land use types such as urban, agricultural, livestock, and industrial areas cause land cover changes which discharges various kinds of non-point source (NPS) pollutants into the streams. The NPS pollutants washed off by rainfall from watersheds contribute to more than 68% of the total pollutant load in terms of BOD in the four major rivers in Korea. This is expected to increase up to 72% by year 2020 as a result of various land use activities [1].

NPS pollutants such as, organics, metals, and minerals, discharged from watersheds eventually accumulates on sediments in lakes or streams. Accumulated sediments contain various types of pollutants that may adversely affect both human and environment

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[2,3]. At an early stage, sediments in streams and lakes assist in the removal of pollutants through ion exchange, adsorption, and precipitation. However, the pollutant contained sediments can act as pollutant sources through molecular diffusion and biological mechanisms [4–6]. Furthermore, the organic materials contained in the sediment layers are degraded by aerobic bacteria which consume dissolved oxygen in streams and lakes. During anaerobic condition, harmful gases, such as methane and hydrogen sulfide that can inhibit both growth and reproduction of aquatic organisms, can be generated. The accumulated nutrients in sediments are released back into the aqueous phase in the form of inorganic ions which causes growth acceleration of Phytoplankton. Therefore, this causes the reformation of new organic matters in the aquatic system through mass circulation process [7,8].

The release of pollutants from sediments is affected by the changes in the condition of the environment such as DO, pH, temperature, concentration of nutrient ions, amount of sediment, and water depth. Furthermore, during flood it is possible that contaminants can be released, metal concentration in sediments can be altered, and activity of micro-organisms on the sediment surface can be affected [9–11]. To diminish the effects of long term accumulation of pollutants in sediments, it is necessary to minimize the discharge of soil particles and pollutants generated from the watershed through the utilization of sediment management strategies. However, since there are various types of land uses, the physico-chemical characteristics of the discharged sediments with pollutants should be analyzed.

Therefore, this study has selected three land use types such as urban, agricultural, and livestock areas as monitoring sites for analyzing and comparing the physico-chemical characteristics and pollutants in sediments discharged during storm events. Furthermore, this study aims to compare the concentration fractions between organics, nitrogen, and phosphorus to derive a limiting factor to prevent eutrophication in rivers and streams. The characteristics of these sediments can be utilized to provide basic and fundamental information to establish strategies on sediment recycling and sediment management. In particular, metal concentrations are important parameters that should be considered for the final disposal of sediments, which is also included in this research.

2. Materials and methods

To identify characteristics of sediments discharged from different land use types, three locations were selected as monitoring sites shown in Fig. 1. Site 1 is an urban area which was mainly roads and parking lots in a university located in Cheonan, Chungnamdo while Site 2 is an agricultural area near Dongjin and Mankyung rivers located in Saemanguem areas in Jeonbukdo. Lastly, Site 3 is the monitoring site for livestock area, where 20,000 pigs are bred, and is located in, Yangjiri, Nonsan, Chungnamdo.

In general, sediment samples taken from streams and lakes were desired to be collected in an undisturbed state. Taking undisturbed samples is crucial since the pollutants easily separate from the soil particles in sediment samples. This could cause dispersion into the aqueous phase due to the difference in the concentration. However, it is also possible to take disturbed samples in two conditions. First, there should be an absence in water since water serves as a medium during pollutant dispersion. Second, there should be a shallow sediment depth because there is an insignificant difference between pollutants in water and sediments. In this study, a total of four disturbed samples were collected from the urban area Site 1 from 2011 to 2012. For the agricultural land use type Site 2, a total of seven disturbed and non-disturbed samples were collected from 2004 to 2005. Livestock land use Site 3 has a total of 17 samples collected from 2009 to 2011, two of which were disturbed samples while 15 samples were undisturbed. Undisturbed samples were collected using a 5 cm diameter acrylic core with a total length of 50 cm. Collected samples were taken to the laboratory and were analyzed for sieve and particle size analyses. These methodologies were done to characterize the particle size that composes the sediment samples. The samples were also classified according to the particle sizes of samples using the Agricultural Soil Textural Classification of US Department of Agricultures (USDA). Moreover, the collected samples were air-dried with room temperature, grinded, and sieved to 2 mm sized sieved for chemical analysis. The sediment samples passing through the 2 mm sieve were analyzed for organics, nutrients, and metal concentrations through soil pollution test method and ICPS-7510.

3. Results and discussion

3.1 Comparison of physical characteristics of sediments

Fig. 2 shows the cumulative particle size distribution of samples collected from the three different land use types. The average particle size at 50% passing rate (D50) in urban area was calculated to be 0.58 mm which was eight times bigger as compared with other land use types. The particle size distributions of sediments with respect to the land use type were identified through the use of Agricultural Soil Textural Classification of USDA. Fig. 3 shows the results for

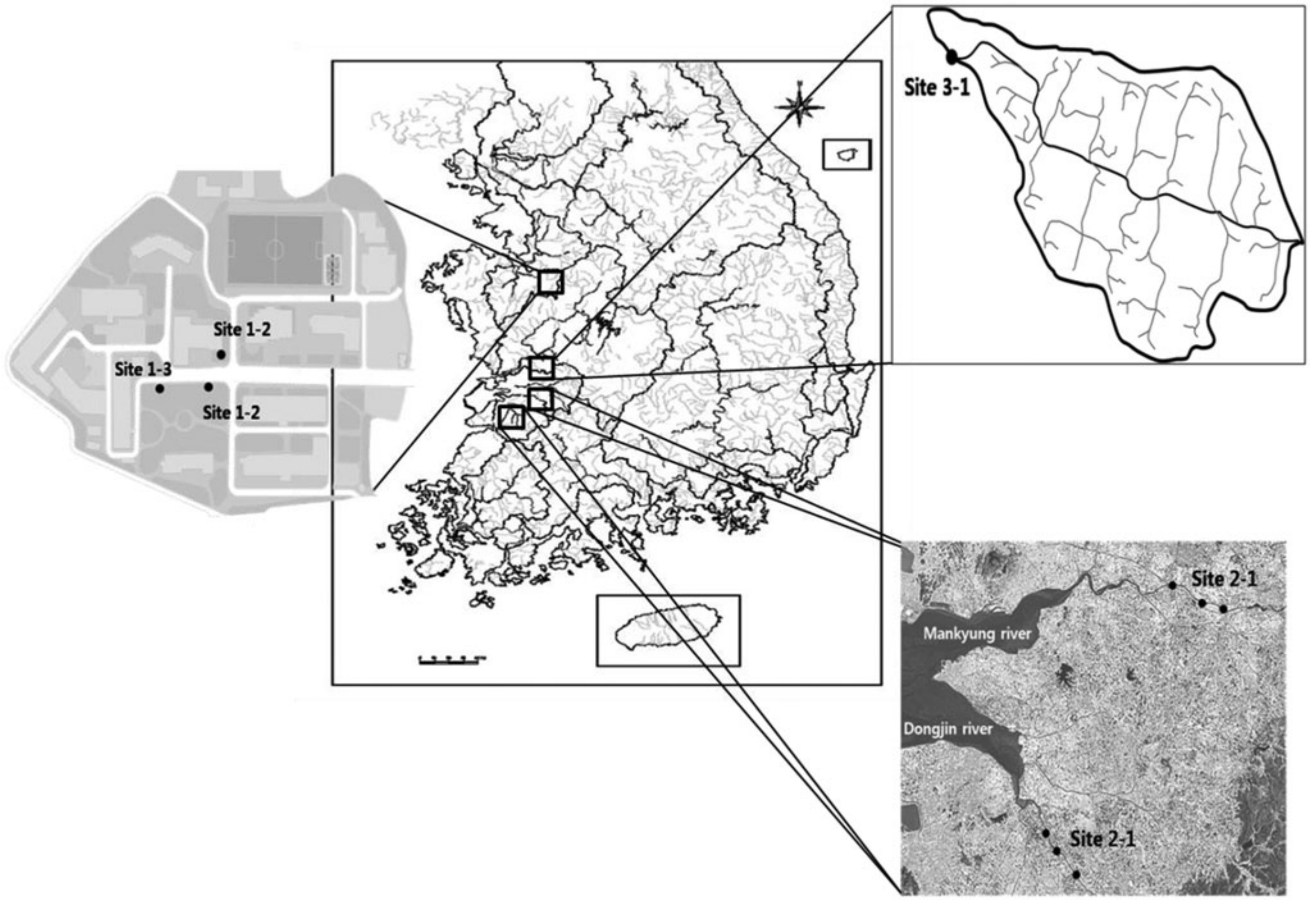

Fig. 1. Locations of each monitoring site in Korea.

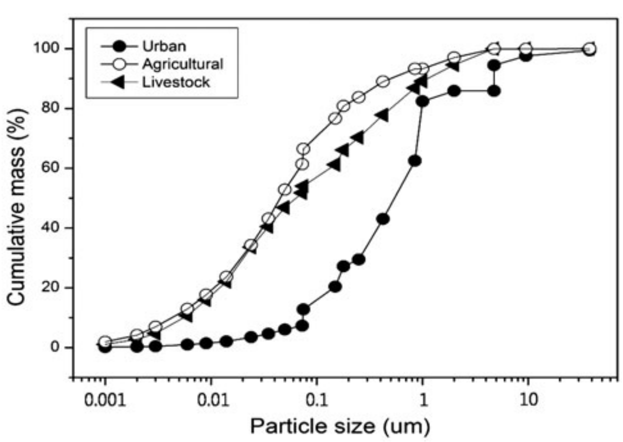

Fig. 2. Cumulative particle size distribution of samples from the different land use types.

the particle size analysis of the soil samples collected from the three different land use types. It was observed that the sample from the urban area was categorized under loamy sand, agricultural area with loamy sand to silt, and the livestock with sandy loam, loam, and silt loam. In general, sediments with smaller particle sizes have bigger surface area which results to bigger pollutant adsorption capacity. Therefore, determination of particle size distribution of sediments is important [12].

3.2 Comparison of chemical characteristics of sediments

Statistical summary of the chemical analysis of sediment samples collected from the different land use types are presented in Table 1. Highest average IL (Ignition loss) was observed in urban area (43.92 ± 14.81%) followed by livestock area (19.74 ± 25.41%) and agricultural area (3.80 ± 1.78%). COD was observed to be highest in urban area with 43.88 ± 26.45 g/kg which was attributed to high adsorption of non-biodegradable organic metals from high-volume discharge in the study area. On the other hand, nutrients from livestock area were observed to be higher as compared with other

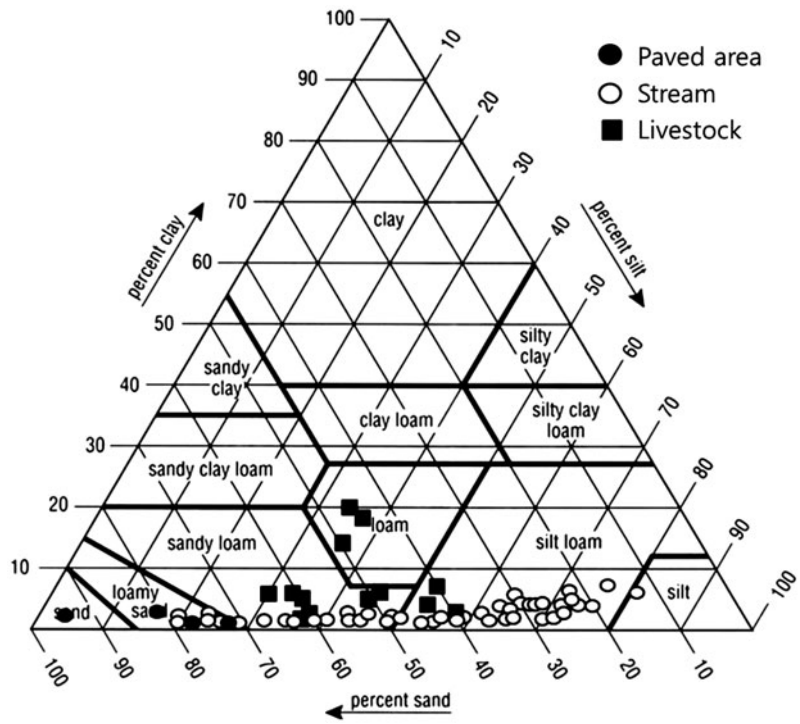

Fig. 3. Particle classification by agricultural soil textural classification of USDA.

Table 1
Characteristics of sediments collected from three different land use types

Parameter	Urban			Agricultural			Livestock		
	Min	Max	Mean ± S.D	Min	Max	Mean ± S.D	Min	Max	Mean ± S.D
Water content (%)	27.78	33.40	29.94±3.03	12.45	55.14	29.28±6.85	19.76	84.50	45.72±21.73
Ignition loss (%)	28.02	57.31	43.92±14.81	0.49	10.34	3.80±1.78	4.50	91.24	19.74±25.41
COD (g/kg)	9.39	73.82	43.88±26.45	0.32	88.48	16.61±12.44	11.38	71.37	30.75±13.47
TN (g/kg)	3.74	7.34	5.54±2.54	0.11	6.35	1.22±0.77	0.12	29.02	7.79±8.32
TP (g/kg)	0.41	0.97	0.66±0.24	0.06	5.41	1.34±0.88	0.37	3.89	1.47±0.81
Cu (mg/kg)	0.59	9.62	6.06±4.02	NA*	NA*	NA*	0.21	40.30	6.90±10.23
Cr (mg/kg)	0.34	1.21	0.66±0.38	0.10	4.32	0.78±0.92	0.11	2.59	0.67±0.64
Cd (mg/kg)	0.52	1.41	0.81±0.41	0.04	0.75	0.24±0.13	0.00	1.36	0.09±0.26
Pb (mg/kg)	4.62	15.07	9.46±4.37	0.47	9.04	3.76±1.76	0.12	6.46	2.35±1.66
As (mg/kg)	2.47	4.92	3.90±1.27	2.14	9.47	4.53±1.47	0.15	3.90	0.50±0.76

land use types, wherein TN was 7.79 ± 8.32 g/kg and TP was 1.47 ± 0.81 g/kg. The high-nutrient content of sediments from livestock area is caused by the wastewater from livestock areas. Cr, which is one of the metal pollutants that can affect human health, was observed with similar values of concentrations for different types of land uses. Furthermore, Cd concentrations present in the study sites highest in urban area followed by agricultural area. Livestock area has the lowest Cd concentration. In general, the urban area showed higher metal pollution concentrations as compared to other land use types. In particular, the Pb concentration (9.46 ± 4.37 mg/kg) was observed to have the highest value among other metal pollutants. This was caused by the presence of metal pollutants discharged by vehicular activities in paved areas [13].

3.3 Ratio of the nutrients and organic

Fig. 4 shows the calculated ratios of TN to TP, COD to TP, and COD to TN for urban, agricultural, and livestock areas. The TN and TP ratio in urban area was highest with 8.35, followed by the agricultural area with 0.91 and livestock area with 5.29. The COD and TP ratio was observed to be the highest in livestock with 66.14 ratio followed by livestock area with 20.87 and finally, in agricultural area with 12.4 COD and TP ratio. Conversely, COD to TN ratio was highest in agricultural area followed by urban area and livestock area with 13.64, 7.92, and 3.95 COD and TN ratio, respectively.

The COD:TN:TP for each land use type was also determined. For the urban area, the ratio was as 66:8:1, wherein the concentration of organics and nitrogen are higher than the TP concentration. This implies that the urban area is affected by the discharge of non-biodegradable organic matters. Furthermore, the ratio in livestock area was observed to be 21:5:1, in which the concentration of nitrogen is higher than the TP concentration. This result implies that the livestock area has high nitrogen and phosphorus concentrations coming from livestock wastewater. On the other hand, the ratio for the agricultural area was observed to be 12:1:1 was the lowest ratio as compared to the other land use types. This simply implies that organic substances are naturally degraded through self-purification by aquatic organisms, plants, and micro-organisms throughout the flow process in the stream. Moreover, a large amount of nitrogen was removed through the processes of nitrification and denitrification.

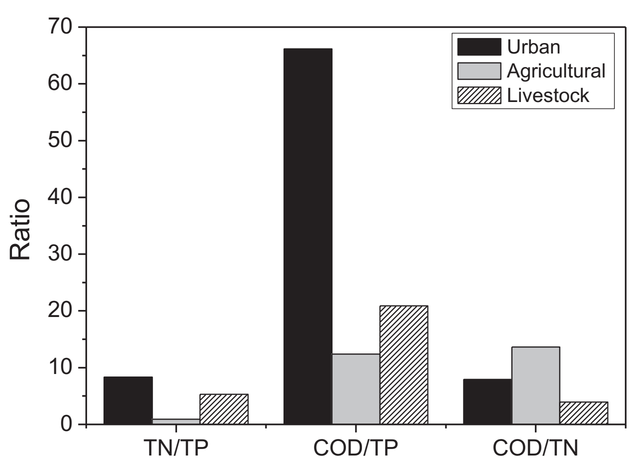

Fig. 4. Ratios of TN to TP, COD to TP, and COD to TN for the three different land use types.

3.4 Assessment of heavy metal pollutions

Fig. 5 shows the comparison of heavy metal concentrations in different land use types with the Korean soil quality standard [14]. Two types of soil standards were used by the MOE, namely the soil quality standard for pollution countermeasure (SQPC) and the soil quality standard for conservation measure (SQCM). It is desirable to maintain the pollutant concentration below the SQCM. However, once the pollutant concentration exceeds the SQCM, the pollutant starts to raise concerns for the aquatic system. Therefore, it is desirable to immediately address the problem to avoid reaching the SQPC. The results showed that the mean concentration of the four metal pollutants such as, Cr, Cd, Pb, and As, generated from each land use type have values less than the Korean SQCM.

The comparison of the results of the heavy metal concentration with the US and Canadian standards are summarized in Table 2 [15]. For both Cr and Pb concentrations from the three land use types, both pollutant concentrations are categorized under the “No effect” standards, classified by US and Canadian standards. The Cd concentrations of the three land use types were less than the maximum allowable standard for US which is six. Moreover, the maximum Cd concentrations of urban and livestock areas are categorized under the “Lowest effect” by Canadian standards.

Lastly, for the As concentrations, based from the US standards, only the mean livestock concentration falls under the category of “No effect”. The maximum and mean urban concentrations, and mean agricultural concentration are categorized as “Moderate effect”. Furthermore, the maximum agricultural concentration which exceeded 8 mg/kg will fall under the “Severe effect” category. However, based on the results from the Canadian standards suggests different evaluations. The mean As concentrations of the three land use types falls under the “No effect” based from the Canadian standards; while, the maximum As concentrations of the three land use types are categorized as “Lowest effect”. Categorized under the “Lowest effect”, by the Canadian standards, implies that the pollutant does not affect the living habitats in streams and rivers. Based from assessment of the results, the sediments are recyclable and are not solid wastes.

3.4 Sediment management practices in different land use types

To be able to draw out the appropriate sediment management measures, the organics and nutrient ions in each land use type should be identified through

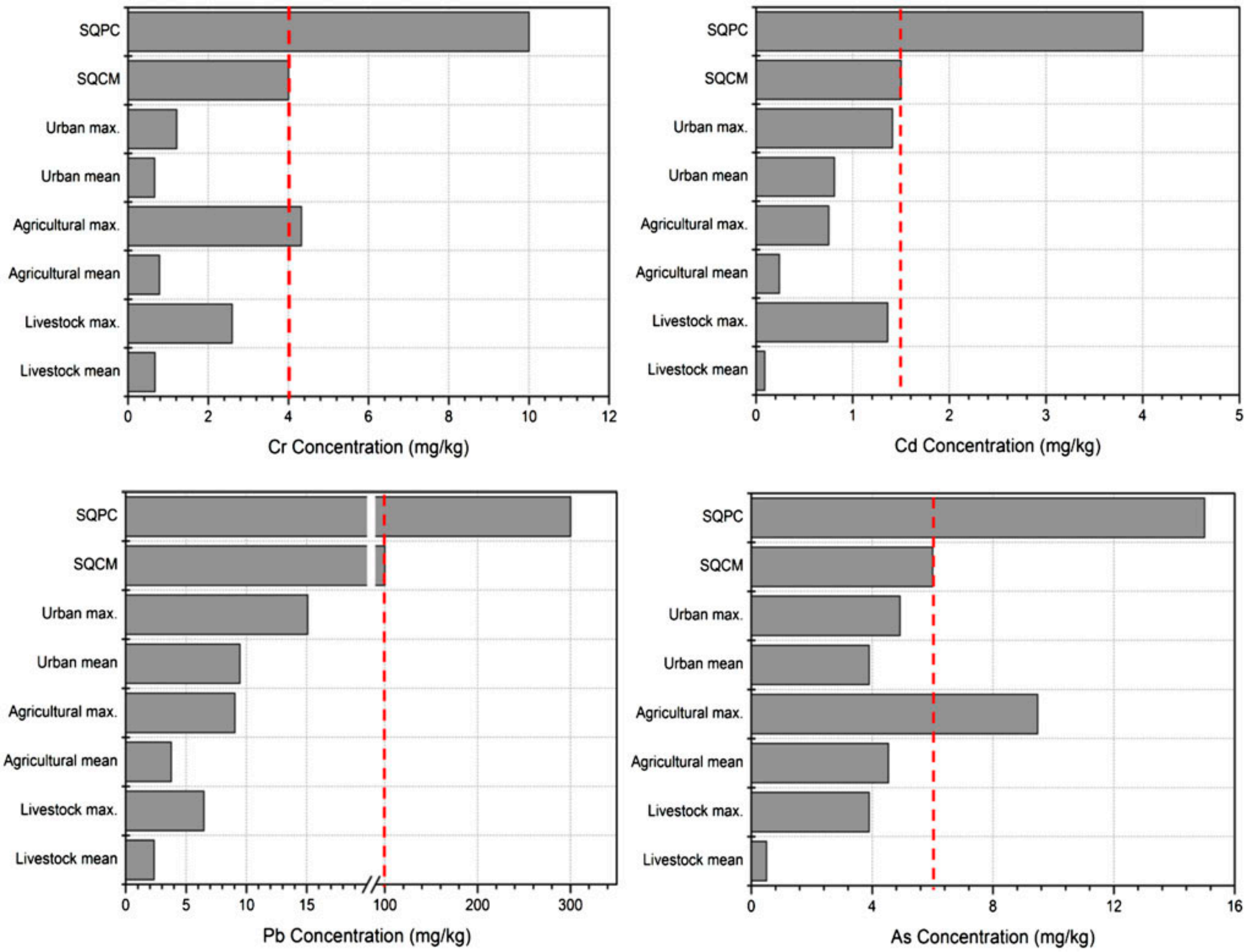

Fig. 5. Comparison of heavy metal concentration in each site with the Korean soil quality standard (The dot line means the SQCM).

Table 2
US and Canadian standards

	US standards			Canadian standards		
Parameters	No effect	Moderate effect	Severe effect	No effect	Lowest effect	Severe effect
Cr (mg/kg)	<25	25–75	>75	22	31	111
Cd (mg/kg)	–	–	>6	0.6	1	10
Pb (mg/kg)	<40	40–60	>60	23	31	250
As (mg/kg)	<3	3–8	>8	4	5.5	33

chemical analysis. Sediment pollution standards vary for different types of water bodies according to the Korean local regulations. Therefore, the results from the chemical analysis done on the sediments samples were compared with the sediment pollution standards in Paldang lake, Downstream of Han River and Daechung lake, summarized in Table 3 [15]. The results showed that pollutions levels of IL, COD, and TN in urban area, were higher as compared to the sediment pollution standards in agricultural area. This

Table 3
Korean standards on sediment removal for rivers and lakes

Parameters	Paldang lake	Downstream of Han-river	Daechung lake	Land use type		
				Urban	Agricultural	Livestock
IL (%)	Above 7.0	Above 10	Above 7.0	43.9	3.8	19.7
COD (g/kg)	Above 20	Above 20	Above 20	43.9	16.6	30.8
TN (g/kg)	Above 0.8	Above 2.0	Above 3.0	5.5	1.2	7.8
TP (g/kg)	Above 1.1	Above 1.0	Above 1.5	0.7	1.3	1.5

was caused by the pollution sources from snow melts such as soil particles, tire wire, leaves, and calcium chloride. To mitigate the discharge of sediments in urban areas, it is necessary to introduce the best management practices, which includes street sweeping and the installation of NPS management facilities. [16] and [17] reported that performing street sweeping could reduce urban NPS pollutant loading by 15–30%. Furthermore, the application of BMPs, modification of impermeable surfaces (i.e. roads and parking lots) to permeable surfaces (e.g. rain gardens Bioretention basins, etc.), could reduce and treat the stormwater runoff.

The TN in agricultural areas exceeded the TN sediment dredging standards at Paldang lake. It was also assessed that TP exceeded TN sediment dredging standards at Downstream of Han River. The results were the by-product of using excessive amount of fertilizers and chemical pesticides in agricultural areas. Pollutant mitigation measures in agricultural areas include the construction of proper scaled buffer zones and wetlands by considering the size, geological types, and cultivation methods of the agricultural area.

The IL, organics, and nutrients in livestock areas exceeded the sediment dredging standards. This was attributed to the lack of livestock wastewater management and appropriate treatment measures due to the deficiency of legal recognition addressing the pollutant emission from livestock areas. The pollutant mitigation measures for livestock areas include the reduction of wastewater loading and pollutant loading in livestock wastewater. The reinforcement of existing treatment facilities can be recommended to efficiently manage solid and liquid fertilizers.

4. Conclusions

This study conducted and compared the analysis of the physico-chemical features of sediments. The sediments used in this study were generated from varying land use types (i.e. urban, agricultural, and livestock areas), in order to provide the basic information for pollutant identification. Results of this study are derived as follows:

The physico-chemical analysis of sediments, from varying land use types, showed that sediments from urban areas consists of big particles such as sand; whereas, the sediments generated from agricultural and livestock areas mainly consists of silt and sand. Therefore, the urban area was analyzed to be mainly covered by impervious areas. Organic and metal pollution concentrations of sediments from urban areas are higher as compared with other land use types. Based from the assessment of these results, the discharge of hydrocarbons (i.e. oil and grease) and metal pollution were mainly caused by vehicles.

The results from the chemical analysis performed in urban area showed that a ratio of 66:8:1 for the COD:TN:TP ratio. Based from this result, it was evident that non-biodegradable organic matters have higher concentrations than the TP concentration, which was primarily caused by the presence of hydrocarbons. For livestock area, a ratio of 21:5:1 was determined for the COD:TN:TP ratio. Nitrogen contents were observed to be higher for livestock areas as compared with other land use types. This was primarily caused by the presence of livestock wastewater in this land use type.

Metal pollutions in sediments discharged from varying land use types (i.e. urban, livestock, and agricultural areas) were compared with the metal concentration standards of Korea, US, and Canada. The results of this study showed that the sediments from each land use type were analyzed to be below the set standards. This suggests that the sediments from each land use type are not solid wastes and are recyclable. However, it is also necessary to establish an appropriate sediment management method for each land use type since unmanaged streams generates sediments which could further lead to greater problems such as eutrophication.

To prevent pollutants from dissipating from pollution sources, the establishment of regional and site controls is necessary. This controls pollutants from the pollution source to the entrance point in the river. Site control methods include road cleaning, NPS BMP installations, fertilizer control, and proper usage of agricultural water. Regional control methods cover buffer zone installation and wetland constructions.

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