RESEARCH PAPER

ATMOSPHERIC AIR DUST CONCENTRATION, COMPOSITION AND SIZE DISTRIBUTION DATA AT BREATHING HEIGHTS IN YEKATERINBURG

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ABSTRACT. Accurate information on air quality serves as the foundation for making regulatory and legal decisions aimed at reducing air pollution. This study investigates the vertical distribution of dust particle concentration, their elemental composition, and size distribution in the atmospheric surface layer in Yekaterinburg. Over eight days in April 2021, 64 dust samples were collected on filters at heights ranging from 0.5 m to 10 m at a single site using a mobile post. The mass concentration of the dust, characterized by heterogeneous data with a coefficient of variation exceeding 30%, exhibited a weak tendency to decrease with height. The proportion of particles smaller than 1 µm decreased with increasing altitude, except for 10 m, where their proportion increased. Conversely, the concentration of p articles ranging from one to two microns decreased closer to the surface. Dust grains of other sizes were nearly evenly distributed at various heights. Dust particles smaller than $PM_{2.5}$ accounted for approximately 45% of the total particles. X-ray fluorescence analysis identified 12 elements in dust particles, with S, Ca, and Fe showing the most substantial content. The proportion of most metals and Ca in solid particles decreased with height, while the content of S and As increased. The Cu, Zn, and Sb content in dust particles remained constant at all measured heights.

KEYWORDS: air pollution, mobile post, dust, particulate matter, particulate composition, vertical distribution, particle-size distribution, urban environment

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INTRODUCTION

Understanding the content of various impurities in the atmosphere and their spatial distribution is crucial for assessing the state of atmospheric air and its impact on the health of urban populations (Baglaeva et al. 2019; Cachon et al. 2014; Hornberg et al. 1998; Jia et al. 2022; Laiman et al. 2022; Lim et al. 2012; Wu et al. 2022; Xu et al. 2021; Yang et al. 2022). Recently, the World Health Organization updated its air quality guidelines, reducing the annual exposure limit to fine particulate matter ($PM_{2.5}$) from 10 to 5 µg/m^3, citing global health considerations (WHO, 2022). Exposure to $PM_{2.5}$ harms human health and is a leading environmental source of premature mortality (Cohen A.J. 2017; Lim S.S. 2012). Monitoring air pollution is vital not only for citizens, raising awareness of health risks associated with air pollutants, but also for policymakers, aiding in the development of regulations and laws aimed at minimizing these risks.

The selection of suitable control methods for these pollutants depends mainly on their nature and size. Predicting the composition of contaminants without direct measurements is challenging since gas and aerosol impurities emitted by anthropogenic sources undergo significant changes in the atmosphere. The chemical composition of atmospheric dust includes compounds of silicon, beryllium, aluminum, cadmium, and other metals, coal particles, and soot aerosol, spores of microorganisms and plant pollen, and other particles of organic origin. Additionally, chemical reactions in the atmosphere form secondary inorganic compounds like nitrates, sulfates, and ammonium (Isidorov 2001; Zaikov 1991).

Roshydromet collects, processes, and analyzes information on the state of the environment, particularly atmospheric air, and its pollution in Russia. The assessment of air pollution in cities is carried out in combination with an evaluation of the meteorological and climatic parameters of the territories under consideration. Industrial enterprises that pollute the atmospheric air of residential areas are involved in the state monitoring of environmental pollution. Alongside regular observations, additional surveys are conducted in some cities, including those under the auspices of industrial enterprises. The location of atmospheric observation points is determined by the objectives related to obtaining data on the characteristics of pollution at global, regional, territorial, and local levels (Federal Service for Hydrometeorology 2020; State Committee for Hydrometeorology of the USSR 1991; Klyuev N.N. 2019; Ministry of Natural Resources 2020). Such monitoring is characterized by recording the concentration of $PM_{2.5}$ and PM_{10} as bulk density, with no determination of size distribution, shape, or chemical composition of PM.

Currently, studies of the particle-size distribution of atmospheric dust are, in most cases, carried out using various types of sensors. However, despite the high level of development of computer technology and measuring equipment, the accuracy and reproducibility of mass and quantitative concentrations reported by different models vary significantly. Studies (Dubey 2022b; Tryner 2020) have shown that particle count data are unreliable, with the distribution of the number and size of dust particles obtained with different sensors not agreeing with each other. Thus, measurements based on direct counting of the number of particles settled on filters remain relevant (Beddows D.C.S. 2023).

The Institute of Industrial Ecology of the Ural Branch of the Russian Academy of Sciences has developed and patented a mobile dust sampling station (Baglaeva 2017). The station consists of a pump powered by a battery, a set of gas meters showing the volume of air that has passed through them, and pipes with filter holders oriented in different directions. In 2016, using a mobile post, a series of measurements of the particulate matter (PM) concentration in the surface layer of the atmosphere of Yekaterinburg at different heights was carried out. The minimum PM value was found at 1 m compared to the values of concentrations at other heights from 0.5 m to 2 m (Baglaeva 2019).

The purpose of the study is to determine the concentration, size, and chemical composition of particulate matter in the ground layer of atmospheric air in Yekaterinburg at different heights. Additionally, this study aims to compare the features of the vertical distribution of dust concentrations amassed by filters based on measurements taken in 2016 and 2021.

DATA AND METHODS

Study area

Dust content measurements in the atmospheric air were conducted in Yekaterinburg, Russia (N56°51', E60°36'). Located in the central part of the Eurasian continent on the border of Europe and Asia, Yekaterinburg is nestled on the eastern slope of the Ural Mountains in the Iset River valley. The city is characterized by temperate continental climate, marked by sharp variability in weather conditions and well-defined seasons. Throughout the year, western and southern winds prevail. The primary contributors to air pollution in Yekaterinburg are road transport and industrial enterprises situated within the city and its vicinity.

Air dust sampling

We adapted the mobile station (Baglaeva 2017) to investigate the distribution of low dust concentrations at a 1-meter height (Baglaeva 2019). The number of filters for sampling was increased to eight on each measurement day, with five filters covering the height interval of 0.5-1.5 m, enabling a detailed study of dust concentration distribution. Filters were positioned at heights of 0.5 m, 0.75 m, 1 m, 1.25 m, 1.5 m, 2 m, 4 m, and 10 m. The appearance of the mobile sampling station is illustrated in Fig. 1.

Measurements were conducted over eight days, from April 9 to April 20, 2021. During the spring months, from early April to mid-May, before trees are covered with leaves and lawns are overgrown, there is a peak in atmospheric air pollution (Goskomgidromet SSSR 1991). The air pollution observation point was situated on an open, dust-free asphalt site, ventilated from all sides, minimizing measurement result distortion by wind shadows from green spaces, buildings, and

Fig. 1. The mobile sampling station

Table 1. Time and meteorological conditions of sampling

Date	Time		Pressure, mmHg	Temperature, °C	Humidity, %	Cloud cover, %	Wind	
	Start	Finish					Direction	Speed, m/s
09.04.2021	11:47	20:47	749.3	12	29%	50	SE	1-2
12.04.2021	11:48	20:52	756.8	13.9	10%	70	NW	2-3
13.04.2021	11:13	20:30	756.8	21.4	9%	10	SW	1-2
14.04.2021	12:10	21:10	749.3	18.1	10%	60	W	3-4
15.04.2021	11:45	21:05	739.8	22.4	12%	20-30	W	5-6
16.04.2021	11:15	20:40	743.8	11.6	23%	10	E	1-2
19.04.2021	12:00	21:00	748	5	18%	5	N	2-3
20.04.2021	11:51	20:51	746	11.2	15%	40	W	3-4

other obstacles. All measurements were carried out at a single site; Table 1 details the weather conditions and sampling times.

The mobile station (Baglaeva 2017) operated for approximately 9 hours a day and pumped an average of 30 m^3 of air daily. To ensure accuracy, we initially pumped 10 m^3 through the connected series of counters (according to the readings of the first counter in the row) before the start of the experiment. A check of the meter readings showed a difference of 0.7%; hence, no correction factors were introduced for subsequent calculation.

Data preparation procedure

Before air pumping, we measured the filter's mass and determined the elemental composition of each clean filter, averaging three different measurements. After air pumping, we re-weighed the filters and determined the mass of the settled dust as the difference between the masses before and after air pumping. Daily recordings of temperature, atmospheric pressure, relative humidity, wind speed and direction were made at the measurement site.

The qualitative elemental composition of pure filters and filters with atmospheric dust was determined using an INNOV X Systems X-5000 X-ray fluorescence spectrometer, with a systematic measurement error ranging from 20% for most elements to 30% for arsenic.

Particle size distribution

Each dust filter was photographed with an XJP-H100 metallographic microscope (Wuzhou New Found Instrument Co., Ltd) and processed for easy analysis. An example of a filtered photograph is shown in Fig. 2. Dust particles on each filter were counted in five fields of view to determine their disperse composition. Subsequently, the total number of dust particles was distributed over 11 size intervals: less than 1 μm, 1–2 μm, 2–3 μm, 3–4 μm, 4–5 μm, 5–6 μm, 6–7 μm, 7–8 μm, 8– 9 μm, 9– 10 μm, and more than 10 μm.

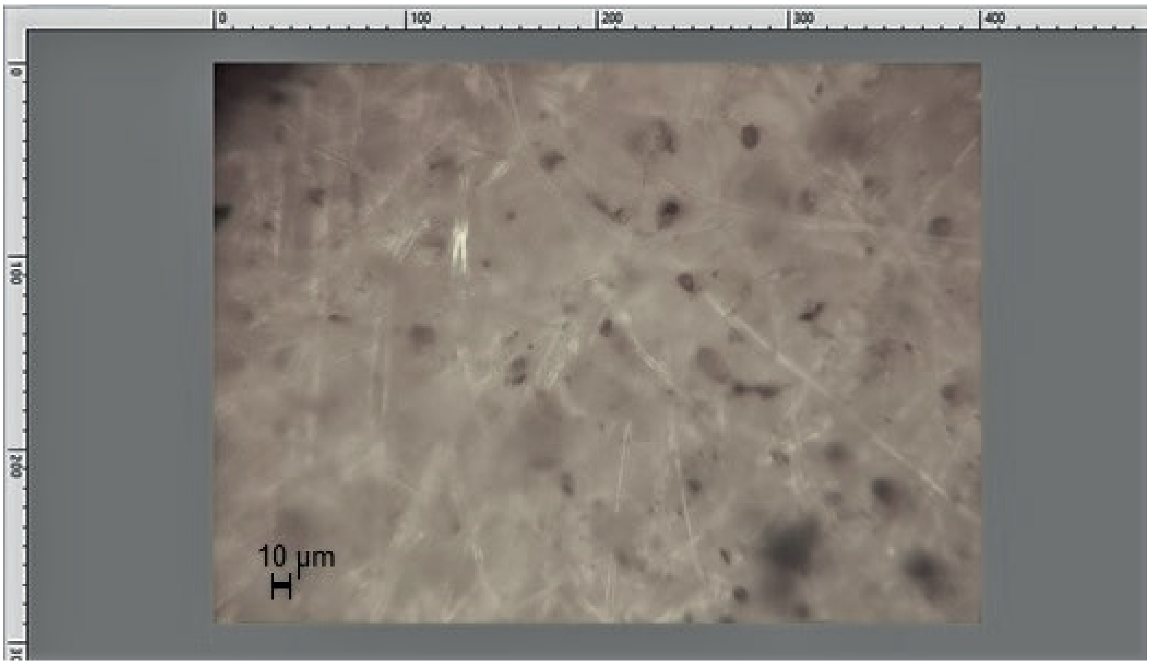

Fig. 2. Photograph of the filter with deposited dust (dark spots)

RESULTS

The calculated dust concentrations averaged over eight days of measurements are presented in Table 2. Dust content is observed to be higher at heights of ≤ 2 m from the ground compared to heights of ≥ 4 m, with no significant differences found within the 2 m range. Coefficients of variation were determined to assess the homogeneity of the data.

Figure 3 shows a comparison of the dust content in the air of Yekaterinburg in 2021 at heights ranging from 0.5 to 10 m with the results of a series of the PM concentration measurements from 2016 (I, II, III seasons) (Baglaeva 2019).

The images of the filters captured in 5 fields of view using a metallographic microscope (similar to Fig.2) were processed. The settled dust grains were counted and distributed over size intervals from 0 μm to 10 μm with a step of 1 μm; the last interval encompassed all dust particles larger than 10 μm. A homogenous dispersed composition was identified for all filters. Figure 4 demonstrates the size distribution of dust particles deposited on the filter for each sampling height, averaged over eight days. The particle size value represents the arithmetic mean over the interval, 10.5 μm corresponds to the maximum PM size. The proportion of the smallest particles (<1 μm) decreased with height, except for 10 m, where their proportion increased. Particles ranging in size from 1 micron to 2 microns, on the contrary, decreased in number the closer they were to the earth's surface. Dust grains of other sizes exhibited almost even distribution along the height.

Subsequently, we identified the elemental composition of the filter with deposited dust using an X-ray fluorescence spectrometer. Chemical elements that were either fixed on the filter with dust or exhibited an increased proportion compared to the clean filter were deemed a part of the chemical composition of the dust.

An analysis conducted on an X-ray fluorescence spectrometer unveiled 12 elements on filters with settled dust. Table 3 presents the averaged content of these elements over all days of measurements. The numbers indicate the mass fraction of the element in the dust. Based on the calculated average dust content in 1 m^3 of air, equal to 0.15 mg/m^3, to calculate the content of each individual element in 1 m^3 of atmospheric air, the value obtained by the XRF method must be multiplied by 0.15*10^{-6}.

Table 2. The value of dust concentration

Height, m	Mean dust concentration ± Standard deviation, mg/m^3	Coefficient of variation	Min dust concentration, mg/m^3	Max dust concentration, mg/m^3
0.5	0.155 ± 0.052	0.34	0.085	0.220
0.75	0.163 ± 0.058	0.36	0.069	0.250
1	0.170 ± 0.053	0.31	0.080	0.220
1.25	0.162 ± 0.049	0.31	0.078	0.213
1.5	0.168 ± 0.058	0.35	0.094	0.259
2	0.167 ± 0.054	0.32	0.081	0.224
4	0.084 ± 0.029	0.35	0.044	0.122
10	0.115 ± 0.043	0.37	0.058	0.178

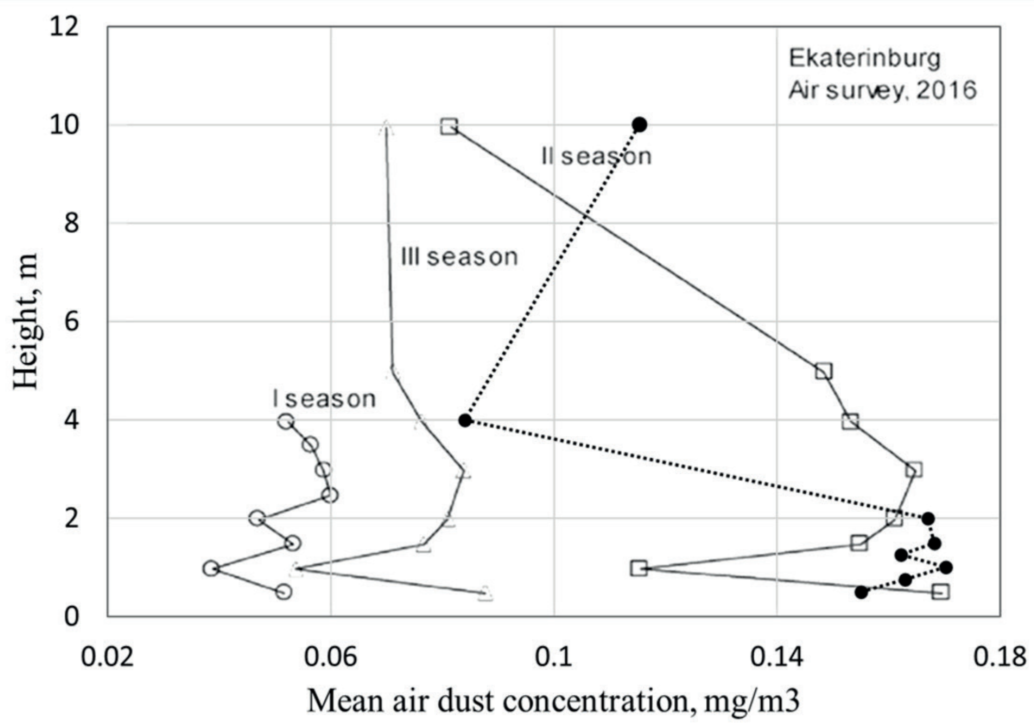

Fig. 3. Relation between the dust content in the atmospheric air and height (average dust concentration for all days of measurements is given. Solid lines refer to 2016, and dotted line refers to 2021)

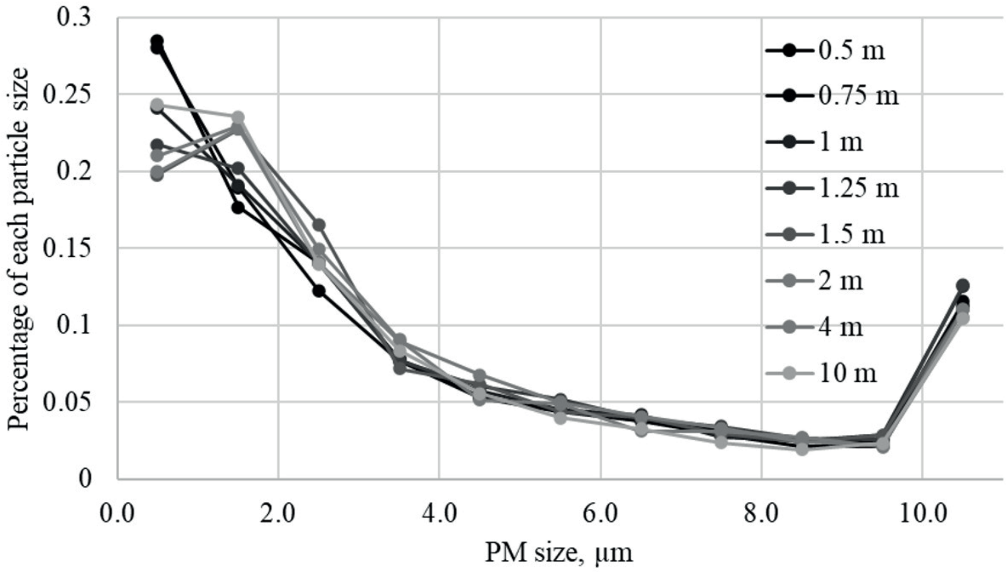

Fig. 4. Dispersed dust composition deposited on the filter

Table 3. The elements' content on filters with settled dust

	S	Ca	K	Fe	Ti	Cr	Mn	Ni	Cu	Zn	Sb	As
ppm	90150	$1.1*10^5$	23220	83313	4190	417	737	430	380	353	700	56

DISCUSSION

In contrast to the previous study (Baglaeva 2019), the minimum dust concentration averaged over 8 days of measurements for the studied human breathing zone (0.5–2 m) turned out to be at a height of 0.5 m (Figure 4). However, on some measurement days, the minimum occurred at heights of 0.75 m, 1.0 m, and 1.25 m. Such results may be associated with the features of air flows in the surface layer of the atmosphere during warm, sunny, calm weather. No statistically significant relationship was found between the obtained data and the main weather conditions (temperature, atmospheric pressure, relative humidity, wind speed and direction (Table 1)). On the days of measurements, there was calm weather (5 days out of 8) or a weak wind, no more than 4-5 m/s. A probable unaccounted parameter is the vertical component of wind speed and force. A slight increase in dust concentration at a height of 10 m (compared to data at a height of 4 m) may be attributed to the peculiarities of the filter location. Unlike others, it was positioned on the edge of the building 3 meters above the roof, which could impact the distribution of dust in that area.

The obtained values of the coefficients of variation for the surface concentration of dust exceeding 0.3 (Table 2) indicate strong deviations of the measured values of concentrations from the arithmetic mean, highlighting the heterogeneity of the data. This result aligns with the information on significant observed diurnal changes in dust content in the surface layer of atmospheric haze up to 70 m high (Kondratiev 1983).

The minimum value of the concentration of dust particles in the surface layer of atmospheric air up to 2 m was observed at a height of 0.5 m, in contrast to the measurement results from 2016, when the PM minimum at a height of 1 m was a special point (Figure 3).

This study's average dust concentration did not exceed 0.17 mg/m^3 (Table 2). The maximum permissible concentration (MPC) for particulate matter in the atmosphere of populated areas according to hygienic standards SanPiN 1.2.3685-21 is 0.5 mg/m^3. The maximum dust concentration obtained at a height of 1.5 m (Table 2) did not exceed this critical value. Additionally, the MPC for dust consisting of particles with a diameter of 10 microns or less is 0.3 mg/m^3. For dust with particles of 2.5 microns or less, it is 0.16 mg/m^3.

Figure 4 shows that the proportion of the smallest particles (<1 μm) decreases with height, except at 10 m where the proportion increases. The proportion of particles whose size varies from 1 to 2 microns, on the contrary, decreases as they approach the earth's surface. Dust grains of other sizes exhibited almost even distribution along the height. The proportion of $PM_{2.5}$ particles is approximately 0.45, and the proportion of PM_{10} reaches 0.89. We do not have the ability to calculate the distribution of mass concentrations of particles by size, since the density of particles of different sizes is unknown, and the assumption about density sameness is incorrect.

Note the similarity of the distributions of the elements' proportion by height for metals. The proportion of most metals and calcium in solid particles decreased with height, following a distribution pattern similar to Fig. 5 (right). The content of sulfur and arsenic at 4 m and 10 m was higher than at heights not exceeding 2 m (Fig. 5 (left)). The copper, zinc, and antimony content in dust particles remained constant at all measured heights.

To estimate the content of some chemical elements in the surface layer of atmospheric air, an average dust content of 1 m^3 was used. The content of toxic elements turned out to be significantly lower than the maximum permissible concentration. In particular, one element of the first hazard class was detected (As). Hygienic standards (SanPiN 1.2.3685-21) establish the average daily maximum concentration limit for As in the atmospheric air of urban settlements at the level of $3*10^{-4}$ mg/m^3. In this study, the calculated average value of arsenic content is $8.4*10^{-6}$ mg/m^3.

CONCLUSIONS

1. Inhomogeneities in the dust concentration distribution in the human breathing zone were identified. The average dust concentration in the study area, 0.155 mg/m^3, was observed at a height of 0.5 m. The obtained dust concentration values remained below the highest

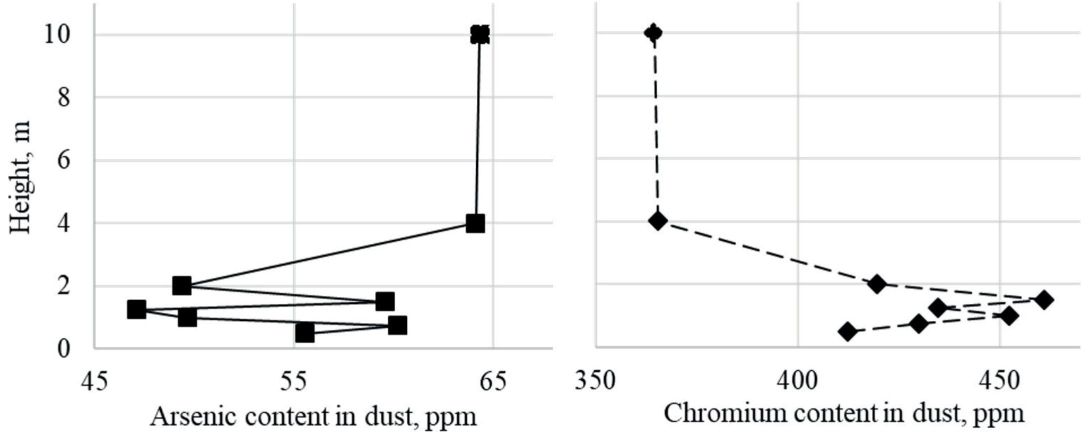

Fig. 5. Relation between the content of chemical elements in dust and height

permissible values according to the hygienic standards (SanPiN 1.2.3685-21). To comprehend the nuances of the dust's vertical distribution, it is advisable to employ a device to monitor the vertical wind speed.

2. The primary chemical elements in the composition of dust sampled at the height of human breathing were identified (Table 3). The 8-day average of dust content is provided in parentheses: Ca (106,140 ppm), S (90,150 ppm), Fe (83,313 ppm), K (23,220 ppm), Ti (4,190 ppm), Mn (737 ppm), Sb (700 ppm), Ni (430 ppm), Cr (417 ppm), Cu (380 ppm), Zn (353 ppm), As (56 ppm).

3. The dispersed composition of dust in the human breathing zone was determined. The proportion of $PM_{2.5}$ particles was approximately 0.45. The fraction of the smallest particles (<1 μm) decreased with height, except at the height of 10 m, where their fraction increased. Particles ranging from 1 to 2 microns, on the contrary, decreased in number, the closer they were to the earth's surface. Dust grains of other sizes exhibited almost even distribution along the height.

4. The mobile station can be effectively utilized in the urban environmental monitoring system to assess the level of dust pollution in the atmospheric air, including at the height of human breathing, in specific local areas.

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