Factors Affecting Gross Solids and Anthropogenic Litter Volume and Mass in Stormwater Runoff from Roads

Facteurs influant sur le volume et la masse de déchets solides et anthropiques dans le ruissellement des eaux pluviales des routes

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RÉSUMÉ

Les particules présentes dans les eaux de ruissellement constituent une source considérable de pollution diffuse à l'échelle mondiale. Les matières solides grossières, ou la fraction de particules d'un diamètre supérieur à 5 mm, sont rarement analysées dans les études sur les eaux de ruissellement parce qu'elles sont trop grandes pour passer dans le passeur automatique d'échantillon. Une étude de surveillance sur le terrain a été entreprise sur 11 routes de l'Ohio, aux États-Unis, afin de mesurer le volume et le poids humide des matières solides grossières transportées par les eaux de ruissellement. Des échantillons de matières solides grossières ont été prélevés en moyenne tous les 11,6 jours dans des puisards spécialement conçus à cet effet. Le volume et la masse médians des matières solides grossières totales des échantillons étaient de 2,7 L et de 0,1 kg, soit des taux de charge volumétrique et massique de 7,1 L/ha/jour et 0,45 kg/ha/jour, respectivement. Le volume et la masse maximaux des échantillons étaient respectivement de 66,6 L et 28,1 kg. Comme l'ont démontré des études antérieures, la végétation a principalement contribué au volume et à la masse totale des matières solides grossières, avec une moyenne de 80,3 % et 79,7 %, respectivement. La végétation, le volume et la masse de matières solides grossières totales étaient nettement plus importants à l'automne. Les caractéristiques climatiques et du site étaient peu ou moyennement corrélées au volume de matières solides grossières. Peu de corrélations avec la masse de matières solides grossières ont été observées et elles se sont révélées plus faibles que celles du volume des matières solides grossières. Ces données fournissent des renseignements essentiels pour déterminer la fréquence d'entretien des dispositifs de prétraitement des mesures de contrôle des eaux pluviales, des puisards, des séparateurs hydrodynamiques.

ABSTRACT

Particulate matter in stormwater runoff is a substantial source of non-point source pollution worldwide. Gross solids, or the fraction of particulate matter greater than 5 mm in diameter, are infrequently characterized in stormwater runoff studies because they are too large to fit through autosampler tubing. A field monitoring study was undertaken at eleven road sites in Ohio, USA, to quantify the volume and wet weight of gross solids transported by stormwater runoff. Gross solids samples were collected in purpose-built catch basin inserts on average every 11.6 days. Median total gross solids volume and mass for samples were 2.7L and 0.1 kg, resulting in volumetric and mass loading rates of 7.1 L/ha/day and 0.45 kg/ha/day, respectively. Maximum sample volume and mass were 66.6L and 28.1 kg, respectively. Similar to previous studies, vegetation was the primary contributor to total gross solids volume and mass, averaging 80.3% and 79.7%, respectively. Vegetation and total gross solids volume and mass were significantly greater in the autumn. Climatic and site characteristics were weakly to moderately correlated to gross solids volume; correlations to gross solids mass were infrequently observed and were weaker than those for gross solids volume. These data provide critical insights needed to determine maintenance frequencies for pretreatment devices for stormwater control measures, catch basin inserts, and hydrodynamic separators.

KEYWORDS

Trash, particulate matter, floatables, pretreatment, debris

1 INTRODUCTION

Gross solids are a category of urban stormwater pollutant comprised of organic material (e.g., leaves, branches, and grass clippings), litter (e.g., plastic, metal, glass, paper, cardboard, and styrofoam), and large particulate matter (e.g., fragments of pavement and gravel). They are generally characterized by a particle diameter greater than 5 mm. Total maximum daily loads for these pollutants have been established in watersheds across the United States, including in California and Maryland. Therefore, it is important to quantify the mass and volume of these pollutants contributed by stormwater runoff.

Marais et al. (2004) monitored gross solids from 9 urban catchments in Cape Town, South Africa. Between 2-62 kg/ha/yr (median 40.4 kg/ha/yr) of organic debris and 0.0-27 kg/ha/yr (median 10 kg/ha/yr) of anthropogenic refuse (cardboard and plastic) were collected at the monitoring sites. Gross solids samples collected weekly at four road sites in North Carolina, USA, had median dry weights of 0.3, 0.4, 0.8, and 1.1 kg/ha, respectively (Winston and Hunt 2017). Wiackowski (2015) monitored and analyzed gross solids from four different development intensities, and observed weekly gross solids loadings between 0.2 and 6.8 kg/ha (median 1.3 kg/ha). In a study of six highway sites in southern California, Kim et al. (2006) found 90% of gross solids mass was vegetation and 10% anthropogenic litter.

The goal of this study was to quantify the volume and mass of gross solids contributed by stormwater runoff from roads on an annual basis to inform the design of catch basin inserts and pretreatment devices for stormwater control measures (SCMs). Data were collected at 11 road monitoring sites in Ohio, a midwestern U.S. state with cold winters and 1140 mm of annual precipitation.

2 METHODS

Monitored roads were located in the Columbus, Cincinnati, Dayton, Lima, Cleveland, and Akron, Ohio, U.S., metropolitan areas, with sites selected considering an array of potential gross solids predictors, including: rainfall patterns, pavement type, annual average daily traffic (AADT), speed limit, adjacent land use, and development density. Gross solids were collected in purpose-built catch basin inserts built from aluminum angle iron supports which fit just inside the catch basin frame and allowed the grate to be installed so water could enter as usual. A wire mesh netting with an aperture of 5 mm was attached to the angle iron to capture all debris larger than this diameter. Gross solids samples were collected on average every 11.6 days over sampling periods that varied from 193 to 233 days at the monitoring sites.

Each gross solid sample was analyzed in the laboratory to determine its content on a volume and mass basis. A Tupperware bin, either small, medium, or large (6.1, 12.5, and 29.3 L, respectively), was selected for use depending on the total sample volume. The bin was placed onto a laboratory scale (20 kg capacity, resolution 0.1g) and tared. The entire sample was placed in the bin and a total wet weight recorded. To determine a loose bulk density, the depth of gross solids was measured to the nearest millimeter at 6 locations in the bin. Given a measured depth versus volume relationship for each bin, the average depth across the six locations was used to determine the total volume of the sample. Using tweezers, gross solids were separated into one of nine categories: natural vegetation (grass, leaves, twigs etc.), cigarettes, plastic, fabric, wood, glass, metal, paper and rock/gravel. These subsamples were analyzed for mass and volume using the methods described above.

Instrumentation was installed at each monitoring site to quantify rainfall hyetographs and runoff hydrographs (measurements on 2-minute intervals), since these factors could impact gross solids mass and volume. Summary statistics were developed these factors as well as for site characteristics to provide potential explanatory variables for use in Spearman’s rank correlation and multiple linear regression analyses. Cumulative mass (kg) and volume (L) were determined for total gross solids and all gross solids categories. To determine the prevalence of each gross solid category, percent by weight and volume for each gross solids category was calculated as a function of the entire weight or volume of that sample. To calculate total normalized load, total mass or volume was divided by the drainage area and the total duration of the monitoring period. All statistical analyses were performed in the statistical software R version 3.5.1 (R Core Team, 2018). Data were analyzed using a criterion of 95% confidence (α=0.05) unless otherwise noted.

3 RESULTS AND DISCUSSION

3.1 Summary Statistics for Sample Collection and Climatic Conditions

Sites were visited to collect gross solids samples every 11.6±7.3 days (average ± std dev.). Across the 11 sites monitored, a total of 197 gross solids samples were collected during 2016 and 2017. The number of gross solids samples collected by site varied from 14 to 22 (mean 18.3). The majority of the samples were obtained during the summer months (102), with 57 in autumn and 38 in spring. No significant differences were observed in rainfall depth, duration, peak intensity, average intensity, or ADP across the 11 monitored sites (p>0.50). Thus, rainfall summary statistics were pooled across all sites. Rainfall depth varied from a minimum of 2.5 mm to a maximum of 180 mm (median 23.4 mm), while duration varied from 0.5 hr to 134 hr (median 9.1 hr). Peak (6.1-94.5 mm/hr) and average (0.5-77 mm/hr) intensity varied over similar ranges. Median ADP was 6.9 days and varied from 0.4 days to 28.4 days. The substantial variability in rainfall characteristics indicated that the data set provides a reliable indication of the mass and volume of gross solids from roads in Ohio.

3.2 Gross Solids Volume

Median total gross solids volume for each sample (collected every 11.6 days on average) varied from 0.94-9.7L (median 2.7L) across the eleven sites (Figure 1). Maximum volume by site varied from 4.4-66.6L. The largest gross solids volume was collected during autumn when a nearby tree completely filled the catch basin insert with leaves (vegetation 98% of total sample volume). This event was representative of the broader data set, with vegetation contributing, on average, 3.9L of the 4.7L of total gross solids across all samples. All other gross solids categories represented less than 0.37L per sampling period. Total sampled gross solids over the monitoring periods varied from 28-220.3L at the 11 sites. The volumetric loading rate of total gross solids varied from 2.9-23.6 L/ha/day (median 7.1 L/ha/day). On average, this corresponds to 2582L of gross solids per hectare annually from transportation imperviousness in Ohio, USA. These data could be utilized to size forebays of stormwater control measures draining road rights-of-way or to determine how frequently catch basin insert need maintainance.

Paired comparisons using Dunn's test with a Bonferroni correction showed that the total gross solids, vegetation, and cigarette volume were significantly greater in the fall than in the spring or summer ($p<0.001$). Seasonality in vegetation volume was expected, especially at the five monitoring sites with nearby deciduous trees. Multiple linear regression suggested that on average four times more total gross solids volume was derived from urban sites (24.2L) than suburban (5.1L) or rural (7.3L) sites. Similar trends were observed for vegetation. Volume of cigarettes and plastic from urban sites was two times greater than from rural sites. AADT was significantly, albeit weakly ($0.2<\rho<0.4$) correlated to total volume, vegetation, cigarettes, and plastic. Drainage area was weakly correlated to total volume, vegetation, cigarettes, plastic, and wood and moderately correlated ($0.4<\rho<0.6$) to glass. Rainfall depth and duration were weakly correlated to total volume and plastic. Antecedent dry period was moderately correlated to glass and weakly correlated to vegetation, while elapsed time since the previous sample collection was weakly correlated to total volume, vegetation, gravel, cigarettes, and plastic, suggesting that build-up and wash off processes are occurring.

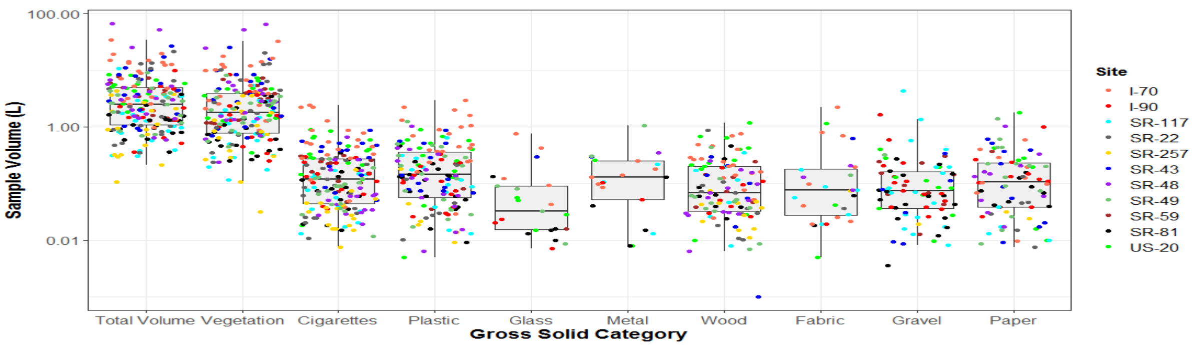

Figure 1. Total gross solids volume (liters) and categorical characterization of gross solids volume.

3.3 Gross Solids Mass

Median total wet weight per sampling event (average every 11.6 days) varied from 4 g to 1.27 kg (median across all samples of 0.1 kg; Figure 2). Mass loading rates varied from 0.09 to 1.15 kg/ha/day with a median rate around 0.45 kg/ha/day. This corresponds to 164 kg/ha/yr of gross solids entering the average catch basin in Ohio, USA. Maximum gross solids weight by site varied from 22 g to 69.4 kg. The sample with the largest weight occurred after mowing of the adjacent shoulder as well as several vehicular accidents that contributed gross solids to the catch basin. Vegetation represented 63.2-96.7% of the total wet weight at each site (average 79.7%), and was the primary contributor to gross solids mass at ten of the eleven sites (gravel was the primary contributor at the 11th site). The I-70 produced the significantly greater total mass than 7 other sites. This site had approximately 3 times greater AADT than the next site; thus, AADT may play a role in gross solids mass. Using multiple linear regression, it was observed that the urban sites produced on average 1.1kg total gross solids mass, twelve times higher than that for suburban and rural sites (0.08-0.09 kg).

Paired comparisons among seasons using a Dunn's test with a Bonferroni correction showed that gross solids total mass and vegetation mass was significantly greater in fall than summer, while fall was not significantly greater than spring (p-values of 0.12 and 0.16, respectively). This suggests that if catch basin inserts were utilized to capture gross solids, maintenance would be more onerous during the autumn. Rainfall depth and duration were weakly correlated to total gross solids mass, vegetation, and cigarettes. Antecedent dry period, peak intensity, and average intensity were not well correlated to gross solids mass, nor were site characteristics, including AADT, speed limit, and catchment area.

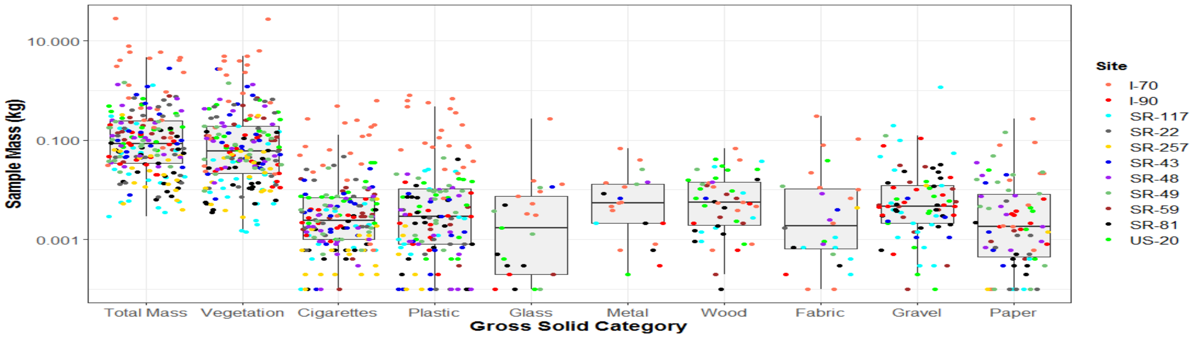

Figure 2. Total gross solids mass (kg) and categorical characterization of gross solids mass.

4 CONCLUSIONS

Gross solids represent a class of infrequently quantified pollutants in stormwater runoff that contribute to global problems such as the great Pacific garbage patch. As such, a monitoring study was undertaken to quantify the volume and mass of gross solids in road runoff. Median total gross solids volume and mass for samples collected on average every 11.6 days were 2.7L and 0.1 kg, resulting in volumetric and mass loading rates of 7.1 L/ha/day and 0.45 kg/ha/day, respectively. Maximum sample volume and mass were 66.6L and 28.1 kg, respectively. Vegetation was the primary contributor to gross solids volume and mass, averaging 80.3% and 79.7% of the total collected gross solids, respectively. Vegetation and total gross solids volume and mass were highest in the autumn season. Climatic and site characteristics were weakly to moderately correlated to gross solids volume; correlations to gross solids mass were infrequently observed and were weaker than those for gross solids volume. The data presented herein will help engineers to determine maintenance frequencies for pretreatment devices for SCMs, catch basin inserts, and hydrodynamic separators.

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