RESEARCH OF CONCENTRATIONS OF POLLUTANTS IN THE VERTICAL PROFILE OF THE ATMOSPHERE OF THE ZENICA VALLEY USING UNMANNED ARIEAL VEHICLES

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SUMMARY

This paper presents a study of air pollution in the vertical profile of the atmosphere during periods with and without temperature inversion in the Zenica valley. Unmanned aerial vehicles (drones) equipped with sensors for measuring the concentration of suspended particles, atmospheric pressure and air temperature were used for the study. The measurements were carried out at three different locations in the Zenica valley in two different periods. The study shows that pollutants remain below the inversion layer during the inversion period and that concentrations drop sharply at heights above the floor of the inversion layer. The measurements were carried out in December 2024 and January 2025 at three locations (Institut, Kamberovića polje and Banlozi) along the Zenica valley, which, in addition to industrial sources of pollution, also contains a large number of small house stows distributed on the slopes of the hills surrounding the Zenica valley on three sides.

Keywords: vertical profile of the atmosphere, ground temperature inversion, pollutants, mixing layer height

INTRODUCTION

The Zenica basin is orographically very specific, which is why, in conditions of weak airflow, ground and elevated temperature inversions are created.

During the cold part of the year, ground and elevated inversion layers of the atmosphere often occur over the Zenica valley, i.e. layers in which the air temperature increases with increasing altitude. Measurements carried out for the purposes of the Study [1] show that in the cold part of the year, both ground inversion (up to 20 m above ground) and elevated inversion (at heights of 600 to 1000 m above ground) are present in the Zenica valley throughout the day. The study was carried out with the aim of determining the impact of high-level sources of sulfur dioxide pollution on the quality of the ground layer of the atmosphere during the steady state of the atmosphere in the cold part of the year. The study concludes that the impact of high-altitude sources of pollution in conditions of a steady state of the atmosphere is not primary and that in such conditions, the impact of low-altitude sources of pollution on the quality of ambient air should be investigated.

The slopes of the local hills and mountains descend relatively steeply towards the valley and a large number of individual residential buildings are located on them, which are heated mainly by burning coal from the Zenica mines. Pollutants (primarily sulfur dioxide and particulate matter) descend into the valley at night due to the existence of local nighttime downslope currents (mountain breeze). This wind, wich usually blows into the valleys, carries pollutants into the valley, which is why concentrations, especially sulfur dioxide, are significantly higher at night than during the day [2].

Previous research has shown that there is a connection between the inversion layer and the level of pollution in the ambient layer of the atmosphere, and that without knowing the characteristics of the inversion layer, it is not possible to make a quality assessment of the impact of pollutant emissions from pollution sources on ambient air quality. Research [3] shows that air pollution is higher on days when an inversion of the atmosphere is registered, but the degree of correlation between temperature inversion and air pollution is very low. The research does not mention the level of deterioration in air quality on days when an inversion occurs compared to days without an inversion.

Research [4], which analyzed the dependence between air pollution by PM2.5 particles and temperature inversion, states that there is generally a positive linear correlation between the characteristics of the inversion layer and the level of air pollution, but does not provide any quantitative indicators for this correlation.

Research of relationship between air pollution by suspended particles PM_{10} and $PM_{2.5}$ and the characteristics of temperature inversion (thickness of the inversion layer and temperature gradient per 100 m of the inversion layer thickness) conducted in the city of Wrocław (Poland) during the winters of 2015/16, 2016/17, 2017/18, 2019/20 [5], shows in a very unique way a positive relationship between the degree of pollution and the characteristics of ground and elevated inversion, but still at a qualitative (descriptive) level, i.e. no quantification of the impact is given. The research also states that in cases of very high pollution this relationship is not so unambiguous.

Research conducted in the Sarajevo valley [6] also states that there is a strong positive relationship between temperature inversion and the level of air pollution, but still without any quantitative indicators. The paper provides diagrams of the vertical distribution of the level of air pollution under temperature inversion conditions, from which it is clearly seen that the concentration of $PM_{2.5}$ particles below the base of the inversion layer is significantly higher than in the inversion layer itself and above it. Research [7], also conducted in the Sarajevo valley analyzes in more detail the relationship between the characteristics of the inversion layer and the level of pollution. This researche states that shallow and strong inversions with an inversion gradient greater than 30 K/km and occurring below 150 m above the ground can be associated with very high levels of air pollution, especially PM_{10}, although the authors do not state the correlation coefficient.

Research conducted in the Tuzla valley [8] also links high air pollution in conditions of stable atmospheric conditions and the occurrence of inversion, but without any quantitative indicators.

Research [9] conducted in the Belgrade area between July 2002 and July 2003 suggests that one of the causes of the high air pollution recorded during that period could be an inverse state of atmosphere.

Research [10] conducted in the Zenica valley provides results of measurements of SO_2 and PM_{10} concentrations in the vertical profile at three representative locations in the Zenica valley. The research was conducted on days without inversion layers and shows that the concentration of SO_2 and PM_{10} is fairly niform up to a height of 300 m above the ground, where a raised inversion occurs during the cold part of the year. The results also show that in the central part of the valley, pollutants accumulate at heights of 230 to 300 m above the ground.

Common to all of the above studies is that the relationship between the inversion layer and the level of ambient air pollution is very difficult to quantify, and most studies conclude that air pollution is higher on days of inversion. In addition, the authors do not state the possibility of generalizing the relationship between the inversion layer and the level of air pollution, i.e. the results of the influence of the inversion layer of the atmosphere on the level of air pollution in one basin cannot be applied to another similar valley.

RESEARCH METHODS

The characteristics of the inverse layer of the atmosphere, in which air temperature increases with height, can be determined in various ways: by satellite observations, microwave radiometry, sounding measurements, and measurements using drones [11-13].

Unmanned aerial vehicles - drones, which are actually helicopters shown in Figure 1, were used to measure the temperature and concentrations of pollutants (PM_{10}, $PM_{2.5}$, PM_1 and SO_2) in the vertical profile of the atmosphere.

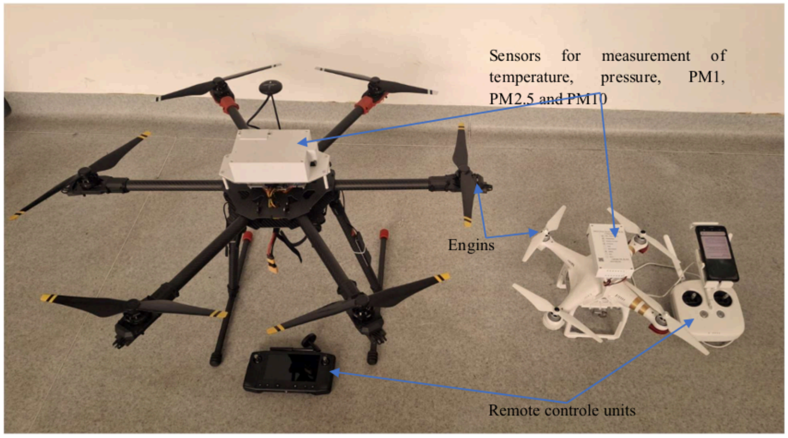


Figure 1. Unmanned aerial vehicles

A specially designed housing for the sensor and air inlet for measurement was installed on the top of the drone, as previously described in [14]. In this work, sensors for PM_{10}, $PM_{2.5}$, PM_1 and SO_2 pollutants and atmospheric parameters with the following characteristics were used:

- Sensor for PM_{10}, $PM_{2.5}$ and PM_1 (Measurement technique - light scattering method, equipment model - PLANTOWER PMS5003, measurement range 0 – 500 μg/m^3)
- Temperature: temperature range from -40 to +125 °C, sensor accuracy ±0.2°C,
- Atmospheric pressure: measurement range from 300 to 1100 hPa, operating temperature from 40 to 85 °C.

2.1 Locations and measurement period

The Zenica valley is about 12 km long and about 2 km wide. Valley is about 350 m above sea level and is bordered by surrounding hills that are about 1000 m above sea level. This configuration means that weak air currents prevail in Zenica valley and poor conditions for the dispersion of pollutants. Industrial zone of the city is located in the northern part of the valley with chimneys about 100 m in hight, at most 150 m. Given the configuration of the terrain, and location of industrial zone three representative locations were selected for measurement, namely:

- Banlozi (industrial zone, geographical coordinates: E 44° 14' 44", N 17° 53' 54", 306 m above sea level)
- Kamberovića polje (urban area, geographical coordinates: E 44° 12' 22", N 17° 54' 53 ", 312 m above sea level) and
- Institute (campus of the University of Zenica - urban area, geographical coordinates: E 44° 11' 59", N 17° 54' 04", 330 m above sea level).

Measurements were taken in the winter of 2024/2025, namely in December 2024 and January 2025.

The following picture shows the measurement locations.

Figure 2. Measurement locations

RESEARCH RESULTS AND DISCUSSION

The following figures show the vertical profiles of temperatures and suspended particles at the selected locations. Data analysis shows that during the measurements up to 300 m above the ground, the temperature inversion was not registered only on 19.12.20224 at the Banlozi location with small temperature gradient amounted to 6.6 K/km. The dust concentration was uniform over the entire vertical profile.

A slight inversion was registered at the measuring location Banlozi on 08.01.2025 at a height of 500 to 550 m above the ground. The data show that there was an accumulation of dust at a height just below the inversion layer.

A strong inversion at this measurement location was registered on 23.01.2025 at heights of 50 m above the ground with a temperature gradient of 7 K/km. A decrease in dust concentration with increasing height was registered. In this conditions dust spreads in the ground layer, as can be seen in Figure 3.

At the Kamberovića Polje measuring location, an inversion was also registered on 09.01.2025 directly above the ground. Dust spread in the ground layer of the atmosphere was also registered.

Based on data obtained using an unmanned aerial vehicle at the Institute measurement location on 07.01.2025 a ground inversion was registered up to 50 m above the ground and. Data clearly shows a sharp decrease in dust concentration above the ground inversion layer (Figure 5). This ground inversion limits vertical mixing only within the inversion layer (50 m) and does not allow the transport of pollutants to higher layers of the atmosphere which causes a very rapid accumulation of pollutants only in the ground layer of the atmosphere. In these conditions concentrations of pollutants can exceed limit values in a very short time.

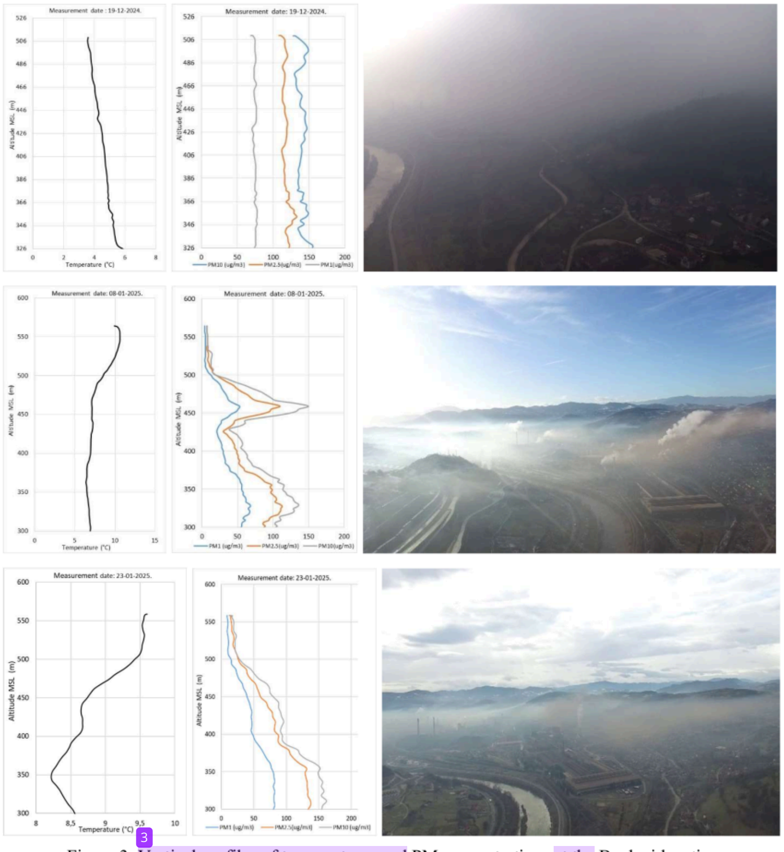


Figure 3. Vertical profiles of temperatures and PM concentrations at the Banlozi location

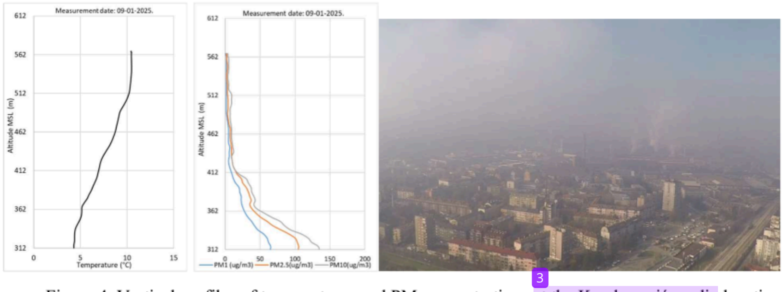


Figure 4. Vertical profiles of temperatures and PM concentrations at the Kamberovića polje location

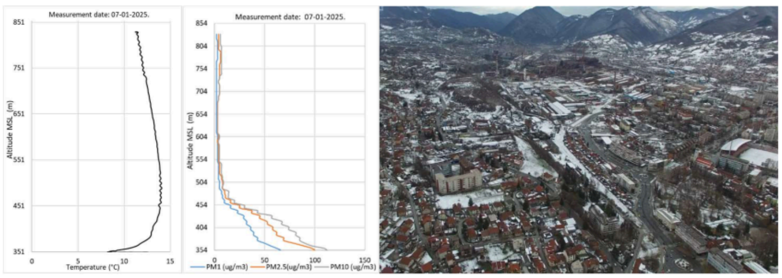
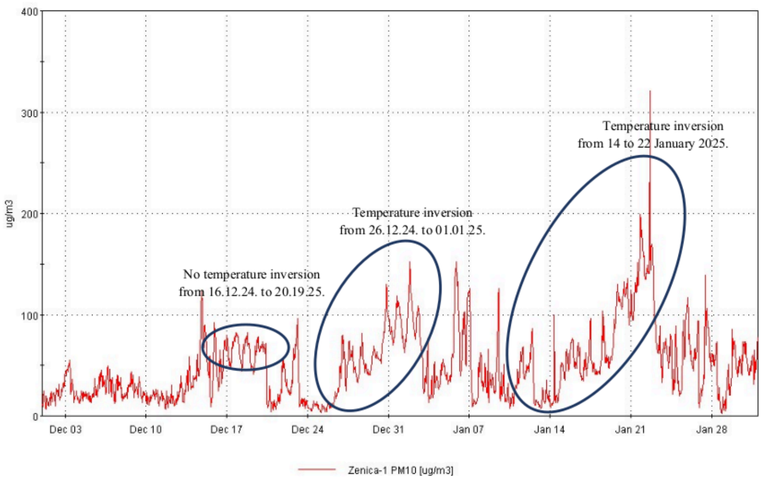


Figure 5. Vertical profiles of temperatures and PM concentrations at the Institute location

Based on the data obtained using an unmanned aerial vehicle graphically shown in the above images, it can be seen that in the Zenica valley, ground-level and elevated inversions occur, which significantly limit vertical mixing only in the layer of the atmosphere below the inversion layer, which, in some cases, is formed at heights of 50 m above the ground. This layer and does not allow the transport of pollutants to higher layers of the atmosphere, which is especially pronounced in the cold part of the year. Figure 6 shows the average hourly PM_{10} concentrations measured at the air quality measuring station "Centar". The location of the "Centar" station is given in Figure 1. The figure shows that in the Zenica valley, temperature inversions are common, lasting for several days, with the concentrations of pollutants constantly increasing and quickly exceeding the permitted limit values.



Figute 6. PM_{10} concentrations measured at the air quality measuring station "Centar"

Figure 6 shows 3 periods during which measurements of dust concentrations in the vertical profile of the atmosphere were made. In the first period (16.12.2024 to 20.12.2024), no temperature inversion was recorded and dust concentrations had the usual daily range in the interval from 50 to 80 µg/m^3. The dust concentration in the vertical profile was uniform from the ground to the final measurement height (526 m above the ground). In the second period (26.12.24 to 01.01.2025), a temperature inversion was recorded and dust concentrations increased from day to day to a maximum of 150 µg/m^3. After the temperature inversion ceased, dust concentrations dropped to values below the limit. In the third period (14.01.2025 to 22.01.2025), the temperature inversion lasted almost 6 days and the concentrations increased to 300 µg/m^3 on the last day of the inversion, due to the accumulation of pollutants below the inversion layer where they remain until the cessation of the inversion state of the atmosphere. There is an obvious connection between the appearance of the inversion layer and the level of air pollution, but there is still not enough information to determine the degree of correlation. One way to determine the degree of correlation could be the proportion of secondary aerosols in suspended particles, because secondary aerosols are formed due to chemical processes in the atmosphere after a certain period of time, which can be from several hours to several days, and are often in the form of SO_4-, NO_3- and NH_4+. The results of the study [15] showed that the proportion of secondary aerosols in suspended particles ($PM_{2.5}$) in Zenica is up to 35% whichi indicates strong correlation between air pollution and inversion state of atmosphere.

CONCLUSION

The measurement of temperatures and dust concentrations in the vertical profile of the atmosphere presented in this paper represents a very suitable tool for researching the impact of the inverse layer of the atmosphere on ambient air quality. On days when a temperature inversion was recorded, pollutants accumulated below the lower floor of the inverse layer because atmospheric mixing in the vertical layer was limited only to the layer of the atmosphere below the inverse layer. In some cases, the thickness of this layer is only about 50 m above the ground. After the appearance of the inverse layer, concentrations increase from day to day, and the period of the inverse state of the atmosphere can last up to 7 days. Due to the frequent occurrence of inverse states of the atmosphere and the complex orography of the Zenica valley, it is necessary to establish continuous monitoring of the height of the mixing layer in order to forecast the state of air quality, and to manage air quality in episodes of increased air pollution.

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