On the Pollution of the Atmosphere of the City of Kabul with Fine Dust

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Abstract. The article presents new results of many years of research conducted by the national agency of Afghanistan on ecology and environmental protection as well as studies by Russian authors on the assessment of atmospheric air pollution in Kabul. The paper presents data for the spring months (March, April, and May) of 2016. The analysis of information on the quality of atmospheric air in the city of Kabul examining its street-road network and the mining industry located near the city as a source of chemical pollution of the air was performed. A mathematical model of the dependence of the concentration of fine dust (PM₁₀) on three factors: wind speed, humidity, and temperature for each month has been obtained. For the maximum daily concentration (PM₁₀), a density function and an integrated distribution function are obtained. A comparative analysis of atmospheric air pollution in the spring months of 2015 and 2016 was performed. It was not possible to obtain a general mathematical model for all three months.

1. Introduction

According to recent scientific data, one of the factors that significantly affect people's health is air pollution by chemical substances and fine solid PM₁₀ particles. Fine particles PM₁₀ can enter the atmosphere in the form of emissions from industrial enterprises, as well as dust emissions from transportation infrastructure. In addition, air quality is affected by individual meteorological conditions that are unique to each locality and have significant temporal variability [1-9].

To study the emission of PM₁₀ particles into the atmosphere, Kabul was chosen because it is one of the cities with a high level of environmental pollution. The city of Kabul is characterized by rather dry weather with wind, so the transportation and road complex is a "supplier" of fine dust to the urban air environment and there is a mining industry near the city [10-14].

During 2015-2016 in the spring months (March, April, May) in Kabul, PM₁₀ fine dust concentrations were measured as part of monitoring air pollution. The measurements of PM₁₀ (mg/m³) were carried out using the Air pointe instrument; three other factors were simultaneously measured: \( V \) - wind speed (m/s), \( \varphi \) - humidity (%) and \( T \) – air temperature (degrees C). According to the air quality standards for Afghanistan, the PM₁₀ solid particle concentration should not exceed 150 mg/m³ per day. The results of the measurements showed that the number of exceedances of the PM₁₀ particulate matter concentration at 150 mg/m³ in the spring months of 2015 occurred 38 days out of 64...
and in 2016 - 40 days out of 60. At the same time, the $PM_{10}$ concentration reached 877 mg/m$^3$ on some days, especially high values were observed at low wind speeds.

2. The dependence of $PM_{10}$ on three factors

Let’s take a look at the assessment of the dependence of $PM_{10}$ on three factors (wind speed, humidity, and air temperature) for the spring months of 2016, as for the year 2015 it was obtained earlier [10].

All the initial data were reduced to the normalized form by the formulas (1).

$$y_j = \frac{Y_i - Y_0}{\Delta y}; \quad x_i = \frac{X_{ij} - X_{i0}}{\Delta x_i}; \quad X_{i0} = \frac{\max_{j} \{X_{ij}\} + \min_{j} \{X_{ij}\}}{2}; \quad \Delta y = \frac{\max_{j} \{X_{ij}\} - \min_{j} \{X_{ij}\}}{2}, \quad (1)$$

$i = 1, 2, 3; \quad j = 1 + n$, where $Y_i$ is a concentration of suspended particles $PM_{10}$; $X_{ij}$ - wind speed; $X_{ij}$ - humidity; $X_{ij}$ - the air temperature in the $j$-th day, and $n$ is the sample size in the corresponding month.

For each month a linear (2) and a quadratic (3) function of regression were obtained i.e. the regression equation was calculated in two forms:

$$y = c_0 + c_1 x_1 + c_2 x_2 + c_3 x_3 \quad \text{and} \quad (2)$$

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_1^2 + a_5 x_2^2 + a_6 x_3^2 + a_7 x_1 x_2 + a_8 x_1 x_3 + a_9 x_2 x_3. \quad (3)$$

The regression equations were obtained with the following initial data (table 1).

| Table 1. The values of the variables for normalizing. |
|------------------------------------------------------|
| Notation of mean | Mean values | Intervals of change $\Delta y, \Delta x_i$ |
|------------------|-------------|------------------------------------------|
| $Y_0$            | 499,5       | 377,5                                    |
| $X_{10}$         | 3           | 3                                        |
| $X_{20}$         | 46,5        | 37,5                                     |
| $X_{30}$         | 19          | 13                                       |

As shown by the research and testing by the Fisher criterion, quadratic regression is significant for March and April months, and linear regression is for May. The universal form of the $PM_{10}$ dependence on three factors: wind, humidity and air temperature cannot be obtained for all three months since no model gives a good correlation coefficient. The sample size for each month was collected for 20 days.

Using Student's t-test, only significant coefficients were selected in the regression equations. The resulting regression equations are listed in table 2.

| Table 2. Regression equations for $PM_{10}$ with normalized variables. |
|----------------------------------------------------------|
| Month | Regression equations | Multiple correlation coefficient $R$ |
|-------|----------------------|-----------------------------------|
| March | $y = -0.5535 - 2.9026 x_1 x_2 - 1.2357 x_1 x_3$ | 0,62 |
| April | $y = -0.802 + 0,186 x_1^2 - 0,144 x_2^2.$        | 0,52 |
| May   | $Y = -0.4788 - 0,1337 x_1 + 0,3212 x_2 - 0,0619 x_3$ | 0,77 |

Using the inverse transformation, i.e. transition of variables from the normalized form to the non-normalized form, the regression equations were obtained (table 3). Also in table 3 the regression equations that were obtained earlier for the spring months of 2015 are presented for comparison [10]. The values of $V, \varphi$ and $T$ are dimensionless, referred respectively to 1 m/s, 1% and 10°C.
Table 3. Calculated regression equations for $PM_{10}$.

| Year | Month  | Regression equation                                      | Multiple correlation coefficient $R$ |
|------|--------|----------------------------------------------------------|-------------------------------------|
| 2016 | March  | $PM_{10} = 716.5V + 29.4\phi + 36.2T - 9.8V\phi - 12.1VT - 360.5$ | 0.62                                |
|      | April  | $PM_{10} = 7.928V^2 - 47.565V - 0.038\phi^2 + 3.511\phi + 186.5$ | 0.52                                |
|      | May    | $PM_{10} = 247.265 - 17V + 3.4\phi - 1.9T$                | 0.77                                |
| 2015 | March  | $PM_{10} = -0.2007 + 0.0127V - 0.1892\phi + 0.1031T$       | 0.87                                |
|      | April  | $PM_{10} = -0.2873 + 0.603T^2 + 0.4997\phi T$             | 0.65                                |
|      | May    | $PM_{10} = -0.0698 - 0.1078V + 0.7852\phi + 0.6204T$       | 0.62                                |

The wind speed $V$ varied from 0 m/s to 7 m/s in 2015 and from 0 m/s to 6 m/s in 2016. Humidity $\phi$ varied from 5% to 86% in 2015 and from 9% to 84% in 2016. The air temperature $T$ varied from -3$^\circ$C to 31$^\circ$C in 2015 and from 6$^\circ$C to 32$^\circ$C in 2016.

3. The law of distribution of the maximum daily dust concentration of $PM_{10}$

It is known that the maximum daily concentration of dust can be considered as a random function of a normal stationary process [14-22]. To obtain the distribution law of the maximum daily dust concentration of $PM_{10}$ in the spring months of 2016 in the city of Kabul, its type and parameters were determined. Calculated for a sample size of 60, the values of the distribution parameters are presented in Table 4.

Table 4. Values of the parameters of distribution function $PM_{10}$.

| Function parameters for distribution of dust concentration | Values of parameters | Year 2016 | Year 2015 |
|-----------------------------------------------------------|----------------------|-----------|-----------|
| Mean                                                      | 252                  | 161       |
| Dispersion                                                | 17810                | 1338.94   |
| Mean square deviation                                     | 133.45               | 36.59     |
| Mode                                                      | 234                  | 156       |
| Median                                                    | 221.5                | 156       |

By the type of distribution histograms (figure 1), based on the analysis of sample data and values of the distribution parameters, it seemed that there may be a normal or a log-normal law for the maximum daily dust concentration. Verification of assumptions about the normal and lognormal distribution laws was carried out with the help of the $\chi^2$ Pearson and Kolmogorov-Smirnov criteria at a significance level $\alpha = 0.05$. The results of the calculated statistics for the spring months 2015-2016 are displayed in Table 5.

Table 5. Values of statistics of the sample $PM_{10}$.

| Year | Distribution law | $\chi^2$             | $\chi^2_{crit}$ | Kolmogorov-Smirnov | $\lambda$ | $\lambda_0$ |
|------|------------------|----------------------|-----------------|--------------------|-----------|-------------|
|      |                  | $\chi^2_{obs}$       | $\chi^2_{crit}$ | $\lambda$         | $\lambda_0$ |
| 2016 | normal           | 20.87                | 14.067          | 1.035              | 1.36      |
|      | log-normal       | 9.078                | 14.067          | 1.058              | 1.36      |
| 2015 | normal           | 3.977                | 14.067          | 0.471              | 1.36      |
|      | log-normal       | 6.506                | 14.067          | 0.850              | 1.36      |
According to $\chi^2$ Pearson’s criterion, if the observed value of the criterion is less than the critical one, i.e. an inequality $\chi_{\text{obs}}^2 \leq \chi_{\text{crit}}^2$ is satisfied, then the hypothesis of the chosen theoretical law agrees with the empirical data. When the Kolmogorov-Smirnov criterion is applied, the theoretical law agrees with the experimental data if the inequality $\lambda \leq \lambda_0$ holds. According to table 5, it can be concluded that for both criteria a logarithmic normal law with parameters (5.529, 133.45) can be used to describe the maximum daily dust concentration for the spring months of 2016. For the spring months of 2015, considering that for the normal law the values of the statistics $\chi_{\text{obs}}^2$ and $\lambda$ are less than the corresponding statistics of the lognormal law, the empirical data are in better agreement with the normal law with the parameters (161; 36.59). Knowing the distribution law and its parameters, one can identify its density and distribution functions.

4. Conclusion

The conducted studies showed that in order to describe the distribution of the maximum single values of $PM_{10}$ in the spring months in the city of Kabul, a normal law, as in 2015, or a log-normal law, as in 2016, can be used. The concentration of $PM_{10}$ fine dust varies from 61 mg/m³ to 301 mg/m³ in 2015 and from 122 mg/m³ to 877 mg/m³ in 2016.

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