ECOLOGIA BALKANICA
2024, Vol. 16, Issue 1 June 2024 pp. 157-166

The relationship of atmospheric pollutants and meteorological variables for the Sofia region, Bulgaria

Gaukhar Baubekova[1], Chingis Tauakelov[1], Sevara Daribayeva[1*], Lyudmila Gosteva[2]

[1]Akhmet Baitursynuly Kostanay Regional University, Umirzak Sultangazin Pedagogical Institute, department of natural science, 110000, Kostanay, KAZAKHSTAN
[2]University of Forestry, Faculty of Ecology and Landscape Architecture, 10 Kliment Ohridski Blvd., 1797 Sofia, BULGARIA
*Corresponding author: sevara.daribaeva@gmail.com

Abstract. The research on the relationship between meteorological conditions and atmospheric air pollution in Sofia city was conducted based on 1-hour data on meteorological variables (air temperature, global solar radiation, wind speed) and atmospheric pollutants (NO_2, CO, O_3, SO_2, PM_{10}) for 2012-2016. As a result of the correlation and regression analysis of the influence of meteorological variables on the daily concentrations of atmospheric pollutants, the strongest effect is expressed in ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and particulate matter (PM_{10}). In urban areas, air temperature (AT), the intensity of global solar radiation (GSR) and, wind speed (WS) have a stronger impact on the concentration of pollutants. There is a strong correlation between air temperature ($r = 0.53 \div 0.76$) and solar radiation ($r = 0.65 \div 0.77$) with ozone concentrations. An exception is the area of Orlov most, where there is an average correlation with temperature and a minor correlation with solar radiation. In regions (except Kopitoto) there are average correlations between air temperature and PM_{10}, SO_2, and CO ($r = 0.55 \div 0.62$). There is a weak correlation between NO_2 and air temperature and solar radiation in the areas of Druzhba and Nadezhda.

Key words: air pollution, meteorological variables, nitrogen dioxide, ozone, sulfur dioxide, particulate matter.

Introduction

Weather conditions have a significant impact on the processes of diffusion of emissions of harmful substances from various sources, as well as on the level of ground-level pollution and air quality in urban and suburban environments. Between atmospheric pollution and a number of meteorological variables such as air temperature, humidity, precipitation, wind direction and wind speed, global solar radiation has a certain relationship described by a number of authors (Lazareva & Popova, 2014; Kryukova & Simakina, 2015; Kadinov, 2019a,b; Kerimray et al., 2020; Bozhkova, 2020, Kadinov, 2021a,b). According to other authors (Seinfeld & Pandis, 1998; Altwicker et al., 1999; Collier, 2006; Bagitova & Nyssanbayeva, 2018), meteorological phenomena and changes in weather conditions are related to the chemical state and processes in the atmosphere, and hence to air quality. For the study of the influence of meteorological variables on atmospheric pollutants, the methods of mathematical statistics are mainly applied – correlation and regression (linear and multiple) analyses (Song et al., 2020; Hu et al., 2021; Pasic et al., 2023; Khedekar & Thakare, 2023). Based on these dependencies., Gong et al. (2015) and Radaideh (2017) found that wind speed has a direct impact on urban air pollution. Increasing speed affects the dispersion of pollutants and reduces their concentration, while low speed is associated with local pollution. Wind speed directly affects the levels of PM, sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO) (Gorai et al., 2015; Kadinov, 2019a,b; Taleghani, 2022) and the variable tropospheric ozone (Jammalamadaka & Lund, 2006; Kadinov, 2021a) as the concentration of its precursors decreases with increasing speed. Strong winds can also have the opposite effect – long-distance transport of dust and PM (Mues, 2013; Chen et. al., 2015; Yin et al., 2016). The role of wind direction on air pollution is mainly related to the specific conditions in the area (Tian et al., 2014; Xie et al., 2022). Wind direction and speed, as well as atmospheric pressure, play an important role in the occurrence of episodes with high concentrations of PM_{10} (Kadinov, 2021b). The authors who have studied the thermal regime of the atmosphere believe that it significantly affects the retention and distribution of pollutants (Doncheva-Boneva et al., 2017; Soyol-Erdene et al., 2021; Morozov & Starodubceva, 2020). Temperature inversions and fogs in the cold period of the year are unfavorable for the dispersion of pollutants (Morozov & Starodubceva, 2020; Rendon et al., 2014). A strong negative correlation of air temperature was found with CO and NO_x (Hester & Harrison, 2009; Wu et al., 2013; Ruan et al., 2021). Higher concentrations of global dust and SO_2 are associated with lower temperatures directly as a result of their retention in the ground layer (Rogalski et al., 2014) and indirectly due to an increase in their emissions in the winter (Zyromski et al., 2014; Bernhard et al., 2023).

PM and ozone (O_3) are especially sensitive to temperature, a strong positive correlation with ozone (Gvozdić & Kovač-Andrić, 2011; Bernhard et al., 2023) and much weaker with PM (Chen et al., 2021) has been proven, a negative correlation with nitrates in the air (Ge et al., 2017) and an ambiguous correlation with the precursors of PM (Li et al., 2015; Prakash et al., 2022). In addition to temperature, the high intensity of solar radiation activates photochemical reactions in the atmosphere, leading to the formation of ozone and other photooxidants. Peteva & Luybenova (2019) note the influence of anthropogenic factors on PM_{10}. Arslan (2023) found a significant positive correlation between global solar radiation and tropospheric ozone concentrations and a negative correlation with NO_x levels in atmospheric air. Sulfur dioxide levels do not show an unambiguous dependence on global solar radiation (Morozov & Starodubceva, 2020). Kadinov (2019a) found a negative correlation between PM_{10} concentration and basic meteorological variables such as air temperature, solar radiation, and wind speed. The relationship between weather conditions and air pollution is the subject of much scientific research. The impact of various meteorological variables on air quality is interrelated, and it is difficult to distinguish one from the other.

The intervention of many other factors such as terrain, location, urbanization, architecture, infrastructure, etc., as well as the established relationships between weather variables and atmospheric pollutants do not always give a clear answer.

The aim of the present study is to search for relationships between some meteorological variables (air temperature (AT), global solar radiation (GSR), wind speed (WS)) and atmospheric pollutants levels (NO_2, CO, O_3, SO_2, PM_{10}) for the Sofia region by applying correlation and regression analysis.

Materials and Methods

Study area

The city of Sofia (the capital of Bulgaria) is located in the central part of the Sofia Valley at an altitude of 520-560 m above sea level on a territory of 492 km^2. The Sofia valley extends from northwest to southeast between the Stara Planina in the north and the Viskyar, Lyulin, Vitosha and Lozenska mountains in the south. The city of Sofia is highly urbanized, with heavy vehicular traffic, high residential density and industrial activity.

The territory of Sofia falls in the climatic region of the high fields of Western Central Bulgaria to the temperate-continental climate subregion of the European-continental climate area (Stanev et al., 1991). The type of the underlying surface, the relief and altitude, the exposure of the slopes and the direction of the extension of the walled mountains transform the influence of solar radiation and atmospheric circulation. For the Sofia valley, radiation inversions are a typical phenomenon. The longest ground inversions are recorded during the cold half of the year - autumn and winter, which is associated not only with low temperatures, but also with the large number of cases of calm weather. Inversions are the most unfavorable conditions for the spread of pollutants in the ground layer. In global, about 230 days with nocturnal inversions can be observed throughout the year, the maximum is observed in August and September, and the minimum is in February.

Six study areas (Druzhba, Hypodrum, Pavlovo, Nadezhda disricts, Orlov most station and the Kopitoto area, Vitosha Nature Park) were selected as they represent areas where automatic measuring stations of the atmospheric air monitoring network are located, where simultaneously with atmospheric pollutants such as PM_{10}, sulfur dioxide, nitrogen dioxide, ozone and carbon monoxide, the main weather variables are measured - air temperature (AT), relative humidity (RH), global solar radiation (GSR), wind speed (WS) and direction (Fig.1).

The automatic measurement stations are divided into:

* Urban background – influenced by emissions from transport, household sources, industrial sources: Druzhba (1), Pavlovo (3), Nadezhda (4).

* Urban background – influenced by emissions from transport and household sources: Hypodrum (5).

* Transport – under the influence of emissions of motor transport: Orlov most (2).

* Country background – influenced by the transfer of pollutants: Kopitoto (6).

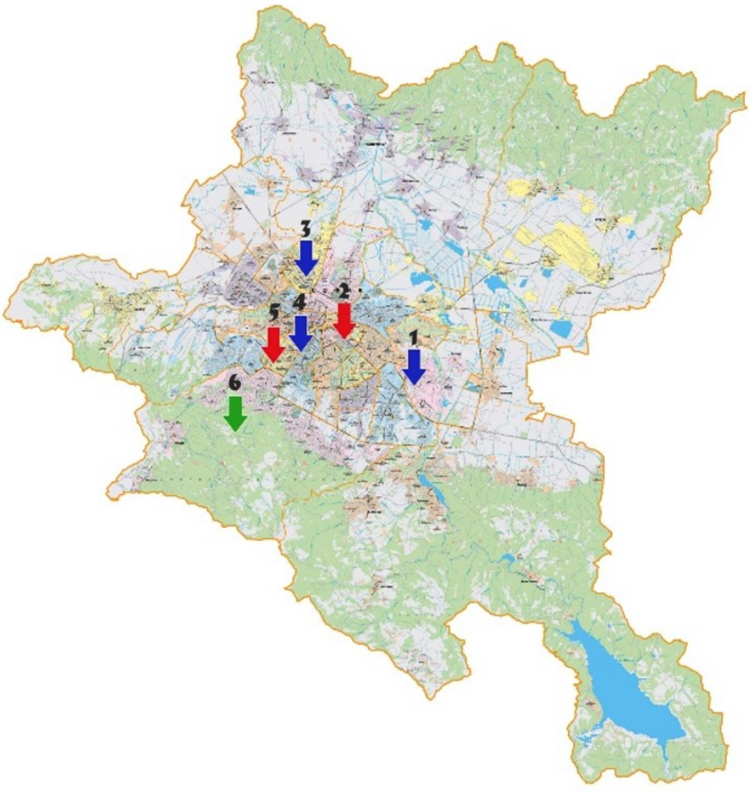

Fig. 1. Location of automatic measurement stations: 1- Druzhba, 2 - Orlov most, 3 – Nadezhda, 4 – Pavlovo, 5 – Hypodrum, 6 - Kopitoto (Kadinov, 2019b).

Stefanov et al. (2011) found that the main contribution to the formation of the average annual and 24-hour concentrations of PM and nitrogen dioxide, not only in the Orlov most station, but also in the neighborhoods, is the transport - over 80%. Kadinov (2019b) found that fine dust particles and nitrogen oxides have a significant impact on air quality in the city of Sofia.

For the purposes of the present study, a database of validated data for 1-hour concentrations of atmospheric pollutants and meteorological variables, provided by the Executive

Environment Agency through a request for access to information from 2012, was used.

Methodical approach

To determine the presence of statistical relationships between atmospheric pollutant concentrations and meteorological variables, regression analysis was used. A special place in regression analysis is occupied by linear regression analysis, or the linear regression model of the relationship between two random variables x and y. The equation of the linear regression model has the form:

$$\boldsymbol{y_x = ax + b},$$

where x is variable, a and b are regression coefficients.

The equations of linear regression between two variables x and y can also be presented in the following form:

$$\boldsymbol{y - y_0 = R_{y/x}(x - x_0)}$$

$$\boldsymbol{x - x_0 = R_{x/y}(y - y_0)}$$

where:

x_0 and y_0 - arithmetic mean of the x and y series;

$R_{y/x}$ and $R_{x/y}$ - regression coefficients.

Regression coefficients ($R_{y/x}$ and $R_{x/y}$) are determined by the formulas:

$$\boldsymbol{R_{y/x} = r\frac{\sigma_y}{\sigma_x}}$$

$$\boldsymbol{R_{x/y} = r\frac{\sigma_x}{\sigma_y}}$$

where:

r – correlation coefficient between rows x and y;

σ –standard deviation.

The correlation coefficient (r) is calculated by the formula:

$$\boldsymbol{r = \frac{\sum_1^n (x_i - x_0)(y_i - y_0)}{\sqrt{\sum_1^n (x_i - x_0)^2 \sum_1^n (y_i - y_0)^2}}}$$

The root mean square deviations (σ_x and σ_y) for the x and y series are determined by the following formula:

$$\boldsymbol{\sigma_x = \sqrt{\frac{(x_i - x_0)^2}{n-1}}}$$

$$\boldsymbol{\sigma_y = \sqrt{\frac{(y_i - y_0)^2}{n-1}}}$$

The correlation coefficient *(r)* is a criterion that expresses the degree of linear relationship between the two variables, its value can take meanings from -1.0 to +1.0. In the case of r=0 the relationship between two phenomena does not exist, and in the case of r=±1, the relationship is functional. In other cases, i.e. in the case of $-1<r<+1$, the relationship is correlative. Its negative value indicates the existing feedback between the signs, while the positive meaning indicates a straight line. The greater its value in absolute value up to 1, the stronger the correlation between x and y. We distinguish the following degrees of correlation:

- $|r| > 0.7$ – strong correlation
- $0.5 < |r| \leq 0.7$ – average correlation
- $0.3 < |r| \leq 0.5$ – weak correlation
- $|r| < 0.3$ – minor correlation

With positive values of the coefficient r, there are straight-line dependencies, in which as the variable y increases, the variable x also increases, and with a negative value of r, with an increase in x, the values of y decrease. With negative values of the correlation coefficient, the regression coefficient is also negative and vice versa.

Results and Discussion

The assessment of the impact of meteorological variables on some atmospheric pollutants in the area of the city of Sofia was carried out using correlation and regression analysis.

The correlation coefficients of the relationship between the average daily values of atmospheric pollutant concentrations and meteorological variables over a five-year period by station are presented in Table 1.

From the presented data, it can be seen that in most of the areas considered, there is a strong correlation between air temperature and solar radiation with ozone concentrations. The same strong correlation was found by other authors (Gvozdić & Kovač-Andrić, 2011; Bernhard et al., 2023). An exception is the station of Orlov most, where there is an average correlation with temperature and an insignificant – with solar radiation. With the exception of the Kopitoto area, in the other areas there are average correlations between air temperature and concentrations of PM_{10}, SO_2, CO. Such a corelation for PM_{10} was found by Chen at al. (2021) while Kadinov (2019a) found out a negative correlation between PM_{10}, temperature, solar radiation, and wind speed.

There is a weak correlation between the NO_2 with air temperature and solar radiation in the areas of Druzhba and Nadezhda. According to some authors (Hester & Harrison, 2009; Wu et al., 2013; Ruan et al., 2021) the corelation between air temperature CO and NO_x was strongly negative.

Table 1. Correlation coefficients between daily concentrations of the main pollutants and meteorological variables in the considered areas.

Variables	AT	GSR	P	WS	Variable	AT	GSR	P	WS
Druzhba					**Hypodrum**				
NO_2	-0.557	-0.451	0.048	-0.141	NO_2	-0.274	-0.276	-0.040	-0.384
O_3	0.719	0.776	0.041	0.048	O_3	0.528	0.650	0.107	0.235
SO_2	-0.402	-0.275	0.191	0.125	SO2	-0.517	-0.400	-0.138	0.186
PM_{10}	-0.346	-0.263	0.126	-0.248	PM_{10}	-0.357	-0.310	-0.001	-0.235
CO	-	-	-		CO	-0.442	-0.419	-0.036	-0.175
Pavlovo					**Nadezhda**				
NO_2	-0.292	-0.208	0.206	-0.502	NO_2	-0.409	-0.311	-	-0.467
O3	0.659	0.716	-0.235	0.386	O_3	0.570	0.683	-	0.309
SO_2	-0.581	-0.351	0.177	-0.100	SO_2	-0.348	-0.186	-	-0.043
PM_{10}	-0.372	-0.261	0.265	-0.402	PM_{10}	-0.356	-0.214	-	-0.337
CO	-0.526	-0.377	0.175	-0.347	CO	-0.409	-0.311	-	-0.467
Orlov most					**Kopitoto**				
NO_2	0.079	-0.006		-0.275	NO_2	-0.038	0.020	0.033	0.011
O_3	-0.419	-0.276	-	0.158	O_3	0.583	0.751	0.127	-0.279
SO_2	-0.347	-0.286	-	-0.322	SO_2	-0.110	-0.107	0.020	0.011
PM_{10}	-0.492	-0.436	-	-0.274	PM_{10}	0.467	0.418	0.213	-0.254
CO	-0.527	-0.439	-	-0.263	CO	-0.229	-0.327	0.104	0.149

Based on the obtained results of the correlation analysis, regression models of the relationships between ozone concentrations with air temperature and solar radiation were searched (Table 2). The models are linear or polynomial of the second order. The correlation coefficients of the regression models ranged $r = 0.53 \div 0.76$.

Regression models of the relationships between ozone concentrations and solar radiation have been obtained for certain areas of Sofia (Table 3). The models are linear with relatively high correlation coefficients r = 0.65 ÷ 0.77.

During the entire study period, the concentration of nitrogen dioxide in Druzhba and Nadezhda is influenced by air temperature ($r = -0.44 \div -0.66$) and the intensity of solar radiation ($r = -0.43 \div -0.55$). The air temperature affects in some years in Pavlovo (for 2013 year: $r = -0.36$ and for 2014 year: $r = -0.40$) and Orlov most (for 2015 year: $r = 0.55$). No significant correlations have been established for the Hypodrum. In Pavlovo ($r = -0.44 \div -0.61$), Nadezhda ($r = -0.32 \div -0.52$) and Orlov most ($r = -0.29 \div -0.39$), an inverse correlation was established between nitrogen dioxide and wind speed.

The concentration of sulfur dioxide in the areas of Pavlovo, Hypodrum, Nadezhda and Orlov most in the period 2012-2016 was influenced by air temperature, and the correlation coefficient for many years ranged from $r = -0.33$ to $r = -0.68$. In Druzhba, this influence was established only in 2012 and 2015. The influence of other meteorological elements is insignificant.

For carbon monoxide, there is a weak correlation with air temperature ($r = -0.42 \div -0.57$) in the Hypodrum and Pavlovo quarters, and in the area of the Orlov most, and with the intensity of solar radiation ($r = -0.37 \div -0.47$) in the Hypodrum and the Orlov most.

Regression models of the relationship between some of the harmful substances and the air temperature are presented in Table 4. The resulting models are polynomials of the first and second order. The relationships have an average correlation $r = 0.55 \div 0.62$.

Table 2. Regression models of the relationship between the average daily ozone concentrations (*y*) and air temperature (*x*) in the considered stations.

Stations	Harmful substances	Regression model	R
Air temperature (AT)			
Druzhba	O_3	$y = 0.0632x^2 + 0.3123x + 22.523$	r = 0.76
Hypodrum	O_3	$y = 1.2462x + 22.307$	r = 0.53
Pavlovo	O_3	$y = 0.0885x^2 + 0.1174x + 26.983$	r = 0.73
Nadezhda	O_3	$y = 1.5261x + 30.634$	r = 0.59
Kopitoto	O_3	$y = 1.7241x + 69.52$	r = 0.62

Table 3. Regression models of the relationship between the average daily ozone concentration (*y*) and solar radiation (*x*) in the considered areas.

Stations	Harmful substances	Regression model	R
Global solar radiation (GSR)			
Druzhba	O_3	$y = 0.148x + 14.436$	r = 0.77
Hypodrum	O_3	$y = 0.133x + 16.421$	r = 0.65
Pavlovo	O_3	$y = 0.2358x + 12.906$	r = 0.73
Nadezhda	O_3	$y = 0.2433x + 18.416$	r = 0.69
Kopitoto	O_3	$y = 0.1825x + 59.484$	r = 0.76

Table 4. Regression models of the relationship between the average daily concentrations of SO_2, NO_2, CO (*y*) and air temperature (*x*) in the considered areas.

Stations	Harmful substances	Regression model	R
Air temperature (AT)			
Hypodrum	SO_2	$y = 0.0208x^2 - 0.8715x + 14.072$	r = 0.57
Pavlovo	SO_2	$y = 0.0264x^2 - 1.0799x + 15.341$	r = 0.62
Druzhba	NO_2	$y = -0.9049x + 33.859$	r = 0.62
Orlov most	CO	$y = -0.0404x + 1.564$	r = 0.56
Pavlovo	CO	$y = 0.0008x^2 - 0.0561x + 1.2975$	r = 0.55

In addition to the established relationships between some of the pollutants and meteorological variables, the current work identifies regression relationships between the concentrations of individual harmful substances. Table 5 shows the regression models of the relationship between O_3 and its precursor NO_2 in some of the studied areas. The relationship is exponential or power-law with an average correlation ($r = 0.65 \div 0.69$).

Regression relationships between fine particulate matter and nitrogen dioxide have been found, with a strong correlation between these pollutants prevailing (Table 6)

Relatively close linear relationships were found between concentrations of fine solid particles and concentrations of carbon monoxide. There is a close exponential relationship between ozone and carbon monoxide (Table 7).

Table 5. Regression dependencies between the average daily ozone concentrations (*y*) and NO_2 (*x*) at the considered stations.

Stations	Harmful substances	Regression model	R
NO_2			
Druzhba	O_3	$y = 609.96x^{-0.987}$	r = 0.66
Hypodrum	O_3	$y = 983.53x^{-1.053}$	r = 0.65
Pavlovo	O_3	$y = 85.273e^{-0.027x}$	r = 0.66
Nadezhda	O_3	$y = 84.93e^{-0.03x}$	r = 0.69

Table 6. Regression relationships between the average daily concentrations of fine particulate matter PM_{10}, SO_2, CO (y) and NO_2 (x) at the considered stations.

Stations	Harmful substances	Regression model	R
		NO_2	
Druzhba NO_2-PM_{10}	PM_{10}	$y = 1.8058x + 1.4855$	r = 0.79
Hypodrum NO_2-PM_{10}	PM_{10}	$y = 0.009x^2 + 0.945x + 0.0747$	r = 0.78
Orlov most NO_2-PM_{10}	PM_{10}	$y = 1.4743x - 7.9524$	r = 0.56
Pavlovo NO_2-PM_{10}	PM_{10}	$y = 0.0138x^2 + 0.4786x + 8.2956$	r = 0.87
Nadezhda NO_2-PM_{10}	PM_{10}	$y = 0.0232x^2 + 0.0011x + 19.279$	r = 0.84
Pavlovo NO_2-SO_2	SO_2	$y = 0.0012x^2 + 0.1011x + 3.7748$	r = 0.54
Hypodrum NO_2-CO	CO	$y = 0.0002x^2 + 0.0086x + 0.2139$	r = 0.77
Pavlovo NO_2-CO	CO	$y = 0.0281x - 0.068$	r = 0.82

Table 7. Regression dependencies between the average daily concentrations of ozone, PM_{10} (y) and CO (x) at the considered stations.

Stations	Harmful substances	Regression model	R
		CO	
Hypodrum CO-O_3	O_3	$y = 62.186e^{-0.94x}$	r = 0.75
Hypodrum CO-PM_{10}	PM_{10}	$y = 59.659x - 4.688$	r = 0.91
Orlov most CO-PM_{10}	PM_{10}	$y = 59.995x - 13.176$	r = 0.93
Pavlovo CO-PM_{10}	PM_{10}	$y = 58.357x - 5.5158$	r = 0.90
Pavlovo SO_2-PM_{10}	PM_{10}	$y = 3.019x + 17.29$	r = 0.55

Conclusions

In conclusion, it can be emphasized that the main meteorological factors that affect the concentrations of atmospheric pollutants in Sofia are air temperature and solar radiation. The other weather variables, such as wind and atmospheric pressure, have a negligible effect. Close regression relationships between individual pollutants have been established. The regression models obtained can be used in restoring or extending the rows and in predicting the possible concentrations of atmospheric pollutants with the help of weather forecasts for the air temperature in Sofia.

Acknowledgement: The study was funded by the Agreement on International Scientific and Academic cooperation between Akhmet Baitursynuly Kostanay Regional University, Kazakhstan and University of Forestry, Bulgaria, №20.02.2023 and №D-33/20.02.2023.

References

Altwicker, El. R., Canter, L. W., Cha, S. S., Chuang, K. T., Liu, D.H.F., Ramachandran, G., Raufer, R. K., Reist, P. C., Sanger, A. R., Turk, A., & Wagner, C. P. (1999). *Air pollution in Environmental Engineers' Handbook*. Boca Raton, FL: CRC Press LLC

Arslan, H. (2023). Impacts of Meteorological Parameters on Tropospheric Ozone Concentrations in Çanakkale. *International Journal of Advances in Engineering and Pure Sciences*, 35(1), 10-17. doi: 10.7240/jeps.1078886

Bagitova, B.E., & Nyssanbayeva, A.S. (2018). Assessment of air pollution of the Caspian region. *Journal of Geography and Environmental Management*, 2(49), 27-35.

Bernhard, G.H., Bais, A.F., Aucamp, P.J., Klekociuk, A.R., Liley, J.B., & McKenzie, R.L. (2023). Stratospheric ozone, UV radiation, and climate interactions. *Photochemical & Photobiological Sciences*, 22, 937–989. doi: 10.1007/s43630-023-00371-y

Bozhkova, V., Liudchik, A., & Umreika, S. (2020). Influence of meteorological conditions on urban air pollution. *Acta Geographica Silesiana*, 14/4(40), 5–21.

Chen, B., Lu, Sh., Li, Sh., & Wang, B. (2015). Impact of fine particulate fluctuation and other variables on Beijing's air quality index. *Environmental Science and Pollution research*, 22, 5139-5151. doi: 10.1007/s11356-014-4024-z

Chen, S.L., Chang, S.W., Chen, Y.J., & Chen, H.L. (2021). Possible warming effect of fine particulate matter in the atmosphere. *Communications Earth & Environment*, 2(1), 208. doi: 10.1038/s43247-021-00278-5

Collier, C.G. (2006). The impact of urban areas on weather. *Quarterly Journal of the Royal Meteorological Society*, 132(614), 1–25, doi: 10.1256/qj.05.199

Doncheva-Boneva, M., Koleva-Lizama, Iv., Mitkov, Sv., & Gosteva, L. (2017). Analysis of air temperature and pollutant variations in Sofia. *Forestry Ideas*, 23(54), 152-159.

Ge, X., He, Y., Sun, Y., Xu, J., Wang, J., Shen Y., & Chen, M. (2017). Characteristics and Formation Mechanisms of Fine Particulate Nitrate in Typical Urban Areas in China. *Atmosphere*, 8(3), 62. doi: 10.3390/atmos8030062

Gong, J., Hu, Y., Liu, M., Bu, R., Chang, Y., Li, Ch., & Wu, W. (2015). Characterization of Air Pollution Index and Its Affecting Factors in Industrial Urban Areas in Northeastern China. *Polish Journal of Environmental Studies*, 24, 1579–1592. doi: 10.15244/pjoes/37757

Gorai, A.K., Tuluri, F, Tchounwou, P.B., & Ambinakudige, S. (2015). Influence of local meteorology and NO_2 conditions on ground-level ozone concentrations in the eastern part of Texas, USA. *Air Quality, Atmosphere & Health*, 8(1), 81-96. doi: 10.1007/s11869-014-0276-5.

Gvozdić, V., & Kovač-Andrić, E. (2011). Influence of Meteorological Factors NO_2, SO_2, CO and PM_{10} on the Concentration of O_3 in the Urban Atmosphere of Eastern Croatia. *Environmental Modeling & Assessment*, 16(5), 491-501. doi: 10.1007/s10666-011-9256-4.

Hester, R.E., & Harrison, R.M. (2009). Air Quality in Urban Environments (Issues in Environmental Science and Technology, Vol. 28), 1st edition. UK: Royal Society of Chemistry, 162 p.

Hu, M., Wang, Y., Wang, S., Jiao, M., Huang, G., & Xia, B. (2021). Spatial-temporal heterogeneity of air pollution and its relationship with meteorological factors in the Pearl River Delta, China. *Atmospheric Environment*, 254, 118415. doi: 10.1016/j.atmosenv.2021.118415.

Jammalamadaka, S., & Lund, U. (2006). The effect of wind direction on ozone levels: A case study. *Environmental and Ecological Statistics*, 13, 287-298. doi: 10.1007/s10651-004-0012-7.

Kadinov, G. (2019a). Relationship between Meteorological Variables and PM_{10} Concentration in Plovdiv District, Bulgaria. *Journal of Balkan Ecology*, 22, 303 – 310.

Kadinov, G. (2019b). Quantitive Assessment of the Importance of the Atmospheric Environment on Air Pollutant Concentrations at Regional and Local Scales in Sofia. *Ecologia Balkanica*, SE2, 63-70.

Kadinov, G. (2021a). Comparative Assessment of Tropospheric Ozone Loads of Two *Fagus Sylvatica* Sites. *Journal of Balkan Ecology*, 24(2), 157-72.

Kadinov, G. (2021b). Relationship between Meteorological Variables and Occurrence of Severe Particulate Matter Pollution in Sofia. *Journal of Balkan Ecology*, 24(3), 317 – 330.

Kerimray, A., Baimatova, N., Ibragimova, O.P., Bukenov, B., Kenessov, B., Plotitsyn, P., & Karaca, F. (2020). Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan. *Science of The Total Environment*, 730, 139179. doi: 10.1016/j.scitotenv.2020.139179.

Khedekar, S., & Thakare, S. (2023). Correlation analysis of atmospheric pollutants and meteorological factors using statistical tools in Pune, Maharashtra. *E3S Web of Conferences*, 391, 01190. doi: 10.1051/e3sconf/202339101190.

Kryukova, S.V., & Simakina, T.E. (2015). Analiz temperaturnyh inversij v Sankt – Peterburge. *Uchenye zapiski Rossijskogo gosudarstvennogo gidrometeorologicheskogo universiteta*, 40, 150-159. [in Russian]

Lazareva, E.O., & Popova, E.S. (2014). Osobenosti prostranstvenno-vremennoj dinamiki antropogennyh primesej vozduha g. Sankt-Peterburga za perioda vremeni s 1980 po 2012g. (na primere oksida ugleroda, dioksida azota, vzveshennyh veshchestv). *Uchenye zapiski Rossijskogo gosudarstvennogo gidrometeorologicheskogo universiteta*, 37, 204-215. [in Russian]

Morozov, A.E., & Starodubceva, N.I. (2020). *Meteorologicheskie usloviya i zagryaznenie atmosfery*. Yekaterinburg, RF: UGLTU. [in Russian]

Mues, A. C. (2013). *Modelling air quality in a changing climate*. PhD thesis at the Department of Geosciences at the Free University of Berlin, 118 p.

Mukhtarov, R., Ibragimova, O.P., Omarova, A., Tursumbayeva, M., Tursun, K., Muratuly, A., Karaca, F., & Baimatova, N. (2023). An episode-based assessment for the adverse effects of air mass trajectories on $PM_{2.5}$ levels in Astana and Almaty, Kazakhstan. *Urban Climate*, 49, 101541. doi: 10.1016/j.uclim.2023.101541.

Pasic, M., Hadziahmetovic, H., Ahmovic, I., & Pasic, M. (2023). Principal Component Regression Modeling and Analysis of PM_{10} and Meteorological Parameters in Sarajevo with and without Temperature Inversion. *Sustainability*, 15, 11230. doi: 10.3390/su151411230.

Peteva, S.P., & Luybenova M.I. (2019). Green System and Air Quality in Sevlievo Town, Bulgaria. *Ecologia Balkanica*, 11(1), 87-97.

Prakash, T., Duckshin, P., & Lee, Y-C. (2022). Recent Insights into Particulate Matter ($PM_{2.5}$)-Mediated Toxicity in Humans: An Overview. *International Journal of Environmental Research and Public Health*, 19(12), 7511(1-22). doi: 10.3390%2Fijerph19127511

Radaideh, J.A. (2017). Effect of meteorological variables on air pollutants variation in arid climates. *Journal of environmental & analytical toxicology*, 7(4), 748(1-12). doi: 10.4172/2161-0525.1000478

Rendon, A.M., Salazar, J.F., & Palacio, C.A. (2014). Effects of Urbanization on the Temperature Inversion Breakup in a Mountain Valley with Implications for Air Quality. *Journal of applied meteorology and climatology*, 53, 840-858. doi: 10.1175/JAMC-D-13-0165.1

Rogalski, L., Smoczynski, L., Krzebietke, S., Lenart, L., & Mackiewicz-Walec, E. (2014). Changes in sulphur dioxide concentrations in the atmospheric air assessed during short-term measurements in the vicinity of Olsztyn, Poland. *Journal of Elementology*, 19(3), 735-748. doi: 10.5601/jelem.2014.19.2.634.

Ruan, H-L., Deng, W-Sh., Wang, Y., Chen, J-B., Hong, W-L., Ye, Sh-Sh., & Hu, Zh-J. (2021). Carbon monoxide poisoning: a prediction model using meteorological factors and air pollutant. *BMC Proceedings*, 15(Suppl 1), 1. doi: 10.1186/s12919-021-00206-7.

Seinfeld, J.H., & Pandis, S.N. (1998). *Atmospheric chemistry and physics from air pollution to climate change*, 1st edition. New York, USA: John Wiley & Sons, Inc., 1326 p.

Song, Z., Deng, Q., & Ren, Z. (2020). Correlation and principal component regression analysis for studying air quality and meteorological elements in Wuhan, China. *Environmental Progress & Sustainable Energy*, 39(1), 13278. doi: 10.1002/ep.13278.

Soyol-Erdene, T., Ganbat, G., & Baldorj, B. (2021). Urban Air Quality Studies in Mongolia: Pollution Characteristics and Future Research Needs. *Aerosol and Air Quality Research*, 21(12), 210163. doi: 10.4209/aaqr.210163.

Stanev, Sv., Kyuchukova, M., & Lingova, St. (1991). *Climate of Bulgaria*. Sofia, Bulgaria: BAN.

Stefanov, B. (2011). Programa za namalyavane na emisiite i dostigane na ustanovenite normi za fini prahovi chastici $FPCH_{10}$ i azoten dioksid NO_2 i upravlenie na kachestvoto na atmosferniya vazduh v Stolichna obshchina za perioda 2011-2014 g. Himikotekhnologichen i metalurgichen universitet (In Bulgarian).

Taleghani, M. (2022). Air Pollution within Different Urban Forms in Manchester, UK. *Climate*, 10(2), 26. doi: 10.3390/cli10020026.

Tian, G. J., Qiao, Z., & Xu, X. L. (2014). Characteristics of particulate matter (PM_{10}) and its relationship with meteorological factors during 2001-2012 in Beijing. *Environmental Pollution*, 192, 266-274. doi: 10.1016/j.envpol.2014.04.036

Wu, M., Wu, D., Fan, Q., Wang, B. M., Li, H. W., & Fan, S. J. (2013). Observational studies of the meteorological characteristics associated with poor air quality over the Pearl River Delta in China. *Atmospheric chemistry and physics*, 13(21), 10755-10766. doi: 10.5194/acp-13-10755-2013

Xie, J., Sun, T., Liu, C., Li, L., Xu, X., Miao, S., Lin, L., Chen, Y., & Fan, S. (2022). Quantitative evaluation of impacts of the steadiness and duration of urban surface wind patterns on air quality. *Science of The Total Environment*, 850, 157957. doi: 10.1016/j.scitotenv.2022.157957.

Yin, Q., Wang, J. Hu, M., & Wong H. (2016). Estimation of daily $PM_{2.5}$ concentration and its relationship with meteorological conditions in Beijing. *Journal of Environmental Sciences*, 48, 161-168. doi: 10.1016/j.jes.2016.03.024.

Zyromski, A., Biniak-Pierog, M., Burszta-Adamiak, E., & Zamiar, Z. (2014). Evaluation of relationship between air pollutant concentration and meteorological elements in winter months. *Journal of water and land development*, 22(VII-IX) 25-32. doi: 10.2478/jwld-2014-0019

Received: 04.12.2023
Accepted: 25.05.2024