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The seasonal characterization of highway particulate pollutants by size fraction

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ABSTRACT

The quality of highway waste sediments collected from Dangjin transfer station of the Korean Expressway Corporation were studied from October 2008 to July 2009, during which time four sampling events were conducted. The particle size distribution and pollutants content of the different particle sizes were analyzed. The results indicated that the particles were coarser in winter and summer than in fall and spring, with about 70% of particles within the range 250–850 μm. The analysis of particles uniformity indicated the particles were non-uniform over the study period. The concentrations of nutrients (TN, TP, COD and VSS) and heavy metals, such as cadmium (Cd), lead (Pb) and zinc (Zn), showed the same trend, i.e. the finer the particles, the higher the pollutant concentrations. The pollutant concentration distributions were analyzed, and the results revealed that around 40–74% of the pollutants were associated with particles less than 250 μm, and accounted for about 30% of total particles. It was concluded that a clear understanding of highway particles size distribution and pollutants contents of the different size ranges is really important in the treatment of highway waste sediments.

Keywords: Sediments; Particle size distribution; Heavy metals; Nutrient; VSS

1. Introduction

Non-point source (NPS) pollution is widely recognized as one of the major source pollutions in developed urban areas [1]. Although the regulation of point source pollution has been in place for over 30 years, that of nonpoint source pollution at a national level was introduced more recently; NPS, especially for runoff, which has become the largest cause of water quality problems in the world today; the USEPA estimates that at least 50% of all water quality problems in the U.S. stem from nonpoint sources.

As a major nonpoint pollutant source, highway waste sediments are particulate matter generated from traffic activity. They are usually collected by vacuum vehicles from the highway surface or washed out to receiving water bodies by direct runoff. The main constituents of highway sediment are road materials, tires and breaks, sands, de-icing salts and other vegetation.

The pollutants contained in highway waste sediments include heavy metals, nutrients and materials contributing to chemical oxygen demand (COD), mainly volatile suspended solids (VSS). Therefore, these pollutants have the potential to impact on the environment, and their influence may be temporary, seasonal or chronic. The deterioration is related to traffic load, pavement materials, average daily traffic (ADT), land use, antecedent dry days, road maintenance and other local natural conditions.

Many investigations over the past decade have focused on highway sediments and runoff. Several studies measured the particle size distribution on urban

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paved surfaces and in runoff. Sartor et al found that 43% of particulate matters were less than 246 μm and Shaheen concluded that 58% of highway particulate matters were less than 250 μm; both these studies were based on gravimetric analysis methods [2, 3]. Zanders found that the higher pollutant contents were associated with fine particles (<100 μm) [4].

The environmental potential of highway sediments is partly dependent on the particle size distribution [5, 6], it is necessary to study the particle size distribution and pollutants content of different size ranges in the best management practice of highway runoff. In order to complete the information available, this study was undertaken with the following specific objectives:

1. To determine the particle size distributions and the pollutant distributions related with different particles sizes.
2. To discuss the characteristics of the particle size distribution and pollutant concentration for different seasons (fall, winter, spring and summer).
3. To provide a statistical summary of the quality of highway waste sediment in Dangjin, Korea.

2. Materials and methods

The experimental waste sediments were collected from the transfer station of the Dangjin branch office of the Korean Expressway Corporation during October 2008 to July 2009; sampling over this extended period was expected to yield a variety of particulate matters in response to seasonal variations in physical and chemical conditions. The sediment from the transfer station was a mixture collected over a long time, with many clean event periods; thus, was seasonally representative.

The hydrological sampling information is illustrated in Fig. 1, which shows two clear peaks for the rainfall depth and temperature (August, 2008 and June, 2009). The annual ADT load was around 42,627 vehicles for workdays and 63,007 vehicles for weekend days during 2008 in the study areas. The highway sediments contained mainly sands, paper, branches, tires, wood, food and other materials, the details of which are shown in Fig. 2. The total load was 16,354 m^3 (data source: Korea expressway corporation, 1998).

The samples were dried under natural conditions and separated using a quartering method. They were then dried to constant weight in an oven at 105°C for 24 h. The prepared samples were size-fractionated by separating works using stainless-steel sieves based on standard sieve sizes. The proportion of organic matter VSS was estimated based on the volatile matter, by measuring the weight loss of the sample after calcination at 550°C for 6 h. Heavy metals (Zn, Pb and Cd) were analyzed using an atomic absorption spectrophotometer with an air–acetylene flame. The COD, TN and TP were analyzed according to Standard Methods [7].

3. Results and discussion

3.1. The particle size distribution

The particle size distribution is influenced by the catchment geometry, land use and land use activities, such as traffic, as well as by geology and event hydrology, differing methodologies and the application of de-icing materials in winter [6].

Because of the random and nondeterministic expressions of waste sediments bigger than 4,750 μm, the analysis of the particle size distribution was only for sediments less than this size. The results indicated

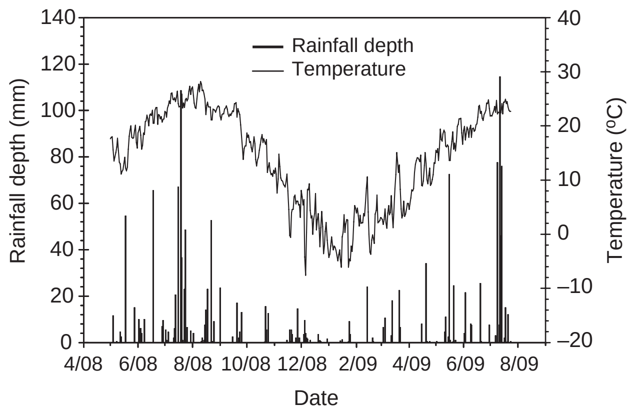

Fig. 1. The hydrograph registers rainfall/humidity.

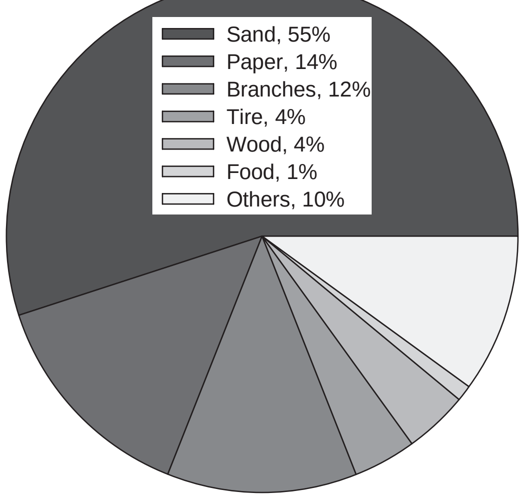

Fig. 2. The composition of highway sediments.

that around 70% of the majority of particles (less than 4,750 μm) lay within the range 250–850 μm during the study period. Legret measured sediments collected from a highway runoff channel; the results indicated that 79% of the particles were coarser than 200 μm [8], which was similar to that found in our study. P_{10} and P_{60}, known as the effective size and sizes of particles at which the cumulative mass fraction, respectively, are presented in Table 1, the results indicated that the uniformity coefficients (U) of particles ranged from 5.3~7.8; thus, it can be concluded that the sediment collected from the surface of Dangjin highway was non-uniform ($5 < U \leq 15$) during the sampling period.

The seasonal difference in the particle size distribution was analyzed (Fig. 3). Particles coarser than 250 μm can be defined as one of two groups, the particles were coarser in winter and summer than those in fall and spring, with no evident difference between the groups. For particles finer than 250 μm, the particle sizes during the study period were as follows: summer > winter > spring > fall. The difference in the particle sizes can be explained as follows: in winter, highway maintenance, such as the application of de-icing materials caused the particles to coagulate and; in summer, known for wet days, some fine particles (especially finer than 250 μm) are washed out by the frequent rainfall; thus, the particles were coarser in winter and summer. Fall is known as the dry season, where there was not much rainfall, and most fine particles remain in the sediments. Conversely, heavy traffic will crush the dry sediments to some degree; consequently, a fine particle size distribution was obtained in fall.

Table 1
The analysis of the uniformity coefficient and effective size.

Items	Fall	Winter	Spring	Summer
D_{10}	70	92	80	102
D_{60}	420	720	420	720
$U(D_{60}/D_{10})$	6.0	7.8	5.3	7.1

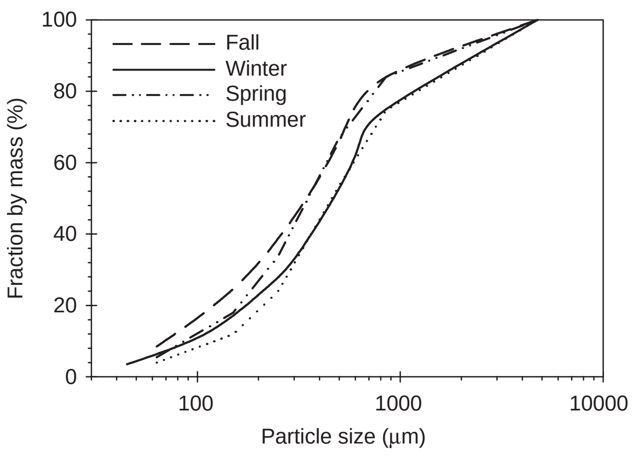

Fig. 3. Cumulative particle size distribution.

3.2. *The pollutant contents along different particle size*

Pollutant content measurements were conducted for particles less than 850 μm in size; the components of particles coarser than 850 μm are complicated and variable; thus, it is hard to collect an average, representative sample for this range. The TN, TP, COD and VSS, as well as heavy metals, such as chromium (Cd), lead (Pb) and zinc (Zn), were analyzed for each particle size range less than 850 μm. According to the results, it can be concluded that the sediments were mostly composed of inorganic matters (annual average 88%), and indicated the similar trend, i.e., the finer the particles, the higher the concentrations of pollutants (Figs. 4 and 5).

For nutrients, the concentrations of VSS, COD, TN and TP were lower in spring than in the other three seasons, with the highest concentrations generally observed in winter, which can be explained by the existence of floating debris, such as leaves, in winter [9]. The concentration ranges for TN, TP, COD and VSS were 0.38–1.83, 0.05–0.25, 25.8–210.6 and 19.5–127.6 g/kg, respectively. The concentration of TP was always lower than TN in the highway sediments, this is agreement with the results obtained from the study on urban road surface sediments [10].

The concentrations of heavy metals varied with different particle size ranges (Fig. 4); the accumulation of heavy metals is greatly dependent on the composition and structure of sediments [11]. Cd is mainly from tire wear, brake linings and insecticide application to the land around the highway. Most heavy metals are effectively removed during storm events. In this study, the Cd concentration ranged from ND to 4.00 mg/kg; not detective in winter and higher in fall. Pb is mainly from leaded gasoline, tire wear, oil and grease and bearing wear; thus, the Pb content is mainly dependent on traffic. Our results indicated Pb contents ranging from 53.34 to 345.74 mg/kg, but with no evident seasonal difference. The highest heavy metal concentrations were found for Zn (from 416.06 to 2,436.80 mg/kg). The main sources of Zn are tire or brake wear, motor oil and grease in highway sediments. In this study, Zn was most often found in the fine particle size range, which was in agreement with the results of Roger [12].

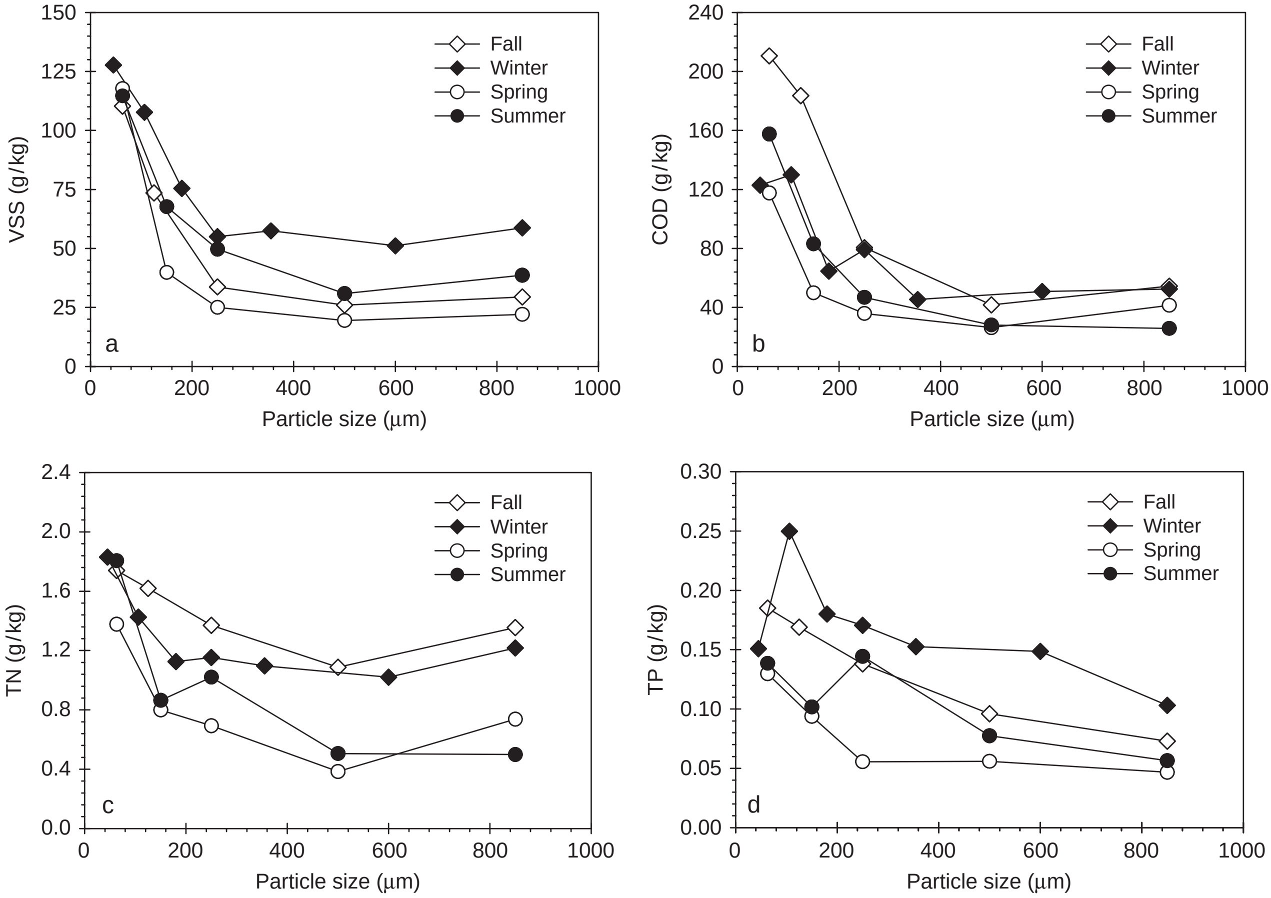

Fig. 4. The size distributions of nutrient pollutants (a) VSS, (b) COD, (c) TN, (d) TP.

3.3. Discussion

The characteristics of the pollutant distributions were analyzed. As shown in Table 2, 40–70% of pollutants were absorbed onto particles finer than 250 μm, and accounted for about 38.7, 27.8, 33.8 and 23.9% of the total particles for fall , winter, spring and summer, respectively, with a higher percentage in fall being especially evident, showing the finer particle size distribution during this season. Vage analyzed the nutrient load associated with different sized particles collected from an urban road surface. The results were similar to those found in our study, where more than 85% of TP or TN was attached to particles finer than 300 μm [10]. Consequently, it can be concluded that the reduction in highway sediments of different size ranges does not mean the pollutants load will be equally reduced proportionally; therefore, special attention should be paid to particles finer than 250 μm in the treatment of highway waste sediments.

Conversely, the fine particles less than 250 μm in size may be easily transported into receiving water bodies without being deposited [14]. Therefore, the portion of highway sediments less than 250 μm is especially important in the development of best practice management for highway. There needs to be a clear understanding of particle size distribution and the pollutants constitution in the design of treatment facilities, such as constructed wetlands and solids separation devices.

4. Conclusions

This study of highway sediments, collected from the Dangjin Branch Office of the Korean Expressway, indicated that: (1) the particle size distribution of highway sediments were coarser in winter and summer than in fall and spring, which can be explained by the different hydrological conditions and highway maintenance in winter. (2) The analysis of pollutant concentrations with different particle sizes indicated that the finer the particles, the higher the pollutant concentrations. The concentration ranges for TN, TP, COD and VSS were 0.38–1.83, 0.05–0.25, 25.8–210.6 and 19.5–127.6 g/kg,

Table 2
The pollutant fractions absorbed onto particles finer than 250 μm.

Pollutant	F				Pollutant	F			
	Fall	Winter	Spring	Summer		Fall	Winter	Spring	Summer
VSS	66.4	48.2	60.1	47.9	Cd	51.7	–	52.5	43.7
COD	72.1	52.8	53.8	57.3	Pb	74	43.9	44.9	51.0
TN	52.3	41.4	52.9	50.8	Zn	60.8	45.0	51.3	41.7
TP	60.9	45.6	51.0	47.0					

F, The pollutants fraction associated to particles less than 250 μm (%).

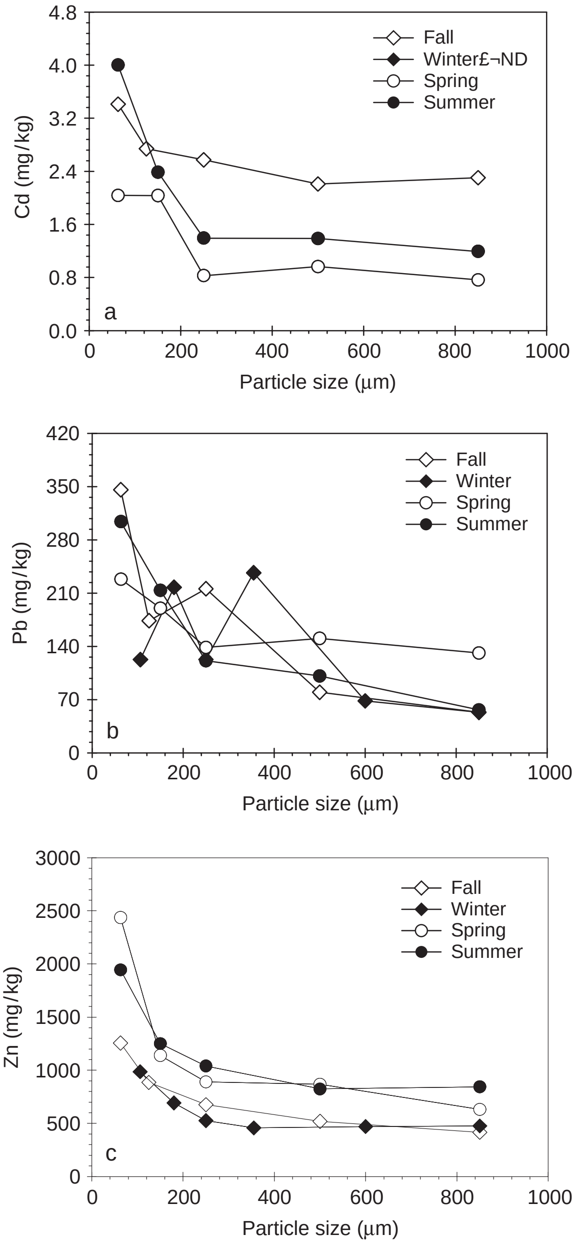

Fig. 5. The size distributions of heavy metals (a) Cd, (b) Pb, (c) Zn.

respectively. The Cd, Pb and Zn concentration ranges were ND–4.00, 53.34–345.74 and 416.06–2,436.80 mg/kg, respectively. (3) About 40–74% of pollutants were associated with particles less than 250 μm in size, which accounted for around 30% of the total particles. Thus, it can be concluded that particles less than 250 μm in size play an important role in the treatment of highway waste sediments; therefore, greater attention should be paid to particles finer than 250 μm in the development of best management practice.

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