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Mineral phase composition of the surface dirt sediment in an urban environment

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Abstract. The accumulation of the contemporary surface dirt and dust sediments is an important problem of an urban area. The surface dirt sediment is deposited on the various surfaces both inside and outside the residential blocks. The sediment represents the secondary and nonpoint pollution source due to the presence of the environmental toxicants, heavy metals and pathogens in their content. The aim of the study was to determine the mineral phase composition of surface sediment in the city of Ekaterinburg in order to identify the sources of its origin. The 60 samples of surface sediment were collected in summer at the different parts of residential blocks (traffic ways, sidewalks and lawns, inner yard area, parking lots, and green areas). The sediment samples were fractionated by the particle size fractions: 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 particle size fractions were analysed by X-ray diffraction. According to the results of analysis the investigated mineral composition of the surface sediments represent the complex multi-phase mixtures, similar in mineral composition (quartz, microcline, plagioclase, magnetite, chlorite etc.). The sources of the mineral component in the surface sediment were identified.

1. Introduction

The urban environment is a complex system of interacting natural and artificial components. Economic, social and cultural activity concentrated in the cities impacts on the environment. The urban landscape is artificially created and is constantly transformed under the influence of natural and anthropogenic factors. A permanent increase in dust and fine erosion products from various sources and their accumulation in the form of sediments became a significant environmental issue in urban areas during recent decades [1–3].

The surface sediments represent the secondary and nonpoint pollution source due to the presence of the environmental toxicants, heavy metals and pathogens in their content [3–7]. Dust in the atmosphere and the heavy metals are reported to be the environmental risk factors for the urban population. The negative effects of accumulation of the surface sedimentary material in an urban area relate to the siltation of the sewage system and compaction of the urban soil.

Sediment production and transport start at the urban territory at the moment of landscape construction. The natural mechanisms of the urban sediments production consist of the destruction of the construction materials, road surface, sidewalks and other surfaces under freezing and thawing, soil erosion and surface transfer of the particle matter by storm water runoff [8–10], dry deposition of particulate matter (PM) and dust from the atmosphere [11]. The anthropogenic impact includes the supply of sedimentary material from destruction of the soil, pavements and road surfaces by vehicles, brake and tire abrasions as well as excavation and earthworks [12, 13]. Urban sediments comprise any sediment present within the urban environment, accumulating on different urban surfaces, in gully pots and sewer systems, and in receiving water bodies [14].

In urban geochemical studies the accumulation of the pollutants over space and time is a remarkable advantage of urban superficial sediments in comparison with the urban soils, which are affected by generally unknown processes of erosion and transport of eroded material [15]. In numerous studies, the concentration of potentially harmful elements (PHE) in sediments from water bodies, road-deposited sediments and sewage sediments is studied as an indicator of the urban environmental quality [16]. Approaches to reconstruction of background PHE concentrations in urban sediments using the 137Cs chronological method, as well the initial baseline relationship between PHE and conservative element concentrations, are suggested [17]. The total and size-fractionated mass of deposited sediment can be used for assessment of implications for air and water quality [2]. Field study of the sedimentary system for analysis and its environmental role requires sampling sediment species actively transported within the sediment cascade. This could be achieved by sampling during runoff events or installing suitable samplers along the dominant sediment transport pathways. Road-deposited sediment samples can be collected from the road surface using a dry mechanical vacuuming, and in combination with manual brushing.

The objective of the study was to determine the composition of the mineral phase of surface dirt sediment in an urban environment in order to identify the sources of its origin. The study was conducted on the example of Ekaterinburg city (Russia).

2. Materials and methods

2.1. Description of the sampling area

Ekaterinburg is located on the eastern side of Ural Mountains in temperate continental climatic zone (geographical coordinates: latitude 56º50'N, longitude 60º35'E; height above sea level about 270 m); its population is 1 455 904 people. The average temperature in Ekaterinburg is -14 ºC in January and +19 ºC in July. The winter lasts from November until April. Summer is short, with warm weather for only 65–70 days. Main sources of pollution in the city are machine building, metalworking, metallurgy, electrical power production, chemical and petrochemical industries, manufacture of building materials, and road and rail transport. In recent years, there has been a tendency towards an increase in emissions from vehicles due to an increase in the number of cars.

2.2. Object of the study

The object of the current study is the surface dirt sediment deposited on the various surfaces:

- both inside and outside the residential blocks in the form of puddle sediments in the local surface depressed zones of the microrelief in the lawn areas and pavements (Figure 1 (a)),
- surface dirt at the organized and unorganized (when cars are parked at lawns) parking lots and intra yard passages (Figure 1 (b)),
- and road deposited sediments (road dust) on the street surfaces in the facade area (Figure 1 (c)).

The sediments represent an independent facie of the contemporary anthropogenic sediments at the urban territory.

Figure 1. Surface sediments in local depressed zone of the microrelief (a), at the unorganized parking lot (b) and road deposited sediments (c)

2.3. Study design

The six experimental sites, representing typical quarters of the city, were selected in Ekaterinburg. Each residential block has the courtyard space and facade area of the adjacent part of the street. The selected blocks were randomly chosen in the microrayons constructed in different periods of the 20th century and located in different geographical parts of the city. The experimental sites adjoined the streets with different traffic intensities. Each experimental site includes the landscape zones:

(1) the carriageway of the street outside the block,
(2) the pavement and (3) lawn from outside the block,
(4) the playground and green area inside the courtyard,
(5) organized and unorganized parking lots of the inner-quarter part of the block.

2.4. Sample collection

The samples of the environmental compartments (potential sources of the surface dirt sediments) were collected at the studied sites in summer season. The combined sample of the environmental compartment (from 5 localizations at the given landscape area) was collected at each landscape zone of the residential block. Additionally, the samples of soil were collected at the lawns. The samples of surface dirt sediments were taken at the parking lots and passages of the courtyard territory. The samples of the road and pavement dust were collected at the facade area. The samples of the sediments of local surface depressed zones of microrelief (puddle sediments) were taken at the zones of the intra yard passage, parking lots and lawn areas. The mass of total soil sample was 1–1.5 kg.

2.5. Granulometric analysis

A granulometric analysis was carried out for each collected sample. The samples of the soil and sediment were air-dried at ambient temperature in the laboratory. The dried samples were crushed with rubber pestle and homogenized. To determine the particle size composition the representative subsample of 200–250 g mass was taken from the homogenized sample.

The subsample of soil and sediments was divided into the particle size fractions. Particle size fractions 0.002–0.01 and 0.01–0.05 mm were separated by the decantation. The decantation procedure was similar to that described in Test Method WA 115.1-2017 [18]. The fractions 0.05–0.1, 0.1–0.25, 0.25–1 mm and > 1 mm were obtained by wet sieving of the remained part of the subsample after decantation. The obtained solid material of particle size fractions was dried and weighted. Then, the mass portion of each particle size fraction was calculated.

2.6. Methods of mineralogical analysis

The samples were powdered in a jasper pounder and were analyzed by X-ray diffraction method (XRD) using Shimadzu XRD-7000 powder X-ray diffractometer with Cu Kα radiation (λ=1.5406 Å) (power of 40 kV and current of 30.0 mA). XRD patterns were obtained with 1°/min step across the angular range of 3–70°. The preliminary qualitative phase analysis of the samples was carried out by the main reflections using the Powder Diffraction File-2 database (ICDD). To perform the quantitative full profile analysis the diffractograms were analysed according to the Rietveld method using the SiroQuant software. The analysis was performed at the Geoanalyst Center for Collective Use.

3. Results

Totally, 30 samples of surface dirt sediments and soil were collected at six experimental sites in summer season 2017. The mass of 360 granulometric subsamples was determined. Mineral phase composition of the samples was determined for granulometric fractions 0.002–0.1 mm, 0.01–0.05 mm and 0.05–0.1 mm in 48 subsamples. The grain size distribution of samples of summer season is exhibited on Figure 2. The mineral phase composition of the subsamples is represented in Figures 3–8.

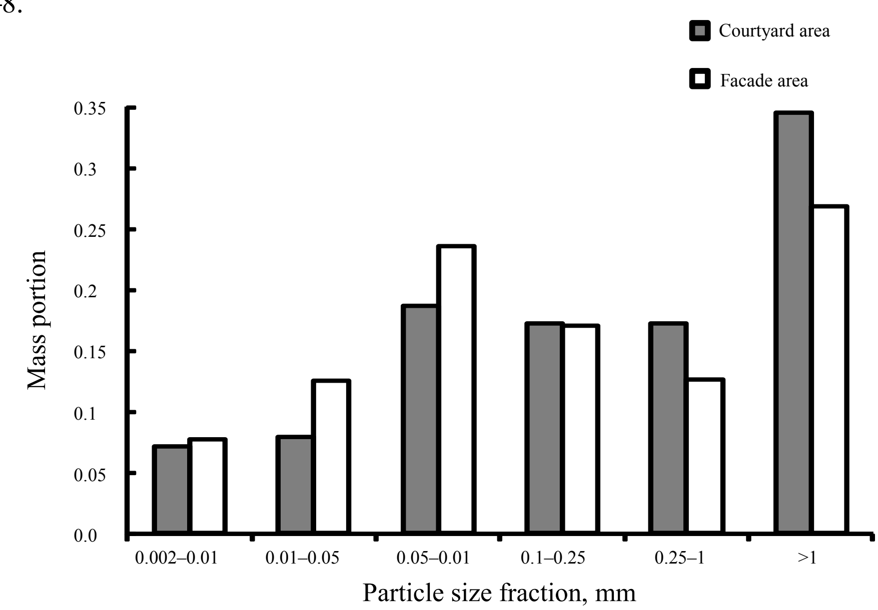

Figure 2. Grain size composition of the samples collected in the summer season

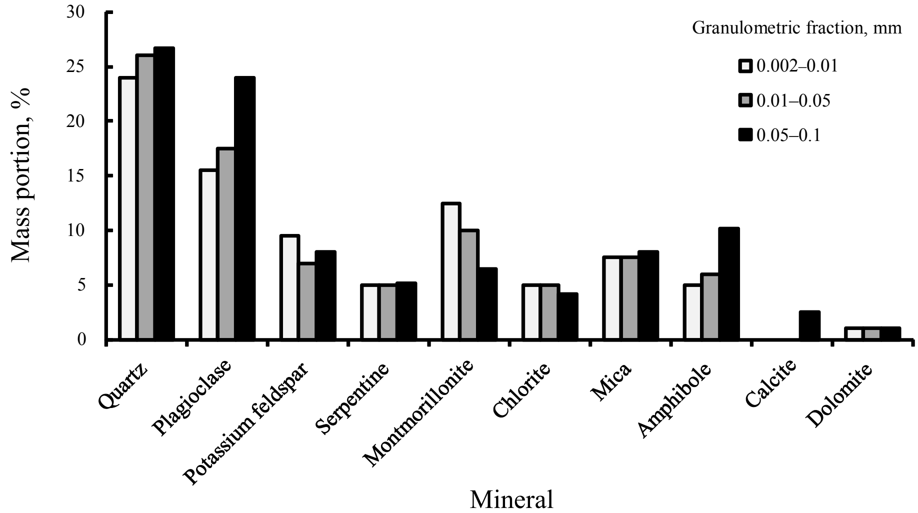

Figure 3. The mineral phase composition of the subsamples from dirt sediment samples collected in the courtyard area on lawn

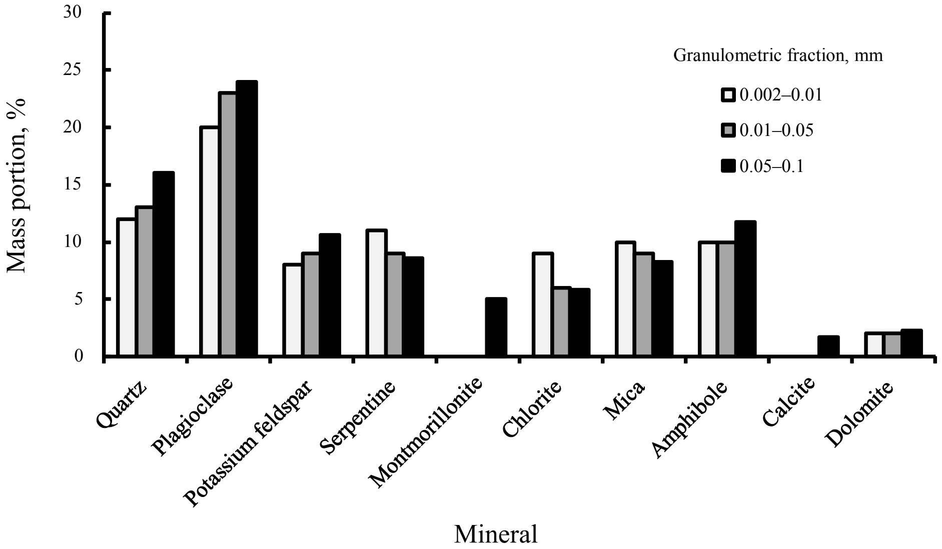

Figure 4. The mineral phase composition of the samples collected in the courtyard area on the parking lot

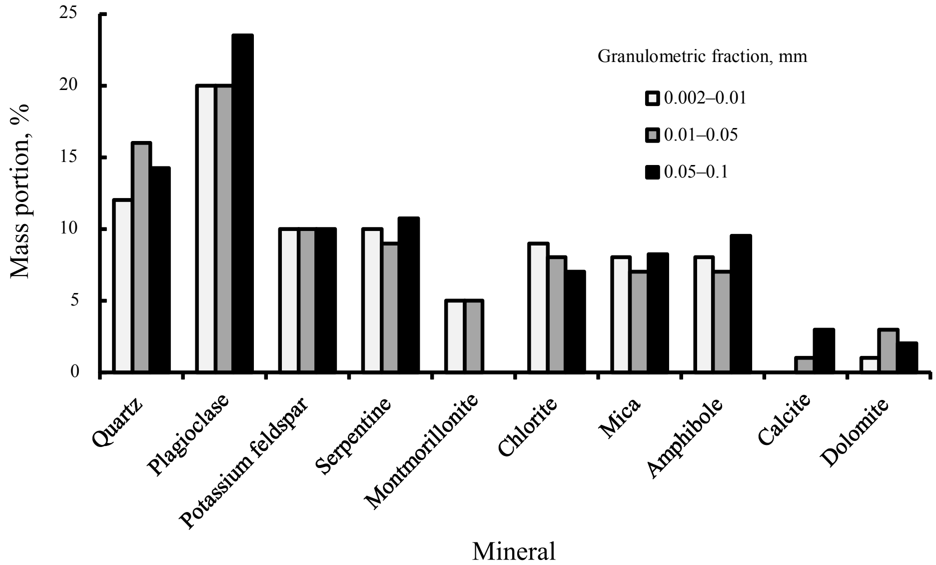

Figure 5. The mineral phase composition of the subsamples from sediment samples collected in the courtyard area on the passage

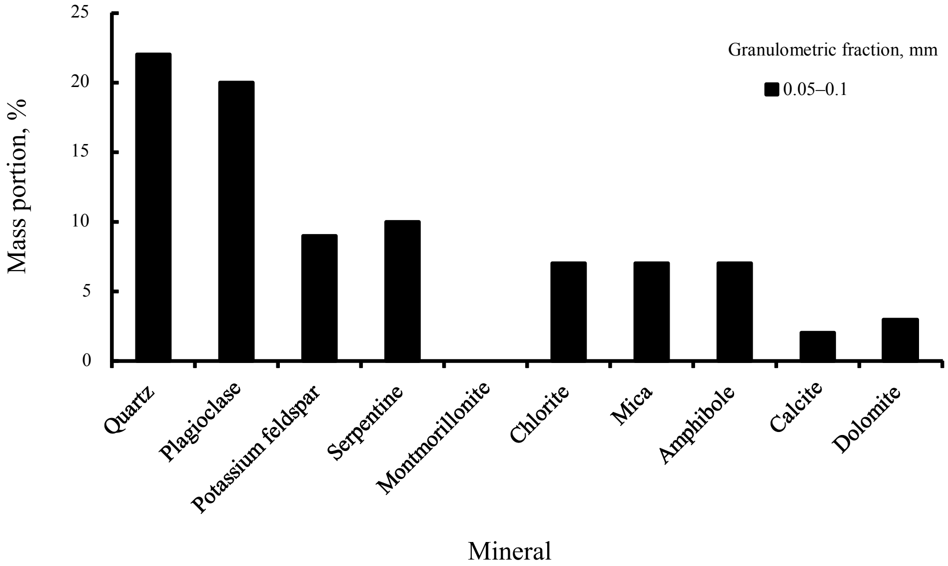

Figure 6. The mineral phase composition of the subsamples from sediment samples collected in the courtyard area on pavement

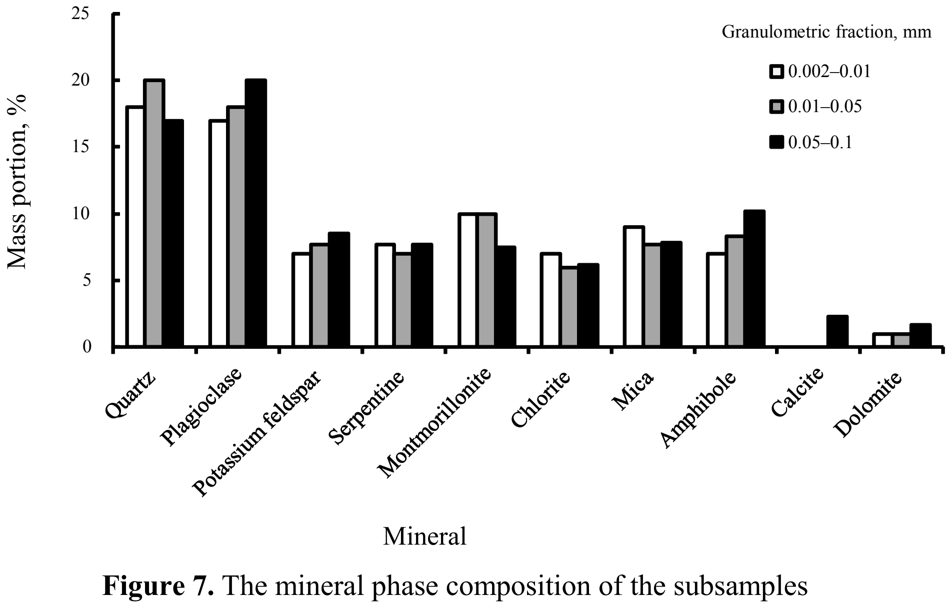

Figure 7. The mineral phase composition of the subsamples from sediment samples collected in the facade area on the lawn

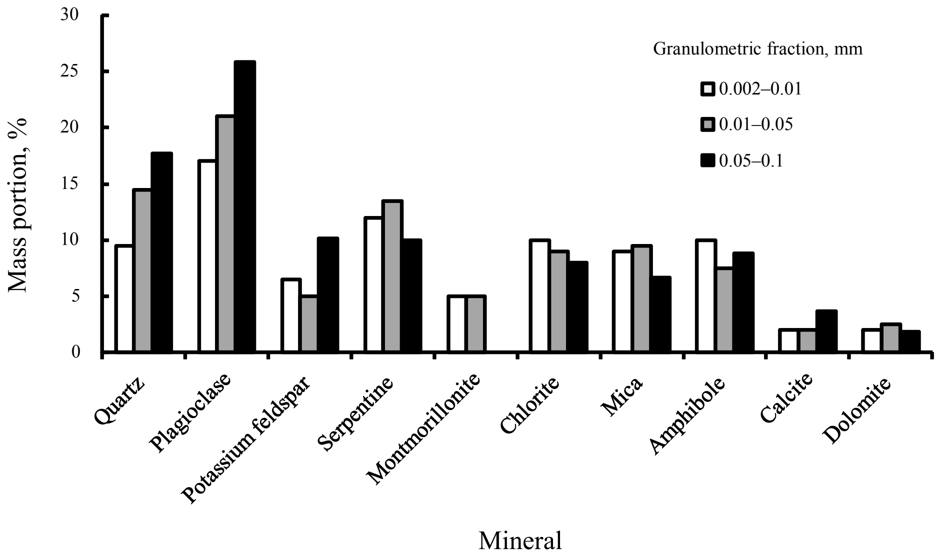

Figure 8. The mineral phase composition of the subsamples from road dust samples collected in the facade area

4. Discussion and conclusion

All the studied granulometric fractions were found in the samples. The particle size fraction > 1 mm represents the fragments of rock; the fine-grained rubble material is often used as anti-ice agent on the roads remained from winter season. The granulometric fraction > 1 mm predominates in the sediment samples (Fig. 2). The content of dust fraction (0.002–0.05 mm) in the landscape areas sections outside the yard is 1.5 times higher than in the inner-yard territories. Apparently, this is due to the presence of roads with intensive automobile traffic. The same content of sand fraction (0.05–1 mm) was obtained in the samples from courtyard and facade areas (50%).

The mineral phase composition of the solid surface sediment does not differ significantly among the studied groups of samples, and landscape zones, as well as over the investigated granulometric fractions. Thus it can be concluded that the dust fractions represent the fragments of the larger particles.

The 3/4 of the mineral content of the studied samples in the city are fine fraction products of crushed stone and building materials represented by the mineral raw materials: granite, gabbros, serpentines, hornblende and others. These rocks are typical for the Middle Urals and form both the basis of the lithogenic substrate and the resource base of the building materials industry. However, taking into account the fact, that there are no undisturbed natural landscapes within the residential neighborhoods of Ekaterinburg, the formation of the mineral constituent of surface dust and dirt sediment must be associated with materials used in construction, including road construction.

The accumulation of dust is associated with a large area of dusty surfaces during the warm period of the year. In dry weather conditions, due to the wind transfer, the surface sediment, primarily the dust fraction, is redistributed over the territory. In rainy weather, the transfer occurs due to surface runoff. In the cold period there is increased abrasion of road surfaces with studded car wheels.

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