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Dust concentration in the air of roadside areas

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Abstract. The article addresses a pressing issue – air pollution in cities with fine dust particles. This study collected 18 dust samples during spring and autumn periods in various parts of Elista city. Based on the analysis results of the selected dust's dispersed composition, regression equations were developed, where the dependent variable was the concentration of PM10 and PM2.5, and the independent variables were the distance from the sampling site to the highway and the height of the sampling site from the ground. Samples were collected from window sills and other horizontal surfaces where dust settled from atmospheric air. Thus, the study aimed to critically analyze the patterns of dust composition changes in the air influenced by various factors, excluding the impact of industrial production, which is not widespread in this city. Empirical dependencies of fine dust concentrations of PM10 and PM2.5 fractions on the distance from the road and the height of the sampling site were obtained. A general range of values was obtained for the dust mass distribution function by particle diameters during spring and autumn. The study found that the geometry of the building, its relative position to seasonal winds, and the distance from the road play a much more significant role in the dispersed composition than wind speed, humidity level, or season
Keywords: particulate matter, city, particle size distribution, dust

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1. INTRODUCTION

It is widely known that solid dust particles with diameters less than 10 μm (PM10) and, especially, less than 2.5 μm (PM2.5) are air pollutants leading to respiratory diseases. Identifying the patterns of this pollutant's distribution is an important and relevant task addressed in this study. Dust particles with an equivalent diameter d_p <40 μm, according to our experimental data [1], have a settling velocity of about 4 cm/s, allowing them to be transported by slight air currents over considerable distances and remain suspended in atmospheric air for a long time. Of course, larger particles can be transported by strong wind currents, but typically over short distances. Therefore, in a city, on horizontal surfaces

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distant from pollution sources, the presence of fine dust fractions is expected with high probability. Since the dependence of particle settling velocity on their equivalent diameter is quadratic, the probability of detecting particles with larger diameters significantly decreases.

However, this does not indicate that particles less than 10 μm must necessarily predominate on horizontal urban surfaces. Fine dust arises from crushing and abrasion of materials. Statistics show that such processes are most common in industry or during active vehicle operation. Industry in the city is represented by only a few factories, including ZAO KalmTatneft, LLC Plant ZHBI Kalmykia, LLC Standart-Beton, and JSC Plant Zvezda (Mechanical Engineering and Metalworking). Thus, it can be assumed that there is a small amount of fine dust in the city, if we do not consider dust brought in from neighboring regions and, of course, the contribution of vehicles. Therefore, for this study, dust samples were collected from horizontal surfaces in Elista city, distant from pollution sources, to subsequently determine their granulometric composition, assess the proportion of PM10 and PM2.5, and systematize the effects of factors discussed in the next section of this article.

2. METHODS AND MATERIALS

1.1 Literature review

Before carrying out this work, attention was drawn to the following works, which studied the dust pollution of roadside areas with fine dust. The process of particle settling, which is of interest to this work, was experimentally investigated in studies [2-4]. All these works provide a function describing the dependence of settling velocity on particle size. The Stokes formula for settling velocity, presented in works [1-2, 4], is valid when a uniform particle falling velocity is reached, where the medium resistance force balances the particle's gravitational force. In the context of our study, a dust particle needs to be, on the one hand, fine enough to move with the air flow, and on the other hand, large enough to settle. Particles of 2.5 μm in size have a settling velocity of about 0.02 cm/s or 72 cm/h, which does not exclude the possibility of their settling but reduces it. Thus, it can be assumed that the actual content of PM10 and PM2.5 fractions in Elista city air is much higher than what was obtained in our experiment, where dust was collected not directly from the air but from surfaces.

Study [3] provides experimental data on how air humidity levels and artificial wetting increase settling velocity. In the context of our research, this suggests that the main accumulation of fine dust on window sill surfaces may occur under wet weather conditions.

Study [4] conducted a laboratory experiment on dust settling to investigate the influence of concentration and granulometric composition on the settling velocity of fine fractions. To observe the settling velocity, an experimental system consisting of a fiber-optic imaging sensor, a high-speed camera, and a high-intensity light source was used. The developed setup allows simultaneous measurements of particle size and settling velocity. The experiment showed that at high dust concentrations, large particles settle slower than the theoretical value, while small particles settle faster. The influence of granulometric composition on settling velocity may be related to sediment concentration and increases with its rise.

It is worth noting the prevalence of scientific research involving sampling in urban environments. In study [5], dust samples were collected in the Voroshilovsky and Krasnoarmeysky districts of Volgograd at public transport stops and analyzed using a Microtrac S3500 laser analyzer, which determines particle size by measuring changes in light intensity as it passes through the particle. The obtained PM10 fractions were 4% and 1%, respectively. Study [6] determined the dispersed composition of dust collected in the steppe zone using microscopy. It was found that the Elton steppe region is a source of fine natural dust with PM10 reaching 14%, while in the Volga-Akhtuba floodplain, coarse dust predominates, and PM10 content is within 1-2%.

Article [7] presents results of granulometric analysis of 25 road dust samples from Tobolsk. Samples weighing 200 to 300 grams were collected using plastic brushes and shovels from road surfaces divided into 1m x 1m sections. The samples were then placed in plastic bags and delivered to the laboratory for further analysis. Particle size distribution was determined using a Mastersizer 3000 laser particle size analyzer, which uses laser diffraction technology to measure and analyze particle sizes in samples. Fine sand fraction with particle sizes from 100 to 250 micrometers is the

dominant component of the granulometric composition, averaging 64.8% of the total amount. This high sand content is due to the transfer of smaller clay and dust particles through turbulent vortices generated by vehicle movement. Smaller particles ranging from 60 to 90 micrometers may originate from industrial sources and thermal power plants. In Tobolsk, the content of particles ranging from 50 to 100 micrometers is relatively low, indicating minimal industrial influence.

In Grodno, dust samples were collected at five points near dust-generating sources such as road interchanges and sanitary protection zones of enterprises [8]. Microscopic analysis of solid particles adsorbed on filters was conducted using a МИКМЕД-6 microscope equipped with a X40 objective and a ToupCam 14.0 MP video eyepiece with a ToupTek FMA050 adapter. Fifteen separate viewing areas were selected in each filter, the number of particles in each area was counted, and their corresponding sizes were measured. The concentration of solid particles in atmospheric air in different areas of Grodno, determined by gravimetric studies at the extreme points «KSM» and «Biocom», varied significantly, with results ranging from 573 to 1,774 micrograms per cubic meter. The study of particle size distribution showed that the most common fraction in Grodno's atmospheric air at the time of sampling was particles with a diameter of 0.5 to 1 μm. At the time of sampling, the most common particle size in Grodno's air varied across different locations: from 41.51% at «KSM» to 61.33% at «Azot». A clear inverse relationship was observed between particle size and their proportion in the samples.

For the study, leaves of two most common tree species in Tomsk – balsam poplar and birch [9] — were selected. The research results showed that the highest dust contamination was observed in the Kirov district of Tomsk. Specifically, the dust mass per square meter of birch leaf surface in the Kirov district amounted to 28.98 grams. Sovetsky district of Tomsk, the maximum dust settling rate was 39.5 grams per day and was observed on birch leaves. Additionally, the highest dust settling rate on balsam poplar leaves was recorded at 9.8 grams per day.

In study [10], the granulometric composition of airborne dust in a Volgograd shopping center was determined using microscopy. Data analysis was performed using the sectioning method, where particles were conditionally divided into coarse and fine fractions for more detailed analysis. The PM10 content in the air was found to be 10–20%. In research [11], dust samples were collected from different areas of Elista city for microscopy-based analysis of dispersed composition. The maximum PM10 proportion among the samples was 70% in the southern part of the city, while the minimum was 10% in the southwest. Based on wind rose data, it was concluded that dust originates from the desert, and in the southwest area, the spread of fine dust is hindered by a large number of green spaces.

In recent years, concerns have arisen that chemical substances contained in tire materials seep into the environment as part of road debris, such as dust [12]. The researchers wanted to learn more about these chemicals, so they collected dust samples from roads and parking lots in Guangzhou, China. They studied dust particles of different sizes and found that the smallest ones ($d_p < 250$ micrometers) accounted for more than 72% of the total dust amount both on the roadway and in the parking lot. The PM20 fraction in this study was 2-4%. Dust sampling was performed using an affordable handheld vacuum cleaner equipped with a pre-cleaned nylon bag with a pore size of approximately 25 micrometers.

A new sampling method was developed using a mobile sampling system for collecting suspended road dust on paved roads [13, 14]. To calculate the net mass concentration of suspended road dust in the sample collected behind the front wheel of the mobile sampling system, the background subtraction method was used. The ratio of PM2.5 concentration to PM10 concentration in suspended road dust varied from 0.25 to 0.40 depending on the sampling location.

The results of chemical analysis of particulate matter samples showed that there are specific profiles of road dust suspension sources depending on sampling locations and particle size ranges. There is a relationship between sampling location and mass percentage content of elements in samples selected based on granulometric composition. Considering the dependence of mass fractions of Zn and Cu/Sb on average hourly traffic, it is evident that as traffic intensity increases, tire and brake wear increases, and consequently, the amount of dust from the wear of these vehicle components deposited on paved roads rises.

It was found that the values of organic carbon and elemental carbon do not undergo significant changes depending on average hourly traffic. However, it was noted that organic carbon values for coarse dust are two to three times higher than for fine dust, indicating a clear dependence of organic carbon on the particle size range. The mass concentration of PM10 in this study reaches 10–15%, with detailed data provided for individual chemical elements.

A study was conducted on the concentrations of PM10 and PM2.5 in Hong Kong[15]. The annual mean concentration of PM_{coarse} (particles smaller than 10 μm but larger than 2.5 μm) was 14.9 ± 8.6 μg m^{-3} (± standard deviation), which was nearly half (45%) of the ambient PM10 concentration (32.9 ± 18.5 μg m^{-3}). PM_{coarse} also showed large seasonal variations, ranging from 8.1 μg m^{-3} in summer to 24.8 μg m^{-3} in the second winter. Meteorological data suggested that the seasonal contrast was due to variations in source intensity and/or air mass origin. Among the measured components, geological material calculated from crustal element oxides is the largest component of PM_{coarse} (35%), followed by nitrate (15%), sea salt ions (11%) and organics (8%).

Approximately 70% of the total mass is contributed by the two dust particle factors, and the remaining 30% is attributed to the liquid water content. Based on thermodynamic modeling using ISORROPIA II, the original composition of PM_{coarse} varies with the season, primarily due to changes in the air mass source. In summer, sea salt and dust factors dominate the PM_{coarse} loading, while in autumn and winter, dust factors account for a larger proportion. A significant factor for the high PMcoarse levels in Hong Kong is the intense emissions of fugitive dust under favorable weather conditions, which contribute to the regional transport of air pollutants. The study identifies several areas for future research, such as identifying the specific mechanisms underlying high PMcoarse concentrations.

In a different study [16], the particle number (PN) and particle size distribution (PSD) characteristics of several gasoline direct injection (GDI) vehicles with different configurations were examined under several test cycles: NEDC, WLTC FTP-75, and CLTC. The results showed that test cycles had a significant impact on overall PN emissions, with the WLTC showing a greater sensitivity to changes in start-up conditions. Solid PN was predominantly generated during the start-up phase, while volatile and semi-volatile compounds mainly formed during the high-speed segment of the test cycles.

1. Different test cycles have differing emissions characteristics.
2. CLTC cycle, closer to local driving conditions in China, is being considered for future legislation.
3. Sub-23 nm particles account for a significant portion of PN emissions and should be considered in future regulations.
4. GPF shows clear capture effect on sub-23 nm particles across test cycles but is less effective for ultra-fine particles, requiring further research.

The study [17] investigates the total mass and average concentrations of heavy metals in PM10, PM2.5, and road dust along selected road networks in India. Researchers collected a total of 112 PM samples and 21 road dust samples from six stations and one background site in the Indian city of Dhanbad between December 2015 and February 2016, and analyzed them for the presence of seven heavy metals iron, lead, cadmium, nickel, copper, chromium, and zinc. The concentrations of these heavy metals were determined using atomic absorption spectrophotometry. Additionally, Principal Component Analysis was used to determine the sources of the heavy metals. The results may provide crucial insights into the health risks associated with air and road pollution in this area.

The study's findings indicate that the average mass concentration of PM10 and PM2.5 in the area was 229.54±118.40 μg/m3 and 129.73 ±61.74 μg/m3 respectively. The concentration of heavy metals was found to be higher in PM2.5 compared to PM10. The pollution load index value for both PM10 and PM2.5 road dust was found to be in the deteriorating category, with vehicles found to be the major source of this pollution. Based on the analysis of mass concentration, the study area is facing severe contamination of both PM10 and PM2.5 particles. Vehicles were identified as the primary source of heavy metals in these particles and in road dust. Children were found to be more at risk for non-carcinogenic effects from heavy metal exposure compared to adults, whereas the risk of carcinogenicity was negligible.

In a different study [18] particulate matter emissions from traffic in London were measured and analyzed during the period from September 2019 to August 2020, both in roadside and background urban areas. The data showed that brake wear was the highest average non-exhaust emission source, and the concentrations of non-exhaust particulate matter (PM)10, PM2.5, and key tracers such as barium, zinc, and silicon varied with driving style, weather conditions, and the influence of the COVID-19 lockdown. Additionally, statistical analysis revealed that non-exhaust emission factors were dependent on speed and road surface wetness.

A year-long monitoring campaign was conducted at two locations in London (Marylebone Road and Honor Oak Park) to quantify non-exhaust emissions. To determine the concentrations of non-exhaust emissions, previously developed scaling factors for Ba (brake wear), Zn (tyre wear), and Si (resuspension) were applied to the measured concentrations of PM10 and elemental composition. A CO2 dilution method was used to predict fleet average non-exhaust emission factors, which had been previously used in NOx measurements. However, there were systematic temporal variabilities in the CO2 dilution factor, which must be taken into account.

The change in particulate matter concentrations between roadside and background locations (roadside increment) varied significantly over the course of the year. Comparing data pre-lockdown and during lockdown showed a marked decrease in overall roadside increment for both PM10 and PM2.5. Brake wear appeared to be the most prevalent source of non-exhaust particulate matter, however, the reduction in traffic during the lockdown did not significantly decrease the concentrations of this emission source. Tyre wear and resuspension concentrations remained unchanged, suggesting complex relationships with traffic volume.

A spatial analysis of particulate matter (PM) and hydrogen sulfide (H2S) gas pollution was conducted in the area surrounding a university library building [19]. This was done in response to reports of a strong sulfide odor and general dissatisfaction with air quality among employees and students. Measurements were taken at both 10 and 20 meters above ground level using a DJI Matrice 600 UAV. The purpose of the investigation was to assess air quality and compare it to the theory of air flow around the building. Significant differences in pollutant concentrations, up to 63%, were observed in different areas. However, there was a strong correlation between these measured differences and the direction of the wind, as predicted by aerodynamic theory. High levels of PM and H2S were found in areas of strong turbulence, such as the edges of the building and the leeward side. However, H2S was dispersed by air turbulence towards the parking lot side, resulting in lower concentrations of the gas. Analysis showed that the permissible concentration of H2S was exceeded in some areas.

Vehicle exhaust emissions decreased thanks to stricter regulations and advancements [20]. However, non-exhaust emissions, such as brake and tire wear, have not been extensively regulated in the past, and their contribution to particulate matter in urban areas is increasing. On-road data from three different types of vehicles, collected under real-world driving conditions, was analyzed to determine the impact of vehicle mass and braking intensity on brake and tire particles. Measured near the front right wheel, highest concentrations of brake PM2.5 (520–4280 ug/m3) and PM10 (950–8420 μg/m3)

A marked disparity in peak PM2.5 and PM10 concentration levels, for both brake and tire particles, was observed between the heaviest and lightest vehicles. The deceleration rate of braking was found to be crucial in predicting the peak concentrations of PM2.5 and PM10 during heavy braking episodes for all three vehicles. Brake particles had a unimodal mass size distribution with a mode diameter of 3-4 micrometers, whereas tire particles had a slightly larger mode diameter of 4-5 micrometers. This study's findings highlight the influence of driving conditions and vehicle weight on brake and tire emissions.

1.2 Analysis of the composition of visible particles of dispersed dust

The dust dispersed composition is a characteristic of a powder composition or dispersed phase by particle size. It shows how much of the mass is made up of particles in the presented range of their sizes. The characteristics of the dispersed composition in this article are given in the form of tables 1 and 2, obtained from the integral function of the mass distribution over particle diameters. In accordance with GOST 56929-2016, the fractional composition of the selected dust was studied using microscopy and using the SPOTEXPLORER program.

According to the procedure described above, it is required to obtain dust sample particles on a microscope slide for further study. To achieve this goal, a synthetic brush is most often used to apply dust to glass, but this common method has several significant disadvantages such as: the complexity of the process itself, the inability to separate the stuck dust agglomerates that arose during the transportation of the sample to the laboratory in a container, as well as the possibility of carrying away small dust particles before they hit the glass. using a microscope, which distorts the data obtained.

As an attempt to eliminate these shortcomings, a camera was created and used for the first time in this study, the appearance of which is shown in Fig. 1A. This simple device allows you to create a vortex turbulent flow inside an enclosed space, and then all the particles settle on the glass.

After pre-cleaning with a synthetic cloth, the slide is placed on the bottom of the chamber and closed with a housing as shown in Figure 1B. A small amount of the dust sample is placed on a rectangular plate using a laboratory spoon, after which the plate is inserted into the housing in a special groove. The camera is closed with a lid in which there are two holes. The plate with the dust sample is located immediately after the inlet, and an air-permeable fabric is located in front of the outlet, which prevents dust particles from leaving the chamber. A single compressed air stream is supplied using a hand pump or an analog, which blows the dust off the plate inside the chamber and separates the particles from each other before settling onto the plate. Then a few minutes pass so that the small diameters have time to settle on the slide. This device is under development and is being used for the first time, but according to the tests performed, the results are more reproducible, the mass fraction of the fine fraction increases slightly, and the process of applying dust to glass becomes more standardized and simpler.

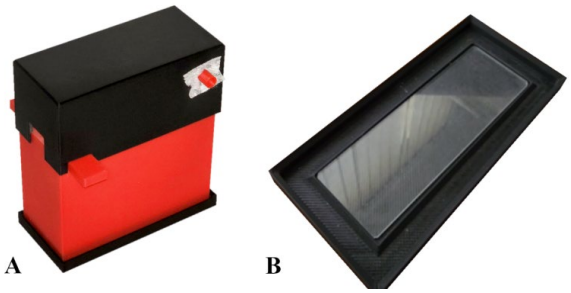

Fig. 1. The chamber of the dust sample uniform distribution on the surface of the microscope slide: a – the camera is assembled, b – the slide inside the camera.

The ToupView program was used to take photos. At least 5 photographs were taken for each sample, each of which contained at least 300 particles. This condition makes it possible to achieve reproducibility and convergence of the experiment. Tables 1 and 2 present the average data of the obtained analysis results. The photograph from the microscope was processed in black and white in the GIMP graphics editor to work with the SPOTEXPLORER program, which supports only black and white images, an example of which is shown in Figure 4.

An integral function of the particle mass distribution over diameters was obtained for each selected sample. Fig. 3-4 show the smallest and largest functions based on the proportion of PM10 for samples taken in spring and autumn, that is, this is the range of values obtained based on the results of the study. Based on the obtained functions, the proportion of PM2.5, PM10 was determined, and D50 was the median diameter, D5 was the diameter less than 5% of the total mass of the material, and D95 was the diameter less than 95% of the total mass of the material.

3. RESULTS AND DISCUSSION

3.1. Granulometric composition of dust

Table 1 shows data from the dispersed analysis of dust collected on April 16, 2025, and Table 2 shows data from September 30, 2024.

Table 1. Results of the analysis of the dispersed composition of dust collected in the spring.

Sampling location	PM2.5, %	PM10, %	D5, μm	D50, μm	D95, μm	Distance from the road, m	Height, m	Coordinates: latitude, longitude
6	0.08	9.8	8	25	40	40	11	46.305, 44.269
8	0.07	7.9	9	28	50	60	6	46.302 , 44.194
4	0.05	5	10	36	50	100	6	46.303, 44.313
2	0.06	3.5	12	34	55	200	2	46.327, 44.279
3*	0.03	2	20	50	80	530	1.5	46.318, 44.317
7*	0.04	1	20	56	80	620	2	46.295, 44.235
5	0.02	0.9	23	60	87	500	2	46.299,44.293
1	0.01	0.4	24	64	90	1250	1	46.330, 44.244

* – Samples marked with an asterisk were not included in the regression equations and were retained for further testing.

The map of sampling in the spring period is presented in Fig. 2.

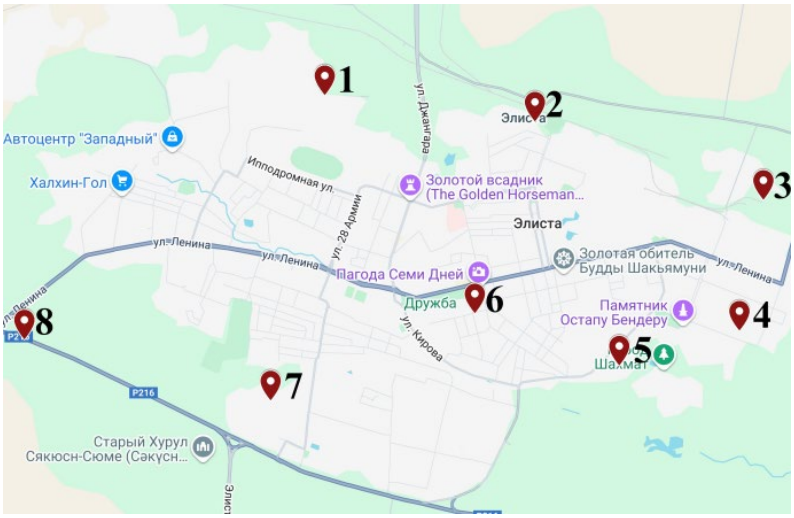

Fig. 2. Sampling points in spring.

Table 2. Results of the analysis of the dispersed composition of dust collected in autumn.

Sampling location	PM2.5, %	PM10, %	D5, μm	D59, μm	D95, μm	Distance from the road, m	Height, m	Coordinates: latitude, longitude
9	0.35	15	7	21	40	60	4	46.292, 44.243
3	0.2	10	8	26	45	250	6	46.313, 44.205
6	0.11	6.8	9	35	60	230	3	46.332, 44.262
8	0.16	5.5	10	30	50	50	0.5	46.302, 44.314
2*	0.09	5	10	40	60	350	2	46.307, 44.216
7	0.06	4	12	47	80	350	1.5	46.317, 44.313
5	0.08	2.2	16	48	80	1160	1.5	46.333, 44.215
1*	0.03	2	18	50	80	600	1.5	46.297, 44.229
10	0.015	1	14	61	90	280	0.5	46.300, 44.285
4	0.01	0.5	24	66	90	1350	6	46.323, 44.193

* – Samples marked with an asterisk were not included in the regression equations and were retained for further testing.

The sampling map for the autumn period is shown in Fig. 3.

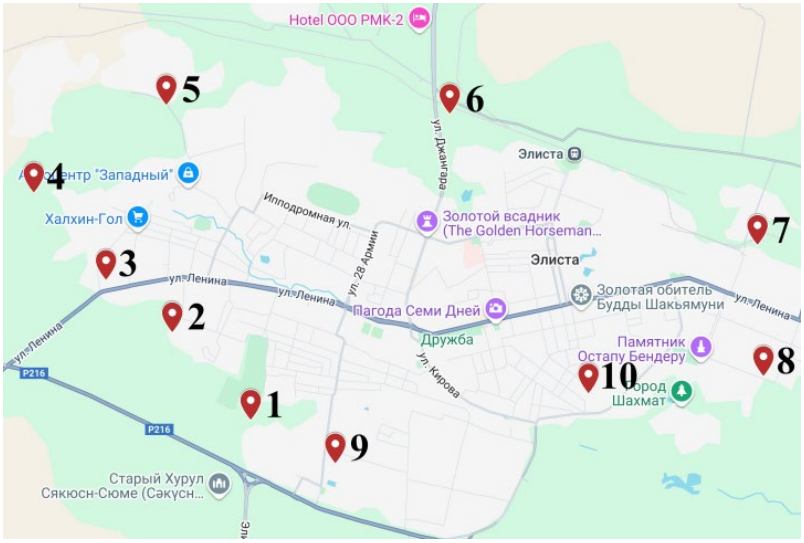

Fig. 3. Sampling points in autumn.

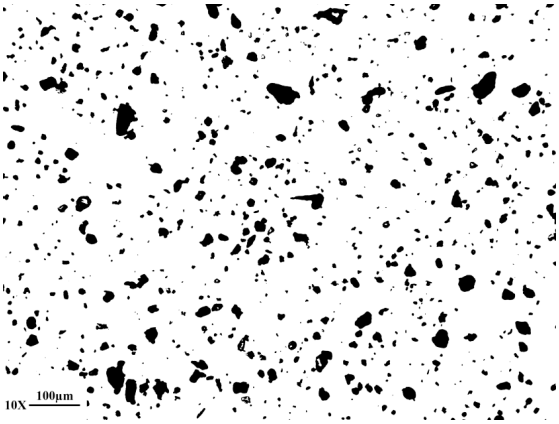

Fig. 4. An image of dust obtained using a microscope and reduced to black and white for analysis in the SPOTEXLORER program.

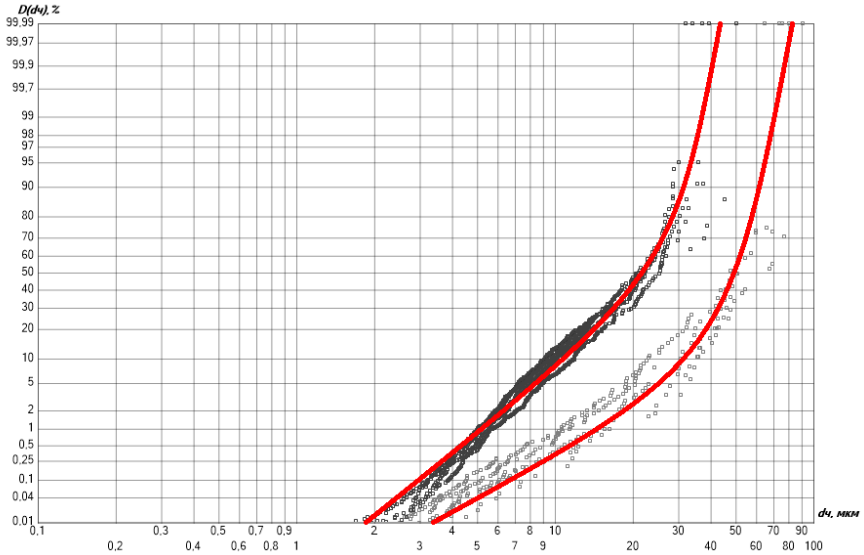

Fig. 5. Integral function of mass distribution over particle diameters for samples 6 and 1 in the spring period.

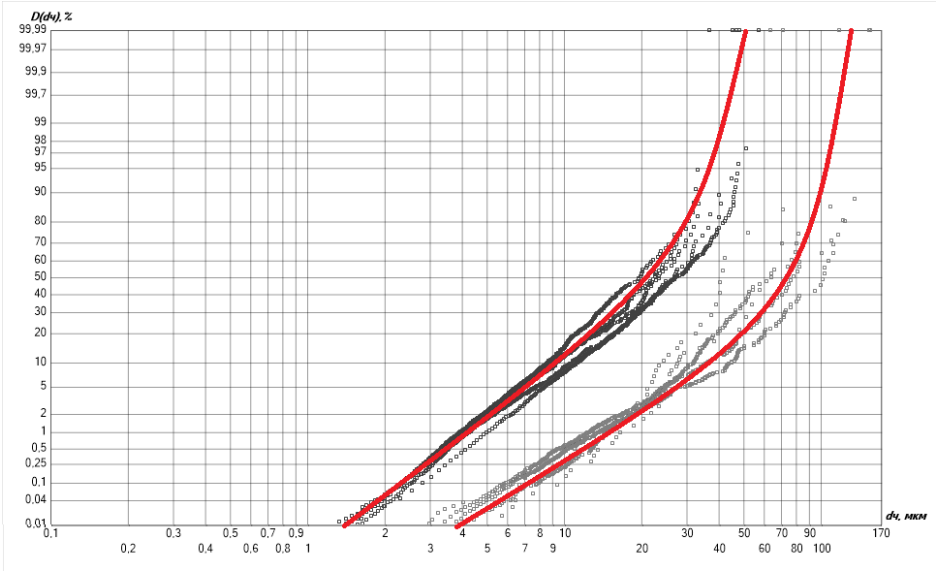

Fig. 6. Integral mass distribution function over particle diameters for samples 9 and 4 in the autumn time period.

3.2. Hypotheses

The sample of the experiment was relatively small, therefore, not all cases were taken into account. However, based on the results of the work carried out, based on the experimental data obtained, a set of cases has been identified that confirm and refute some of the hypotheses given earlier in this text.

Hypothesis «A» was refuted, no significant change in the proportion of fine dust was observed in different seasons. The autumn sample contains more dust samples with a PM10 content of < 4%, but for the spring sample it is noted that rain fell a few days before it, which could change the content of a fine fraction in the total mass of dust.

Hypothesis "B" has been refuted. Both sampling procedures were carried out over the course of one day, during which the air velocity did not change significantly. During sampling in September, the wind speed was 9.1 m/s, the direction was east, humidity was 29%, t^0 = +230C. During sampling in September, the wind speed was 6.9 m/s, the direction was northeast, humidity was 45%, t^0 = +16^{0}C. For convenience, Tables 1 and 2 are presented in the order from the largest to the smallest fraction of PM10, which shows that there is no noticeable difference. In both cases, there are samples with a small, medium and higher content of fine dust. Each of them should be discussed.

Hypothesis «C» has been refuted. There is no stable reproducible relationship between the proportion of fine dust and the location in the city of Elista. There are cases when the composition of the selected dust could differ significantly on almost the same street. It is quite possible that this issue requires further study and is of practical interest, but it cannot be further analyzed in this paper based on the data obtained.

Hypothesis «E» has been confirmed. Moreover, this relationship has proven to be the most stable and reproducible. There is a connection between the proportion of fine dust and the distance from the sampling site to the nearest road with a high traffic level. That is, the shorter the distance from the sampling site to the road, the higher the content of fine dust in the sample.

Hypothesis «F» has been confirmed. There is a pattern between the content of fine dust and the height at which the sample was taken, which is explained by the low settling velocity of fine particles. This pattern was confirmed for many, but not all, of the cases studied, meaning it may not be reproducible.

It is also worth noting that with an increase in height, it is often not the diameter of the dust particles that changes, but their thickness. In some cases, when performing microscopy with an increase in the sampling height from the floor, an increase in the content of transparent thin plates in the dust composition was observed. Thus, the distribution of dust by height is a complex issue that could be the subject of a separate study.

In fact, in most cases, it is not necessary to conduct full microscopy to obtain a preliminary hypothesis about the content of PM10 particles. In the vast majority of cases, if the proportion of PM10 is around 10-15%, the dust «packs» and sticks together. If the proportion of fine dust does not exceed 1-2%, then most likely the processes of sticking and «packing» will not occur, as shown in Fig. 7.

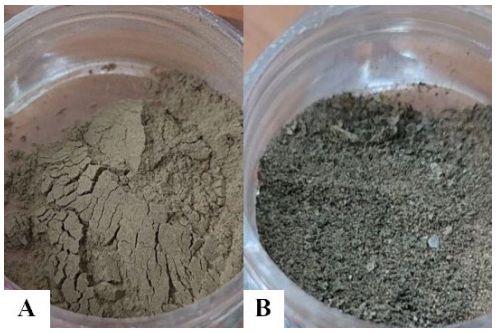

Fig. 7. Dust samples taken from street window sills in the city of Elista, taken during the autumn period: A – Dust with a high fine fraction content (sample "6", PM10 – 6.8%), B – Dust with a low fine fraction content (sample "10", PM10 – 1%).

3.3. Regression equations

Using the LibreCalc tabular processor, regression equations 1-2, 5-10 were obtained. Using these equations, it is possible to predict the fraction of particles d_p <10 microns (PM10) and d_p <2.5 microns (PM2.5). Equations 1-2, 5-8 are linear and logarithmic, while equations 9-10 are quadratic. Equation (1) has a coefficient of determination $R^2 = 0.87$ and (2) $R^2 = 0.73$:

$$Y_{PM10} = -0.022766 \cdot \ln(X_1) + 0.007183 \cdot \ln(X_2) + 0.014038 \quad (1)$$

$$Y_{PM2.5} = -0.000371 \cdot \ln(X_1) + 0.000273 \cdot \ln(X_2) + 0.000489 \quad (2)$$

Here, Y_{PM10} is the fraction of particles less than 10 microns in the dust sample; $Y_{PM2,5}$ is the fraction of particles less than 2.5 microns in the dust sample; X_1 is the normalized distance from the sampling site to the highway; X_2 is the normalized height from the floor at which the sample was taken.

$$X_1 = \frac{l}{1000} \quad (3)$$

l – the nearest distance from the sampling site to the highway, m.

$$X_2 = \frac{h}{10} \quad (4)$$

h – the height from the floor at which sampling took place.

As a test of the obtained equations, we calculate the proportion of PM10 and PM2.5 for two cases that were not used in the formulation of the equation. Equations 1 and 2 were compiled based on data from samples taken in the spring. The remaining samples marked with * were calculated using formulas 1 and 2 and compared with the actual result in Table 3.

Table 3. Comparison of calculated and measured values in the spring.

Sampling location	PM10	PM10 (calc.)	%	PM2.5(calc.)	PM2.5 (calc.)	%
3*	2	1.5	25	0.03	0.02	33
7*	1	1.4	29	0.04	0.02	50

Equations 5-6 were obtained using data from Table 2. The coefficient of determination for equation (5) was $R^2 = 0.86$, for (6) $R^2 = 0.71$.

$$Y_{PM10} = -0.036158 \cdot \ln(X_1) + 0.032195 \cdot \ln(X_2) + 0.060641 \quad (5)$$

$$Y_{PM2.5} = -0.000825 \cdot \ln(X_1) + 0.000618 \cdot \ln(X_2) + 0.001143 \quad (6)$$

Similarly, there were 2 results left in the autumn sample, which were not used to compile the equations. The calculation using formulas 5-6 is compared with the actual analysis data in Table 4.

Table 4. Comparison of calculated and measured values in the autumn.

Sampling location	PM10	PM10 (calc.)	%	PM2.5	PM2.5 (calc.)	%
2*	5	4.7	6	0.09	0.2	55
1*	2	1.8	33	0.03	0.16	20

It was previously noted that there was no significant difference between the samples taken in autumn and spring. The entire database obtained was used to compile generalized regression equations 7-10.

The coefficient of determination for equation (7) $R^2 = 0.58$, and for (8) $R^2 = 0.54$. The decrease in the determination index here can be explained by some difference in weather conditions.

$$Y_{PM10} = -0.023072 \cdot \ln(X_1) + 0.015374 \cdot \ln(X_2) + 0.038531 \quad (7)$$

$$Y_{PM2.5} = -0.000377 \cdot \ln(X_1) + 0.000045 \cdot \ln(X_2) + 0.000409 \quad (8)$$

Finally, generalized equations 9-10 were compiled using quadratic regression. Their coefficient of determination turned out to be higher than in the previous case due to the selection of a more suitable mathematical model. For (9) $R^2 = 0{,}72$, (10) $R^2 = 0{,}61$.

$$Y_{PM10} = 0.094884 \cdot X_1^2 - 0.156189 \cdot X_1 - 0.129865 \cdot X_2^2 + \\ + 0.187759 \cdot X^2 - 0.087659 \cdot X_1 \cdot X_2 + 0.051522 \quad (9)$$

$$Y_{PM2.5} = 0.002622 \cdot X_1^2 - 0.004198 \cdot X_1 - 0.003198 \cdot X_2^2 \\ - 0.002987 \cdot X^2 - 0.001143 \cdot X_1 \cdot X_2 + 0.001416 \quad (10)$$

To verify these equations, we randomly select 2 sampling points and substitute the values X_1 and X_2. The result of this comparison is shown in Table 5.

Table 5. Comparison of calculated and measured values.

Month	Sampling location	PM10	PM10 $_{(calc.)}$	%	PM2.5	PM2.5 $_{(calc.)}$	%
April	3	2	1.4	30	0.03	0.02	33
September	12	15	9.5	37	0.35	0.18	49

4. CONCLUSIONS

1. Empirical formulas have been obtained describing the dependence of PM10 and PM2.5 concentrations on the distance from the road and the height of the sampling site. For all derived equations, the closer the sampling site is to regularly used motor vehicles, the higher the proportion of PM10 and PM2.5. Additionally, the proportion of particles with d_p < 10 μm increases with the sampling height. It is recommended to use these formulas within a range of up to 1.5 km from heavily used roads and for heights up to 10 meters above floor level.

2. A general range of values has been obtained for the dust mass distribution function by particle diameter during spring and autumn periods. PM10 values in spring varied between 0.4% and 9.8%, while in autumn they ranged from 0.5% to 15%. PM2.5 values in spring varied between 0.01% and 0.08%, and in autumn from 0.01% to 0.35%.

3. The hypothesis that there is a significant difference in the proportion of fine dust (d_p < 10 μm) between spring and autumn periods was refuted by this series of studies. There are certain factors that influence the dispersed composition of dust much more rapidly and significantly than the season. The same applies to the influence of humidity and air flow velocity. Based on the obtained data, the geometry of the building, its relative position to seasonal winds, and distance from the road play a much more significant role in the dispersed composition than wind speed, humidity level, or season. The hypothesis about the significant influence of the sampling location in a specific area on the dispersed composition was also refuted. On the same street, there can be a significant difference in the granulometric composition of dust due to different sampling heights or specific building geometries. Hypotheses about the strong influence of distance from the road and height above floor level on the dispersed dust composition were confirmed.

4. Due to the absence of industrial enterprises in Elista city, measurements taken in this city can serve as a basis for developing a calculation methodology for estimating dust emissions from motor vehicles. This relationship can be observed quite clearly for further research.

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