Seasonal variations in the content of dust particles pm10 and pm2.5 in the air of resort cities depending on intensity transport traffic and other conditions

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Abstract. The paper presents the results of the investigation aimed at evaluating the content of dust particles PM_{10} and $PM_{2.5}$ in the air of Yessentuki, one of the resort cities in the Caucasus Mineral Waters region. It gives the data on the size distribution and concentration of fine dust in the city atmosphere with regard to the specific features of urban territory zoning, the climatic factors and seasonal changes in the number of citizens as well as to the remoteness from the industrial zone, the intensity of public and transport traffic. The authors show that it is reasonable to use sequences of random values for the purpose of air quality evaluation in various zones of the city in case of the absence of monitoring stations with continuous measurements checking the probability of the standard values exceedance for fine dust content. Similar investigations are carried out in other resort cities of the Caucasus Mineral Waters region.

1. Introduction

In the present-day world, the level of dust pollution of the atmosphere in cities is one of the global concerns [1-13]. The situation is explainable for industrial zones where the concentration of hazardous substances can many times exceed the permissible standards [5]. However, the situation develops in a different way in the cities where industrial enterprises are absent or they do not determinate the pollution level of the urban atmosphere. In such cases, there is dust of both natural and technogenic origin brought to the territory by the wind. The determination of the content of particles PM_{10} and $PM_{2,5}$ in the atmosphereis an essential prerequisite for the evaluation of the hazardous impact on human health.

In spite of all the attractiveness of the Caucasus Mineral Waters (CMW) region, serious problems exist here, which concern the pollution of the unique environment and demand a prompt solution. For this purpose, a monitoring of a number of ecological characteristics of the CMW region is organized and conducted – of dust and gas pollution of the air in resort cities [14], of the background radiation in the territory, of the noise pollution, etc. – in order to reveal their influence on the social and ecological well-being of the resort cities.

However nowadays, with few exceptions [9, 15], there is practically no experience of the investigation of urban atmosphere pollution with fine dust, the experience of the monitoring of such dust content in the air of residential zones is absent, in particular there are no evaluations of the spreading regularities of particles PM_{10} and $PM_{2.5}$ in urban territories where industrial dust does not prevail, i.e. resort and park zones etc.

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The objective of the workis to investigate the regularities of spatial-temporal distribution of dust particlesPM_{10} and $PM_{2.5}$in the air of various zones of a resort city (park zone, resort zone without automobile traffic, resort zone with automobile traffic, residential zone, and industrial one) taking into account several factors – the temperature and relative air humidity, the wind velocity, the remoteness from the industrial zone, the intensity of public and automobile traffic - in order to ensure the protection of the unique natural environment of CMW region and of the vital interests of people.

2. Experimental section

For the purpose of the investigation with regard to the climatic conditions of Yessentuki [16] the calendar year was divided into 3 periods the characteristics of which are given in table 1. These climatic periods practically coincide with the periods of the seasonal changes in the city population due to the presence of those who come for rest and revitalization.

Table 1. Periods of the year according to the climatic parameters of Yessentuki

Periods of the year	Climatic parameters		
	t, ℃	φ, %	v, m/s
	variation range		
I	$-5 \leq t \leq 5$	$70 \leq \varphi \leq 100$	$0 \leq v \leq 6.5$
II	$5 < t \leq 15$	$50 \leq \varphi \leq 100$	$0 \leq v \leq 5.3$
III	$15 < t \leq 25$	$35 \leq \varphi \leq 100$	$0 \leq v \leq 4.5$

In order to analyze the size distribution and to determine the concentrations of particles PM_{10} and $PM_{2,5}$,samples were collected at 44 spots in Yessentuki in the specified periods of the year. In this connection, 5 zones were distinguished: the resort zone without automobile traffic, the resort zone with automobile traffic, Park Pobedy, the residential zone and industrial zone.

The following factors were registered during the sampling of dust contained in the atmosphere: the climatic ones (the temperature and relative humidity of the air, the wind velocity); the intensity of public traffic; the intensity of automobile traffic; the distance from the sampling spot to the industrial zone.

Measuring the content of dust fine particles in the air was carried out with an electric aspirator EA-1A, which is intended for taking snap samples into absorbing devices with the determination of the dust content of the air to follow. A digital anemometer ISP-MG4 (designed and manufactured by SCB "Stroypribor") with the measurement range for air flow velocity from 0.1 to 30 m/s was used to measure the wind velocity. A digital electronic thermometer RSTO6412/S412 with the measurement range for temperature from – 50^0C to 70^0C and for relative humidity from 1% to 99% was used to measure the temperature and relative humidity of the atmospheric air at the sampling spots.

In the course of the investigation of the size distribution of suspended particles contained in the atmospheric air of the resort cities in the CMW region, the microscopic analysis method [17] was used which had been repeatedly tested and adopted as the RF National Standard "Emissions of polluting substances into the atmosphere. Investigation of the size distribution of dust through the optical method in the process of norm setting for atmospheric air quality" by the Federal Agency on Technical Regulating and Metrology. The DUST 1 software for the processing of particle images (the State Registration Certificate of computer software DUST 1 No2014618468 of 24.08.2014) was applied for the processing of the results of the microscopic analysis.

3. Discussion section

As an example of the data obtained, figure 1 presents the graphic dependences characterizing the size distribution of dust contained in atmosphere of the resort zone without automobile traffic at the temperature of outdoor air $15℃ < t_n \leq 25℃$ (the III period of the year). The rest of the results are given in table 2.

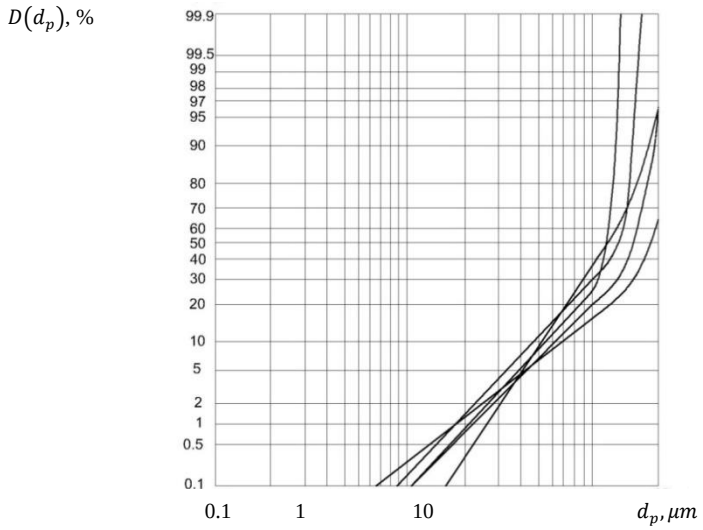


Figure 1. The integral functions of particle mass distribution according to diameters for atmospheric dust in the territory of the resort zone without automobile traffic in the III period of the year

Table 2. Results of the evaluation of dust size distribution

The zone under investigation	Proportion of fine particles, %	
	PM_{10}	$PM_{2.5}$
the I period of the year		
Park zone	2-10	-
Resort zone without automobile traffic	1.3-7.5	-
Resort zone with automobile traffic	3.3-9.8	-
Residential zone (the city center)	3.8-12.3	-
Industrial zone	3.7-18.5	-
the II period of the year		
Park zone	7.7-27	0.3-0.5
Resort zone without automobile traffic	10-26	0.1-0.8
Resort zone with automobiletraffic	10-27.5	0.3-1.6
Residential zone (the city center)	18.6-27.6	0.4-1.0
Industrial zone	16.3-33.6	0.8-2.2
the III period of the year		
Park zone	12-40	1.9-2.5
Resort zone without automobile traffic	17.3-38	0.9-2.5
Resort zone with automobiletraffic	21.3-38.9	0.8-2.5
Residential zone (the city center)	21.8-40	2.0-3.5
Industrial zone	22.1-52.3	2.3-5.0

Figure 2 shows the change in the proportion of particles PM_{10} in the dust contained in the air of the park zone, depending on the air relative humidity at its various temperatures in windless weather and at the absence of visitors. Figure 3 shows the same data for particles $PM_{2.5}$.

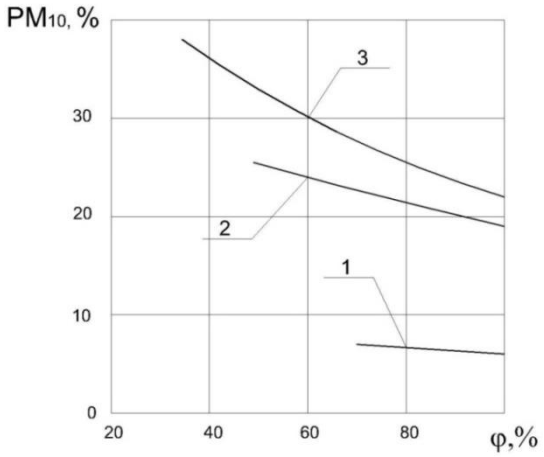


Figure 2. The change in the proportion of particles PM_{10} in the dust contained in the atmospheric air of the park zone, depending on the relative air humidity in windless weather at the absence of visitors:1 – at the temperature of outdoor air 5^0C; 2 – at the temperature of outdoor air 15^0C; 3 - at the temperature of outdoor air 25^0C

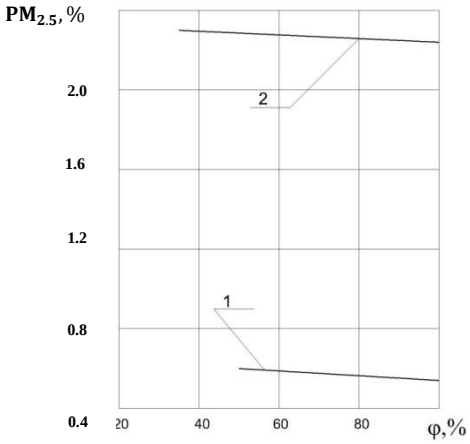


Figure 3. The change in the proportion of particles $PM_{2.5}$ in the dust contained in the atmospheric air of the park zone, depending on the relative air humidity in windless weather at the absence of visitors:1 – at the temperature of outdoor air 15^0C; 2 - at the temperature of outdoor air 25^0C

The obtained data indicate that with the increase in the outdoor air temperature higher than 5^0C above zero, the concentration of fine dust in the atmospheric air grows steeply, for example, the proportion of particles $PM_{2,5}$ increases practically by the factor of 5. It can be explained by the fact that the works aimed at the park territory improvement and at the green plantings management are carried out in this particular temperature interval.

It should be also noted that the number of citizens grow considerably in the high season as a result of the arrival of vacationers, which also influences the condition of the resort city atmosphere, as shown by the results of the investigations carried out (figure 4, figure 5.).

The processing of the results of the experimental data applying the software complex *STATISTIKA* showedthat the proportion of fine particles in various city zones at various meteorological and other conditions can be described by the dependences of the form (1), (2):

- for PM_{10}

$$\mathrm{PM}_{10} = a_0 + a_1(t - a_2)^2 + a_3(v - a_4)^2 + a_5(\varphi - a_6)^2 + \\ + a_7(l - a_8)^2 + a_9(N - a_{10})^2 + a_{11}(n - a_{12})^2 \quad (1)$$

- for$PM_{2.5}$

$$PM_{2.5} = b_0 + b_1(t - b)^2 + b_3(v - b_4)^2 + b_5(\varphi - b_6)^2 + + b_7(l - b_8)^2 + b_9(N - b_{10})^2 + b_{11}(n - b_{12})^2 \quad (2)$$

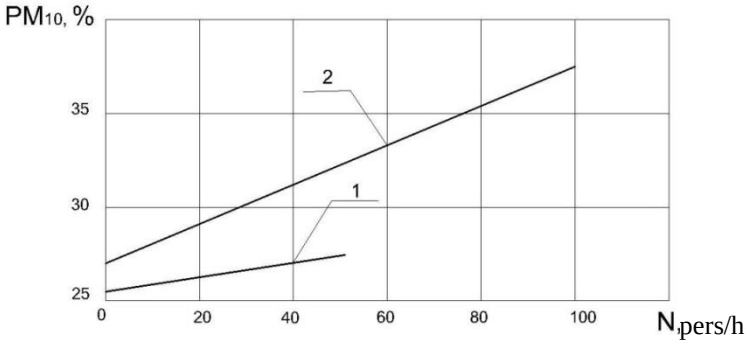


Figure 4 The change in the proportion of particles PM_{10} in the dust contained in the atmospheric air of the park zone, depending on the intensity of public traffic: 1 – at t = 15^{0}C and φ = 50%; 2 – at t= 25^{0}C and φ = 35%

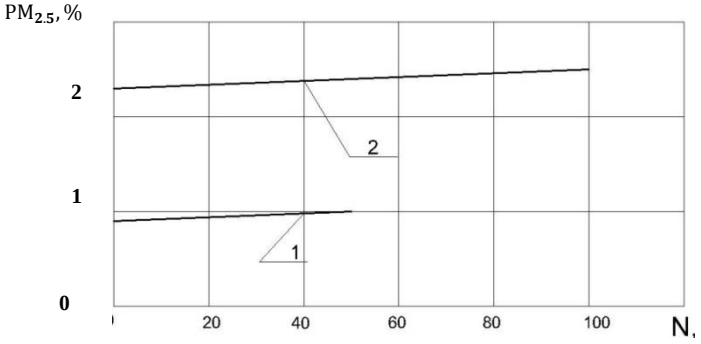


Figure 5. The change in the proportion of particles $PM_{2.5}$ in the dust contained in the atmospheric air of the park zone, depending on the intensity of public traffic: 1 – at t = 15^{0}C and φ = 50%; 2 – at t = 25^{0}C and φ = 35%

where$tt$is the temperature of outdoor air, ^{0}C; v – the wind velocity, m/s; φ – the relative humidity of outdoor air; l – the distance to the industrial area, m; N – the intensity of public traffic, pers./h; n – the intensity of automobile traffic.

For example, for the park zone, the expression (1) has the form:

$$PM_{10} = 5.88 + 0.066(t - 2.8)^2 - 0.2629(v + 3.4)^2 - - 0.001(\varphi - 76.5)^2 \quad (3)$$

at $-5℃ \le t \le 5℃;\ 0 \le v \le 6.5;\ 70 \le \varphi \le 100;$

$$PM_{10} = 5.753 + 0.044(t - 3.6)^2 - 0.0667(v + 1.8)^2 - - 0.0014(\varphi + 34)^2 + 0.009(N + 23)^2 \quad (4)$$

at $5℃ \le t \le 15℃;\ 0 \le v \le 5.3;\ 50 \le \varphi \le 100;\ 0 \le N \le 50;$

$$PM_{10} = 3.506 + 0.0164(t - 1.4)^2 - 0.314(v + 1.42)^2 - - 0.0022(\varphi + 46)^2 + 0.0074(N + 43)^2 \quad (5)$$

at $15℃ \le t \le 25℃;\ 0 \le v \le 4.5;\ 35 \le \varphi \le 100;\ 0 \le N \le 100$

For the same zone

$$PM_{2.5} = 0.1189 + 0.002(t - 1.8)^2 - 0.0013(v + 1.64)^2 - \\ - 0.128 \cdot 10^{-3}(\varphi + 41)^2 + 0.128 \cdot 10^{-3}(N + 19)^2; \quad (6)$$

at $5℃ \le t \le 15℃;\ 0 \le v \le 5.3;\ 50 \le \varphi \le 100;\ 0 \le N \le 50;$

$$PM_{2.5} = 1.5039 + 0.486 \cdot 10^{-3}(t - 2.8)^2 - 0.009(v + 1.52)^2 - 0.065 \cdot 10^{-3}(\varphi + 42)^2 + 0.219 \cdot 10^{-3}(N + 44)^2 \quad (7)$$

$$\text{at } 15℃ \le t \le 25℃;\ 0 \le v \le 4.5;\ 35 \le \varphi \le 100;\ 0 \le N \le 100.$$

The results of the analysis of the obtained data allow concluding on the following. In the park zone, the main influence on the fine dust content in the air is posed by the climatic factors and the intensity of public traffic. At the same time, the occurrence of particles $PM_{10}$is registered throughout the year. Their amount grows steeply when the temperature of outdoor air rises higher than 5^0C above zero, and reduces with the increase in the relative humidity. The occurrence of particles $PM_{2,5}$ is registered at the temperature of outdoor air 5^0C and higher, however, in the contrast to particles PM_{10}, the content of particles $PM_{2,5}$ remains practically steady with the increase in the relative humidity of the air. All the aforesaid can be applied to the resort zone with automobile traffic as well - the content of dust particles in the atmospheric air increases due to the negative effect of transport. Alongside with that, the influence of the industrial zone is not observed in the three abovementioned zones which can be explained by the abundance of green plantings. However, within the limits of the residential development, in addition to other factors, the influence of the industrial zone manifests itself by an increase in the proportion of particles PM_{10} and $PM_{2.5}$. In the territory of the industrial zone, the occurrence of both types of particles is registered throughout the year.

It should be noted that for the evaluation of atmospheric air quality it is of primary importance to know the probability of the exceedance of fine particles content over the standard values for various zones of the resort city. In case of the absence of monitoring stations with continuous measuring, for the purpose of theoretic analysis we will apply the mathematical apparatus with the use of the sequence of random values.

At each of the measurement spots 1-44 the content of particles PM_{10} can be considered as the values at $d_ч$ = 10μm in the realizations of random functions of fractional concentration $C_i(d_ч)$.. Then $\{C_i(10)\}^n$ can be considered as a sequence of random values and the distribution regularities of maxima and minima can be analyzed [18-20].

Let $C_i(C_1, C_2 \dots C_n)$ be a sequence of independent and equally distributed random values, and M_n is the maximum of the first n of these values, i.e.

$$M_n = max(C_1, C_2, \dots C_n) \quad (8)$$

For example, C_i is the concentration of particles PM_{10} and $PM_{2.5}$ etc. at the i-th measurement in the atmospheric air at the spot or section of the territory. It is very important, that it is not the result obtained during the processing of one of the samples, but the result of a measurement with, for example, 5 samples taken. The largest part of the "classical" theory of experimental values deals with the distribution of M_n, especially with its properties at $n \to \infty$. All the mathematical results obtained for the maxima, of course, lead to the similar theoretical results for the minima as well since there is an evident correlation [18-20]

$$m_n = min(C_1, \dots C_n) = -max(-C_1, \dots -C_n)$$

Therefore, we will use the results of the theory only for the maxima, excluding the case when a joint distribution of maxima and minima is considered.

It is obvious, that the integral distribution function of random value $M_n$is calculated according to the formula [18-20]

$$P = \{M_n \le x\} = P\{C_1 \le x, C_2 \le x, \dots C_n \le x\} = F^n(x) \quad (9)$$

where$F$denotes the general integral distribution function for C_i.

Bearing in mind the convergence in the continuity points of the distribution function G, the conditions at which for the constants $a_i > 0, b_i$, selected as appropriate,

$$P\{a_n(M_n - b_n) \leq x\} \overset{\omega}{\to} G(x) \tag{10}$$

Actually, as we will see further, all the distribution functions G of some interest to us are continuous [18-20]. In particular, the important issue here is which distribution functions G can occur as such a limit. It was theoretically shown [18-20] that all the possible no degenerate distribution functions G which can occur as the limits in (10) form a class of maximum-stable distributions, and that every stable distribution G has (accurate to the shear transformation and scale) one of the three parametric forms usually called the three distributions of the experimental values.

In our case:

- type I

$$G(C - C_{\text{cp}}) = exp\left[-e^{-A(C - C_{\text{cp}})}\right] \quad \text{at} -\infty < C - C_{\text{cp}} < \infty; \tag{11}$$

- type II

$$C(C - C_{\text{cp}}) = \begin{cases} 0 & \text{at } C - C_{\text{cp}} \leq 0, \\ \alpha\left[A(C - C_{\text{cp}})^{-\alpha - 1}\right] & \text{at } C < C_{\text{cp}}, \alpha > 0 \end{cases} \tag{12}$$

- type III

$$C(C - C_{\text{cp}}) = \begin{cases} \alpha\left[A(C - C_{\text{cp}})^{-\alpha - 1}\right] & \text{at } C - C_{\text{cp}} \leq 0, \quad \alpha > 0, \\ 1 & \text{at } C - C_{\text{cp}} > 0 \end{cases} \tag{13}$$

The analysis of the physical meaning of the variable C shows that in the real conditions the concentration values cannot be negative. Consequently, the maximum of the values of this random quantity(realizations, measurements) should be described with the type II. For the calculation of the actual values of A, α and C_{cp}, envelopes were used for each of the specified zones of the city, characterizing the maximum (the upper envelope) and minimum (the lower one, respectively) values of the percentage of the mentioned fine particles, obtained as the results of field investigations. For example, the design values of the coefficients of the integral distribution function for the maximum concentrations of fine dust PM_{10} for the resort zone without automobile traffic amounts to A_{10} = 0,055, α = 0.75. For particles $PM_{2.5}$ it amounts to $A_{2.5}$ = 0.11, α = 5.9.

According to the results of the conducted investigations, the mean daily concentrations of dust particles PM_{10} in the atmospheric air of Yessentuki comply with the standards set in [6], in general. At the same time, the mean year concentration of these particles exceeds the set standards even in the so-called clean zone – in the territory of the resort park. The exceedance of the standard concentration for particles $PM_{2.5}$ has not been registered.

Table 3. The results of the determination of fine dust particles content in the atmospheric air of the resort city and the industrial cities

Particles content, %	Yessentuki	Volgograd	Novorossiysk
$PM_{2.5}$	0.3-2	0.2-0.4	0.7-0.9
PM_{10}	12-49	9-22	22-30

On the average, the content of particles of $PM_{2.5}$ amounts to 0.3-2 %, of particles PM_{10} – to 12-49 % in the atmosphere of Yessentuki. Similar investigations were carried out in large industrial cities - in Volgograd and Novorossiysk. The obtained data are given in table 3 for the purpose of comparison. The comparison of the results of fine dust percentage determination in the atmosphere of the resort city and the industrial cities once again proved that fine dust does not practically settle down, it remains in the air in suspension and is transferred to large distances.

Conclusions

1. The analysis of the atmospheric air condition in the resort cities of the Caucasus Mineral Waters region showed that despite the attractiveness of the region, there are some problems here, concerning the ecological safety ensuring and caused by the negative influence of construction, energy engineering, industry and transport on the natural environment of urban and sanatorium-resort complexes. Although the monitoring of the dust content in the atmospheric air is conducted in the CMW region, the concentration of suspended solid particles is determined as the sum of all dust particles without any division into fractions.
2. Based on the field investigations of the regularities of spatial-temporal distribution of dust particles PM_{10} and $PM_{2.5}$ in the atmosphere, the dependences were obtained which characterize the percentage of their content in various zones of the resort city of Yessentuki. (the park zone, the resort zone without automobile traffic, the resort zone with automobile traffic, the residential zone and the industrial one) taking into account the influence of several factors – the temperature and relative humidity of the air, the wind velocity, the remoteness from the industrial zone, the intensity of public and automobile traffic.
3. It was shown that in the process of air quality evaluation in populated localities, in case of the absence of monitoring stations with continuous measurings, it is reasonable to use sequences of random values to determine the exceedance probability of the fine dust content over the standard values. At the same time, the type of the distribution function of the concentration maximums was determined, and the coefficient values of the specified function were found both for dust pollution in general and for fine dust particles PM_{10} and $PM_{2.5}$ for various zones of Yessentuki (the park zone, the resort zone without automobile traffic, the resort zone with automobile traffic, the residential zone, and the industrial one, based on the results of the field investigations.
4. It was found out that the mean daily concentration of particles PM_{10} and $PM_{2,5}$ in the residential and recreational zones does not exceed the permissible values. However, a noticeable exceedance of the mean year concentrations of particles PM_{10} was registered. That is why it is necessary to continue the investigations of dust content in the atmospheric air of the resort CMW region paying special attention to fine dust particles PM_{10}.

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