THE IMPACT OF OUTDOOR MINING ACTIVITIES ON ATMOSPHERIC AIR QUALITY IN NEARBY SETTLEMENTS

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ABSTRACT. Wind erosion breaks down toxic impurities and enables their transport over long distances, thus polluting air, soils and water over vast areas around mines and in surrounding settlements. The purpose of this study is to investigate and analyse the atmospheric air and the concentrations of fine particulate matter in open pits and quarries, and to analyse different types of pollutants. The studies will take into account the pit geometry and the type of the underlying substrate defined by the mined minerals. Specific weather parameters, such as wind pattern defining the direction of transfer, and the temperature profiles defining the temperature inversions which retain the pollution over the region, will be considered as well. The aim is to track the overall process of emission, transmission and sedimentation of aerosol impurities and fine particulate matter concentration in the mine area and in nearby settlements.

Keywords: air pollution, particulate matter, weather conditions, open pit, quarry

ВЛИЯНИЕТО НА ОТКРИТИ МИННИ РАЗРАБОТКИ ВЪРХУ КАЧЕСТВОТО НА АТМОСФЕРНИЯ ВЪЗДУХ В БЛИЗКО РАЗПОЛОЖЕНИ НАСЕЛЕНИ МЕСТА

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РЕЗЮМЕ. Ветровата ерозия води до разпрашаване на токсичните примеси и възможност за пренасянето им на големи разстояния, което причинява замърсяване на въздуха, почвите и водите на обширни райони около минните терени и в населените места до тях. Целта на настоящото изследване е да се проучи и анализира атмосферния въздух и концентрациите на фини прахови частици (ФПЧ) в района на открити рудници и кариери, както и да се анализират различни видове замърсители. При тези изследвания ще бъдат отчетени геометрията на рудника, вида на подложната повърхност в зависимост от полезните изкопаеми, които се добиват. Ще бъдат отчетени и конкретните метеорологични условия, като розата на ветровете определяща направлението на преноса и температурните профили определящи наличието на температурните инверсии задържащи замърсяването над района. Целта е да се проследи цялостния процес на емисия, пренос и утаяване на аерозолните примеси и концентрация на ФПЧ в атмосферата в района на рудника и близките населени мяста.

Ключови думи: замърсяване на въздуха, твърди частици, климатични условия, открит рудник, кариера

Introduction

Open pit mining and quarrying generate significant amounts of particulate matter (PM) and harmful gasses. Particulate matter of varying sizes is generated by rock and soil fragmentation, with particularly high quantities being emitted by blasting. Machines operating on the sites are the main source of aerosol and gas pollution. Measuring the levels of pollution and determining their dependence on quarry-specific activities is important both in protecting the health of the workers and in ensuring a quality of life in nearby settlements.

Pollution spreading is highly affected not only by in-pit operations, but also by the micro-climate specifics of the site. The main meteorological parameters to be monitored are temperature stratification, the site-specific wind patterns, humidity and solar radiation. A number of studies conducted during the recent decades have researched the relation between aerosol impurity dispersion and the regional meteorological features and orography (2, 6, 7, 8, 9 and 10). Digital models for simulation and predictions of hazardous events in quarries (3, 4 and 5) are being developed alongside experimental research.

The present study investigates and discusses the concentrations of differently sized fine particulate matter in the atmosphere of the open gravel quarry of the Balsha AD Mine extractive factory. The main weather parameters such as wind direction and velocity, temperature, and solar radiation, have been considered. The stratification of aerosols was outlined better by two types of study - measurements in a nearly-horizontal plane were carried during the first day, and vertically at different heights along the quarry slope - during the second day.

Experimental site and equipment

The quarry is situated 3 km to the north-west of the Balsha village and is 1 km long from east to west, and 500 m at its widest (eastern) part from north to south. Its slopes are vertical and its west-facing wall has 6 benches, the highest difference in elevation between them being 160 m. The lowest lying western part of the quarry is at 800 m a.s.l., and its eastern end is at 960 m a.s.l.

Figure 1 presents a map of the region with designated measurement points. These data have been taken over two days, 13th and 14th of June 2019, with the following arrangement of the measuring devices: June 13th - points 1 through 4, June 14th - points 5, 6, 3, and 7. The difference in level between the first four points is very little (not more than 20 m). The points of the second day were distributed at height - the lowermost points (5 and 6) were at the quarry bottom, and points 3 and 7 were spaced 30-40 m apart vertically along the eastern slope.

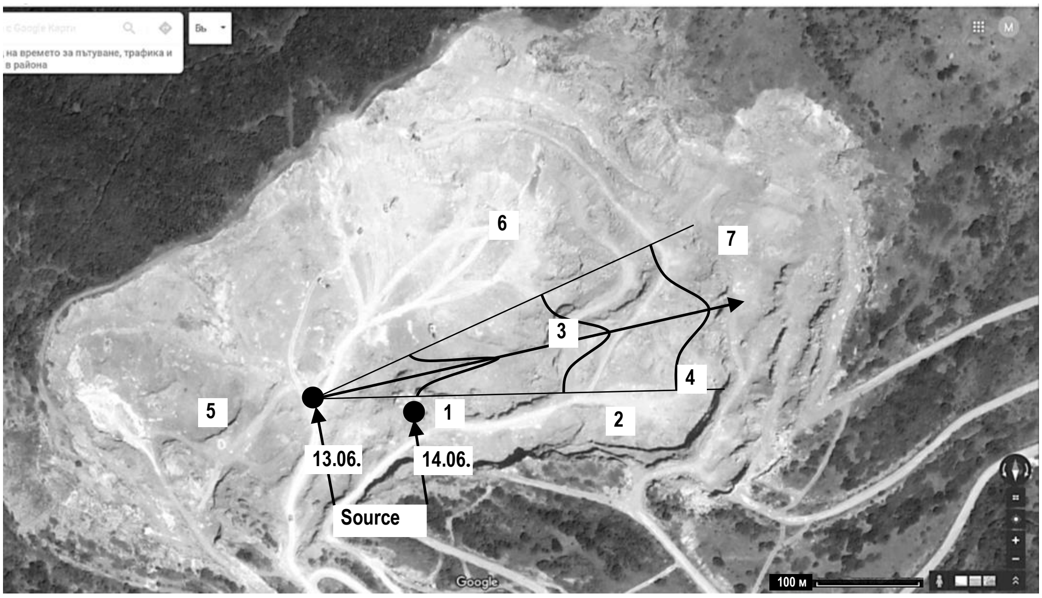

Fig. 1. A map of the quarry with measurement points and pollution sources

The employed devices

Laser particle counters were used during the experimental campaign – one six-channel HHPC-6 (MetOne, USA) with particle size channels at 0.3 μm, 0.5 μm, 0.7 μm, 1 μm, 2 μm, 5 μm and three two-channel BQ20 (TROTEC, Germany) with particle size channels at 2.5 μm and 10 μm for particle number and mass concentration measurements.

The meteorological data were obtained from the multi-functional weather station with four sensors (temperature, precipitation, relative humidity, air pressure, wind direction and speed).

Experimental data

Meteorological data for 13th of July 2019

On this day, meteorological parameters were measured in points 1, 2, and 4. The least change in temperature occurred at point 1, where a slow rise from around 25 degrees to around 26 – 27 degrees was measured at noon. The temperature at point 2, approximately 200 m away from, and 15 m higher than, point 1, rose from 23°C at the beginning of the measurement, to 30°C at lunch. This range was 22-30°C in point 4. A most substantial change in relative humidity occurred at point 4 (at around 30%), and the least change, by less than 10%, was noted at point 1. At noon, the solar radiation reached a high of 850 W/m^2 which is typical of a clear summer day.

The PM counter data

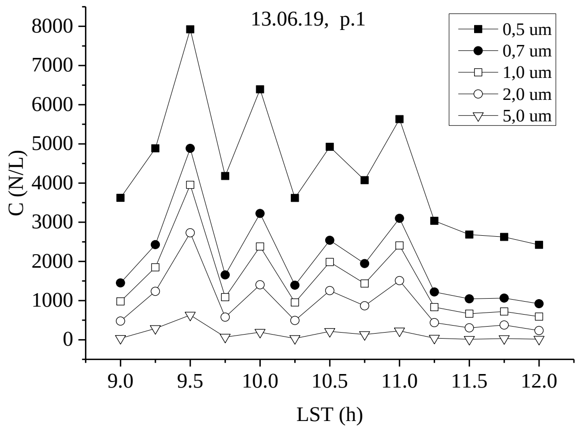

Fig. 2. Numerical concentration of fine particulate matter of varying sizes at point 1 on the 13th of June 2019

Figure 2 shows that the number of particles measured at point 1 by all channels was falling as the day advanced. This is especially true of the finer fraction (0.3 and 0.5 μm) where the number of particles dropped from around 70 000 N/L to around 4 500 N/L. A similar trend was observed at point 2 where the mass concentration for two sizes of fine particulate matter, 2.5 and 10 μm, was measured. No easily discernible trend in the change of mass concentration is present at point 3 (Figure 3).

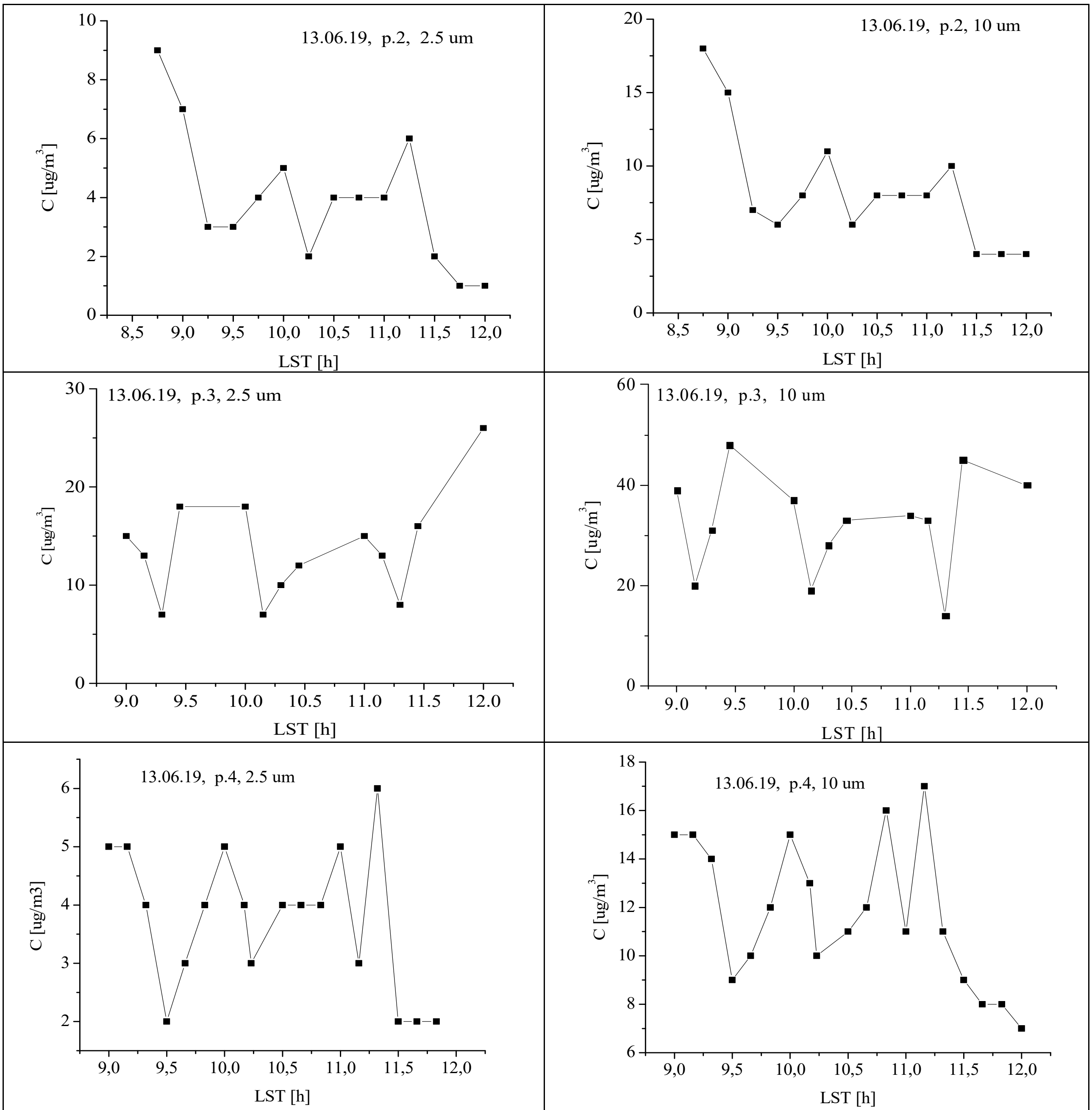

Fig. 3. Mass concentration of 2.5 and 10 µm fine particulate matter at points 2, 3 and 4 on 13th of June 2019

Meteorological data for 14th of July 2019

The second day of the experiment was also clear and sunny, with a monotonous rise in solar radiation up to around 750 W/m^2 at 11 o'clock. On this day, the main meteorological parameters - temperature, relative humidity, wind direction and wind velocity, were measured at each point.

The temperature profile ranged mainly between 25°C and 30°C, with the beginning temperature being lower, at around 22°C, only at point 5. The relative humidity dropped from 65 to 45%.

In all four points the average wind velocity was 1 - 2 m/s, with a slow decrease at experimental point 6 down to around 0 in the afternoon hours. With the exception of point 6 with a predominantly north-north-easterly winds, the wind direction was rather unstable.

Counter data

On this day, the number of fine particulate matter at the beginning of the experiment was around 90 000 N/L, while the coarse particles varied from 800 N/L down to several scores at the end of the experiment.

As the day progressed, the mass concentrations decreased in point 6 as well. Almost no decrease was measured in the two remaining points, 3, and 4.

Discussion

Orographic forms such as an open quarry predicate changes in the evolution of thermal fields and the characteristic circulation of air flows. If the average background wind velocity is not so high (below 5 m/s), the background wind modification is mainly a change in the predominant wind direction along the axis (usually the longest) of the quarry. However, this is typical of long and shallow quarries, the circulation being referred to as straight-through, but the flow becomes much more complex in quarries as deep as their horizontal axis is long, where the so-called recirculation pattern forms, with the flow in the windward part of the quarry running counter to the main wind at height. Such a pattern is referred to as recirculation pattern. In our case the circulation is straight-through.

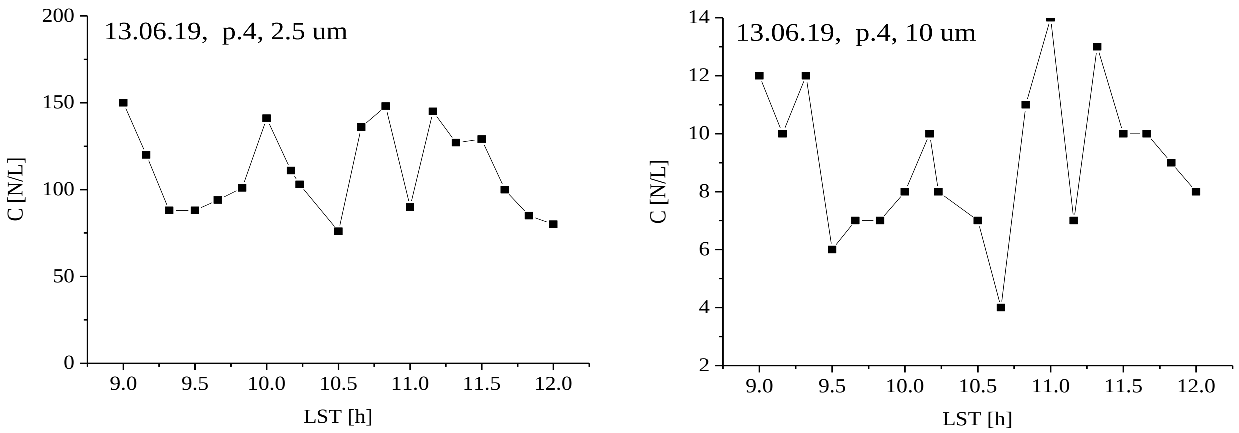

Fig. 4. Numerical concentration of 2.5 and 10 µm fine particulate matter at point 4 on 13th of June 2019

On June 13th, the wind measured at point 1 was predominantly south-western (Figure 5), with velocities of up to 2 m/s.

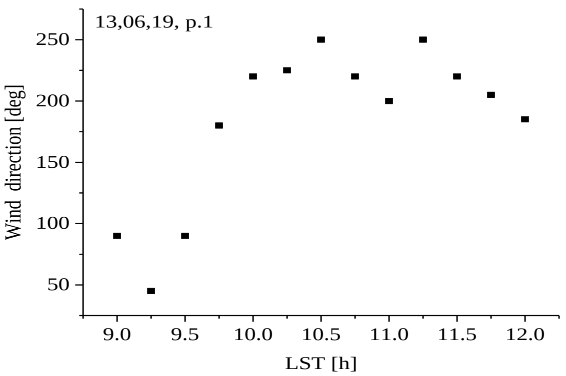

Fig. 5. Wind direction at point 1 on 13th of June 2019

This means that the wind was transferring the aerosol impurities to the north-east from the main pollution source - the automotive plant around the excavator and the near-by pneumatic hammer. In a relatively calm atmosphere (no precipitation or storms), the distribution of fine particulate matter is described rather well by the Gauss distribution law. Examples of Gaussian curves consistent with the predominant wind are shown on Figure 1. The maximum pollution levels follow the central axial line along the wind direction. As this line runs closer to point 3 than to points 2 and 4, the pollution levels measured there were higher (by a factor of 3 or 4) than in the two other points. We believe that the absence of a clear downward concentration trend at point 3 was also caused by the wind direction during that day.

Measurements of the number of particles in one litre of air were made at point 1. A comparison was made possible by the fact, that the same measurement was carried out at point 4, Figures 2 and 4 show that the different concentrations of fine particulate matter (2 – 2,5 µm) had dropped from around 700 N/L to around 100 N/L at point 4, which is around 200 m away from point 1.

The machines stopped working at around 11:30 h, meaning that the main source of pollution has disappeared, as can be seen on Figure 2, point 1, and on Figure 3, points 2 and 4 where mass concentration was measured. High pollution levels continued to be observed at point 3 and may have been caused by the specific orography generating local circulation and retaining the impurities in that area.

On the next day, the measurement points were arranged to determine the distribution of aerosol impurities at height. Point 5 was lowermost, around 50 m below the highest point, 7. The two other points, 6 and 3, were at 15 and 30 m respectively, above point 5. The source of pollution was at the same place as on 13th of June until 9:30 h, when work was stopped and the machines were relocated to the place marked on Figure 1. Figure 6 presents five measurement channels from the counter at point 5 and shows results with similar values.

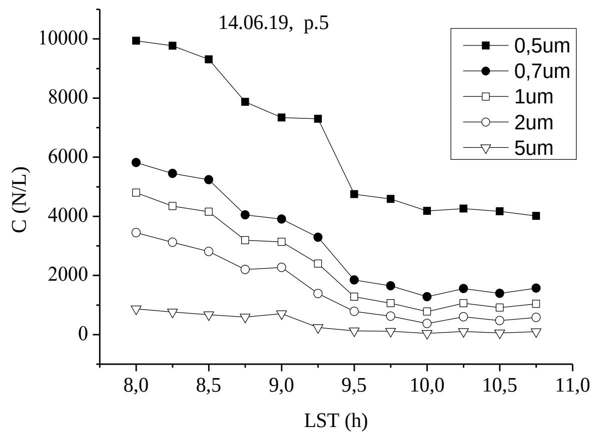

Fig. 6. Numerical concentration of fine particulate matter of varying sizes at point 5 on 14th of June 2019

The concentration of the finest particulate matter (0.3 µm) varies between 91,000 N/L and 63,000 N/L. One point of interest is that the number of particles along the entire spectrum in point 5 was 30 – 40% higher than that in the preceding point 1, although the source of pollution was, initially, at the same place. Subsequently, as the day progressed, the pollution decreased quickly, reaching its levels from the previous day. This means that the temperature inversion had 'caught' the particles and retained them in the bowl on the bottom until the morning. Temperature inversions were registered also by the measurement of the profile at height. A difference of around 2 degrees at the ground level and at a height of 5 m was determined. This is a very strong inversion (4 deg/100 m).

Following the rising of the sun, this inversion, strong but shallow, started to disintegrate and the impurities began to scatter at height, and their ground-level concentration decreased as well.

Preparations for blasting started after 9:30 using other plant, located around point 1 on the previous day. The proximity of the source to points 3 and 4 meant that the level of pollution was 5 to 10 times higher than the level of pollution observed on June 13th. Air pollution at point 6 was comparatively low, similar to the levels at point 2 on the previous day. This is explained with the position of this point - 15 m below the level of the operating machines.

Fig. 7. Picture of the open quarry for extraction of ballast materials at Mining Company 'Balsha' AD

The quarry of Balsha AD Mining Company presented in Figures 7 is located 25 km north of Sofia. Open-air quarries are characterised by the generation and typical circulation of airflows. The analysis of the data shows that the concentration of PM in the area of "Balsha" AD Mining Company is within the norm and for similar days of the same month are even lower than the concentrations of PM in the region of Sofia. The study did not detect any contamination and the measured concentrations of PM in the air in the quarry were below the thresholds for human health protection.

Conclusion

The measurements of fine particulate matter in air in the Balsha quarry lead to the following conclusions:

- Horizontal and height re-distribution of impurities is caused by the specific orography of the region.
- A clear vertical stratification of aerosol impurities is present and, therefore, dispersion is affected more by the vertical positioning of FPM sources within the quarry (the transferring of particles over the quarry walls being harder) than the horizontal movement of machines.
- Given the particular weather (a clear summer day with a relatively light wind), the concentration of aerosol impurities several hundred meters from the source was not above the admissible air pollution limit values, which, according to the EU directive (1) apply to average daily concentration of particulate matter with a radius of up to 10 μm – 50 μg/m^3 and 2.5 μm – 40 μg/m^3, although we had asked that the roads over which the trucks hauling waste rock were moving should not be sprayed for the experiment.

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