

Surface stormwater runoff in the formation of contemporary urban surface deposited sediments

Andrian Seleznev^{1,*}, *Ilia Yarmoshenko*¹, *Georgy Malinovsky*¹, *Daria Kiseleva*², *Ekaterina Ilgasheva*¹, *Anastasia Ryanskaya*², and *Alexander Teterin*¹

¹Institute of Industrial Ecology, Ural Branch of Russian Academy of Sciences, S. Kovalevskoy St., 20, 620219, Ekaterinburg, Russia

²The Zavaritsky Institute of Geology and Geochemistry of the Ural Branch of the Russian Academy of Sciences, 15 Akademika Vonsovskogo str., 620016, Ekaterinburg, Russia

Abstract. Surface runoff represents one of the major mechanism connecting sources, transport, deposition and storage of the particle matter in urban sediment cascade. The urban surface deposited sediment represents a medium for the transport and nonpoint source of pollution in cities. The study is aimed to characterize the role of surface stormwater runoff in accumulation of the contemporary surface deposited sediments in the urban environment taking to account the seasonal factor. The study was conducted on the example of residential area of Ekaterinburg, Russia. The role of the surface stormwater runoff in the formation of the urban surface deposited sediments was discussed. The snow and dirt mixture accumulates surface runoff and pollutants in it during the winter season in an urban area. A large supply of water accumulated in the snow cover during the cold period contributes to the formation of large volumes of snow-mud mixture during spring. The active snowmelt in the spring leads to the formation of snow-dirt sludge and transfer of the sedimentary material.

1 Introduction

The contemporary sedimentation occurs in an urban environment continuously. Both natural and anthropogenic processes participate in the formation and accumulation of the urban sediments. Natural factors include: weathering of building materials, road pavements as a result of freezing and thawing in the presence of moisture; soils erosion under the influence of stormwater surface runoff. Effect of natural factors is associated with seasonality and meteorological conditions [1, 2]. Anthropogenic impact includes the ground excavation and other works associated with soils and pavement deterioration. Street surfaces are abraded with the vehicle wheels. The accumulation of the urban sediments increases significantly under the poor landscape management. An increase of dust and fine erosion matter became a significant problem for urban areas [3, 4]. Urban surface sediments

* Corresponding author: sandrian@rambler.ru

became a medium for the transport of pollutants in cities. Potentially harmful elements and dry particulate matter containing in the sediment may represent the environmental risk factors for urban population [5]. Different types of surface deposited sediments and other anthropogenic ground deposits represent the upper layer of the stratigraphic pile within the urban territory [6].

Urban sediment cascade represents a concept connecting the sediment sources, transport mechanisms, deposition and storage of sediment [7]. The sediment cascade indicates a vector for pollutants transfer and reservoirs for storage. The source component of the urban sediment cascade represents all types of the particulate-generating material in the urban environment [8]. Urban sedimentary system a significant part of the global waste and pollution transport [9, 10]. Urban sediment cascade model includes sediment wash-off from urban surfaces, its transfer through drainage and sewer systems, streams and urban watersheds to rivers, water bodies, seas and oceans [8, 11].

The study is aimed to characterize the role of surface stormwater runoff in accumulation of the contemporary surface deposited sediments in the urban environment. The study was conducted on the example of residential area of Ekaterinburg, Russia, a city with a relatively cold climate and a long winter.

2 Materials and methods

Ekaterinburg is the fourth Russian largest city with a population of about 1,500,000. The city lies on the eastern foothills of the Middle Urals (56°50'N, 60°35'E). The city rapidly grown the middle of the 20-th century in the period of the Soviet industrialization.

The climate in Ekaterinburg is temperate continental. The stable negative air temperature usually establishes in mid-October and lasted 120 days. Snow cover begins at the end of October, and starts melting at the beginning of April.

To characterize the influence of the surface runoff on the formation of contemporary surface deposited sediments, a specific research design was constructed, based on a set of field, laboratory and analytical studies. The research program included sampling of environmental compartments in residential areas in the city in different seasons of the year. The six residential blocks typical for the city were randomly chosen in different geographical parts of Ekaterinburg. The quarters of different years of construction were located in areas with different lithogenic substrate. Each block consists of multi-flat apartment buildings, courtyard, and the adjacent part of the street. In 2017 the samples of snow-dirt sludge were collected in the winter (19 samples) (Fig. 1), and samples of urban topsoil (upper 5-cm layer) and surface deposited sediment were collected in spring (31 samples), summer (27) and fall (13) seasons.

Samples of snow-dirt sludge were collected on roads, intra-yard passages, parking lots, sidewalks and from dirty snow piles stored along the roadsides. The samples of urban surface deposited sediment were taken at parking lots, passages and local puddle sediments in courtyards, at roads and at sidewalks. Samples of topsoil were collected at the lawn areas.

The field descriptive survey was conducted in the residential blocks to characterise the factors that may affect sediment formation: number of vehicles, cleaning, proportion of disturbed areas, and storage of snow in piles for the winter season, earthworks for the warm season etc.

The particle size fractionation was performed with decantation and sieving for samples of soil, sediments and solid matter obtained from melted snow-dirt sludge [12]. The contribution of the following particle size fractions into the sample mass was obtained: 0.002-0.01 mm, 0.01-0.05 mm, 0.05-0.1 mm, 0.1-0.25 mm, 0.25-1 mm and >1 mm. The granulometric subsamples were analyzed by X-ray diffraction method at the Geoanalyst

Center for Collective Use. The total concentrations of the elements were measured in particle size fractions of the collected samples with inductively coupled plasma mass spectrometry. The pH value and organic matter content was determined in all the collected samples.

The surface runoff for the city was calculated by the seasons of 2017 (for the period from November 2016 to December 2017) according to the water balance equation [13]:

$$D_s = Pr - E,$$

where Pr is average monthly atmospheric precipitation value for the meteorological station Ekaterinburg WMO_ID = 28440 from website rp5.ru (http://rp5.ru/archive.php?wmo_id=28440), E – evaporation value. The evaporation value was calculated as $E = 0.37 \cdot n \cdot d$, where n is the number of days for the period, D (mm Hg) – average air humidity deficit at the height of 2 m for the period [14]. The air humidity deficit for the studied period was calculated as a difference of pressure of saturated and partial pressure of water vapor. The partial pressure of the water vapor was calculated for the pressure of saturated water vapor and relative air humidity. The equilibrium pressure of saturated water vapor was determined by psychrometric tables at a positive air temperature above water at a negative air temperature.



Fig. 1. Snow-dirt sludge at the road, intra-yard passage and sidewalk, dirty snow pile stored along the roadside.

3 Results and discussion

The average content of the particle size fractions in the collected samples (Fig. 2) shows seasonal changes of grain size composition in the studied environmental compartments. There is no significant difference between the content of the most transportable dust fractions (0.002-0.05 mm) by the seasons. The highest content of dust particles (0.002-0.1 mm) is observed in the areas of the roadway and on the unpaved surfaces outside the blocks. Areas of lawns with broken or missing grass cover are an intense source of dust. The presence of a fraction > 1 mm in the sediment at the area outside the courtyards is associated with the use of fine fractional crushed stone (screenings), fragments of rock in the winter period as anti-icing material on sidewalks and roads.

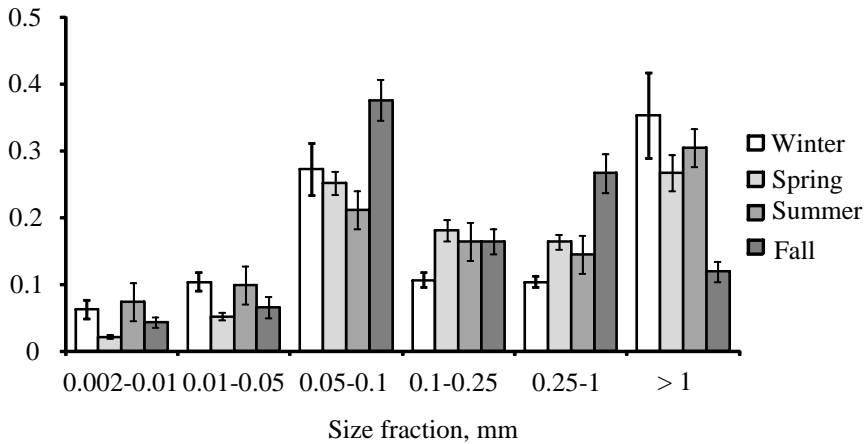


Fig. 2. Contribution of different size fractions to mass concentration (portion) of the solid phase in samples collected in different seasons with standard errors.

The mineral and elemental composition of the samples is the same for all seasons of the year. Minerals of solid material of collected samples are the components of rocks used in the construction industry (including road construction): granites, gabbros, hornblendes, serpentines. In total, the minerals that make up the building materials determine about three-quarters of the solid sediment material in the samples. In general, the dust fraction is debris from larger particles.

There is a tendency for alkalization of surface sediments during the warm season and neutralization of the samples of snow dirt sludge during the cold season. Alkalization is associated with an increase in the amount of organic matter in the surface sediment, due to leaching material from soil.

Table 1 shows the values of precipitations, evaporation, and surface runoff by the seasons of 2017. Surface runoff varies by the seasons. The maximum surface runoff is observed in the end of winter, and then decreases by autumn.

Table 1. The values of precipitations (Pr), evaporation (E), and surface runoff (D) by the seasons.

Season	Pr, mm	E,mm	Ds, mm
Winter	138	34.2	0 (103.8)
Spring	165.8	107.0	58.8
Summer	260.0	220.7	39.3
Fall	65.0	50.2	14.9

The snow dirt sludge formed in winter period preserves surface stormwater runoff containing solid sediment in an urban area. The active snowmelt in the spring tends to the formation of snow-dirt sludge and transfer of the sedimentary material. The surface stormwater runoff transfers the surface sedimentary material which is represented by the products of abrasion of building materials, road surfaces, and eroded soils.

4 Conclusion

The main mechanism of forming the urban surface deposited sediments is the erosion of material of various granulometric fractions of soil, pavement and other surfaces by atmospheric stormwater runoff. In metropolises located in harsh weather conditions, water and wind erosion have a significant impact on the formation of surface mud sludge in the

fall and spring seasons of the year. A large water supply accumulated in snow during the cold period of the year, an increase in the snowmelt surface runoff in spring lead to water erosion and the formation of large volumes of snow dirt sludge, which was clearly demonstrated in spring 2017 (an Internet search with the keywords “Mud, Ekaterinburg, Spring” (in Russian) gives 2.6 million pages of search results).

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