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SPECIFICS OF PARTICULATE MATTER DISPERSION IN THE ATMOSPHERE OF A CLAY QUARRY

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ABSTRACT

In this work, the dispersion of fine dust particles in the atmosphere of a clay quarry is investigated and analyzed. This study will take into account the geometry of the quarry, the emission of fine dust particles and the main meteorological parameters. In the presence of a surface temperature inversion, pollutants are kept low to the earth's surface, and their concentration becomes quite high. The aim is to follow the overall process of emission, transfer and precipitation of aerosol impurities and concentration of fine dust particles in the atmosphere in the quarry area. A decrease in the concentration of fine dust particles in the study is due to a convective ventilation scheme. At the beginning of the day, the number of particles with a radius of up to 0.3 μm is about 60 000, decreasing to about 30 000 in the afternoon, for 2.5 μm particles (from about 200 to 100) and for 10 μm (from 30 to 15). The work uses for the first time a small unmanned aerial vehicle Phantom II drone carrying a sensor for micrometeorological data.

Keywords: air pollution, particulate matter, open quarry.

INTRODUCTION

Mining, as a leading industry, plays a vital role in the changing economic situation of countries around the world and is crucial for the growth of industrialization. On the other hand, it is also true that mining activities are responsible for air pollution. During the construction, operation and extraction phases, the potential pollutants include particulate matter 10 and 2.5 μm (PM10 and PM2.5) and gaseous emissions (CO, CO_2, SO_2, NO_x). Particulate matter is generally emitted during drilling, excavation, loading, site ore processing and haulage. Various operations release huge amounts of particulate matter into the ambient atmosphere [1 - 5]. Air quality management related to mining is primarily focused on the impact of particulate matter. These include dust deposition and the associated effects of PM10 and PM2.5 on the health of people living near pollution sources and particularly on work personnel [6]. Dispersion modeling is an integral part of air quality planning, especially in the quarry planning phase, where detailed models can be used to provide information on the location of certain activities and the necessary controls to adequately manage air emissions. Environmental factors such as temperature, precipitation and humidity, combine to add uncertainty to forecasts. Quarries are not static and are constantly changing, in terms of location and distance to haulage road, amount of waste rock, tailing pond.

The purpose of this work is to investigate and analyze the dispersion of particulate matter in the atmosphere of a clay quarry. The study takes into account quarry geometry, particulate matter emissions and the main meteorological parameters (temperature, wind direction and speed, humidity, pressure, and solar radiation).

In the presence of ground temperature inversion, pollutants are kept low, near the earth's surface, and their concentration becomes quite high. In this work, problems related to different degrees of heating of the slopes of a clay quarry are discussed [7]. Excavation of minerals is accompanied by intensive emission of particulate matter. The main factor influencing the type of aerosol dispersion is the configuration of the local wind system. The work discusses the problematic impact of the complex orography of the quarry on the formation and elimination of temperature inversions in the atmosphere of opencast mines and their impact on the dispersion of fine dust particles in the air of the mine. Comparison is made between the decay rates of temperature inversions in the morning, after sunrise.

In this study, we propose the use of a small unmanned aerial vehicle (drone) carrying a sensor for micrometeorological data, thus allowing precise real-time determination of meteorological indicators. Most pollution dispersion models use predefined estimates of pollution sources and atmospheric conditions; real-time information from within the vertical career profile is virtually impossible to gather. Data on meteorological parameters is recorded in real time in the memory of a high-resolution data logger that is attached to the aircraft. On the basis of this data, the vertical profiles of the temperature and humidity in the atmosphere can be constructed, which significantly enhances the interpretation of the concentrations in the atmosphere of the quarry [8 - 10].

EXPERIMENTAL

Used equipment

The following devices were used during the experimental campaign:

BQ20 particle counter designed to measure the size, number and concentration-by-weight of particles in the air. The 2.5 micron and 10 micron particles are treated equally in this measurement process. BQ20 is a compact air quality meter - it measures dust pollution, temperature and relative air humidity. Measuring range for PM 2.5: 0 ~ 2000 g.m^{-3}, measuring range for PM 10: 0 ~ 2000 g.m^{-3}, measuring range for temperature: 0 ~ 50°C, range of measurement for relative humidity: 0 - 100 % RH.

PC200 portable laser particle counter (TROTEC, Germany) capable of measurement in six channels of size: 0.3; 0.5; 1; 2.5; 5 and 10 µm.

PCE-FWS 20-1 Multifunctional Weather Station - enables accurate measurement of wind direction and speed (anemometer), external temperature and relative air humidity (thermo-hygrometer) and amount of precipitation (rain gauge). The measured parameters are: temperature in degrees Celsius, relative humidity in % RH, atmospheric pressure in hPa, wind direction and speed in deg and m.s^{-1}.

Meteorological parameters on the side slopes were measured with *dataloggers*, which made records in the interval of 1 to 10 min.

Vertical temperature profiles in the quarry were measured using a Phantom II drone equipped with datalogger, the latter recording temperature and humidity values in every 30 seconds. Drone height within the quarry was determined with a laser range finder. For better statistical results, the drone was positioned for 2 seconds in every 5 meters.

Experimental area description

The experiment took place at an abandoned clay quarry near Ovcha Mogila Village situated at a distance of approximately 30 km to the south of the town of Svishtov (Fig. 1). Measurements were carried out on 13 Sept 2021. The quarry is approximately 20 - 25 m in depth. Its width in the NE direction is approximately 250 m, and in EW direction - approximately 150 m. The deepest part of the quarry is inundated, forming a pond of surface area equal to approximately 1/3 of the total surface area of the quarry.

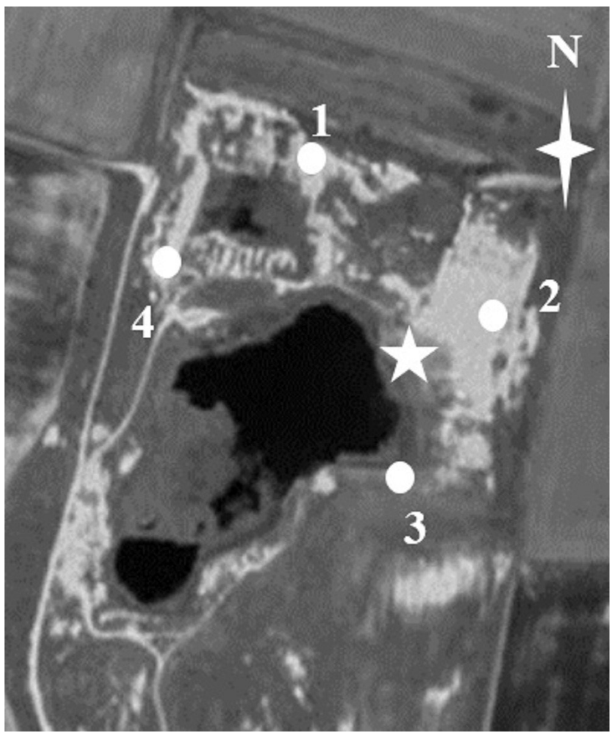

Fig. 1. Clay quarry in Ovcha Mogila Village, Svishtov Region.

Circles and numbers 1 - 4 indicate the locations of the dataloggers, which collect data on the main meteorological parameters (temperature and humidity) on the slopes of the quarry. The sensors were positioned at about 10 m above the bottom of the quarry and at about 1 m from the surface of the side slopes. The location of the weather station is marked with a star, which, in addition to temperature and air humidity, also recorded wind direction and speed. At the same place, which is also the lowest "dry" point in quarry cup, the concentrations of particulate matter were measured and the vertical profiles of the temperature were determined with the help of the drone.

RESULTS AND DISCUSSION

The evolution curve of solar radiation according to local standard time (LST) is shown on Fig. 2. The values are typical of a clear sunny day around mid-September. Quickly, the increasing solar radiation, which in the afternoon exceeds 700 W.m^{-2}, creates good conditions for intensive development of the blending layer by forming thermal turbulence. It, in turn, leads to rapid heating of the air within the quarry, which can also be seen from the graphs presented below for the temperature on the slopes and in height. The Fig. 3 presents data on wind speed (Fig. 3(a)) and wind direction (Fig. 3(b)). At first, it was calm in the quarry, with wind speed reaching 4 m/s in the afternoon. The wind direction is almost constant - from the west - southwest.

In the morning, before sunrise, the atmosphere of the quarry is stably stratified, and the air temperature values are the lowest. After sunrise, especially in summer, as is the case, rapid heating begins of the quarry surface and subsequent warming of the air within. Graphs of air temperature evolution for the four slopes of the quarry are presented on Fig. 4. At the beginning of the measurements, the temperature was around 15^{o}C; thereafter it started rising relatively quickly and by noon reached 27^{o}C - 28^{o}C.

By 3 p.m., the maximum values of the air temperature of about 33^{o}C - 34^{o}C were reached, after which gradual cooling began. It can be seen that the temperature values over time for all four slopes are almost the same. This is due to the specifics of the air circulation. The

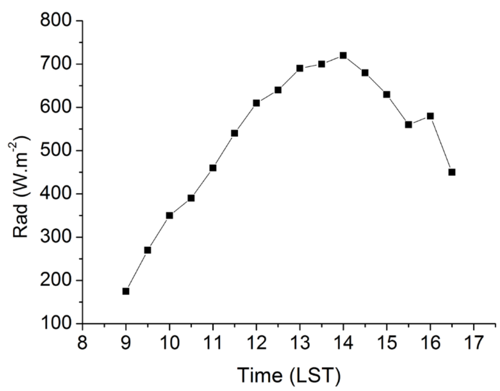

Fig. 2. Solar radiation curve.

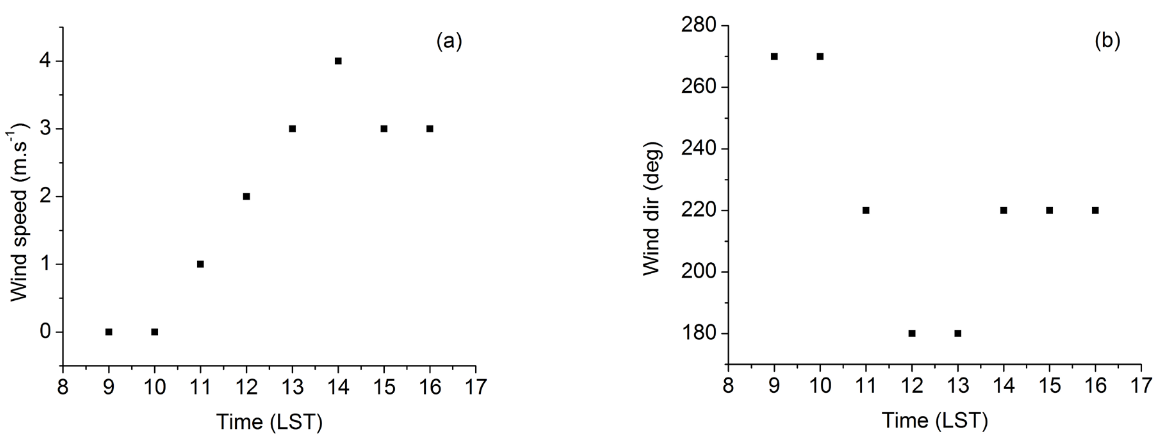

Fig. 3. Wind speed (a) and direction (b).

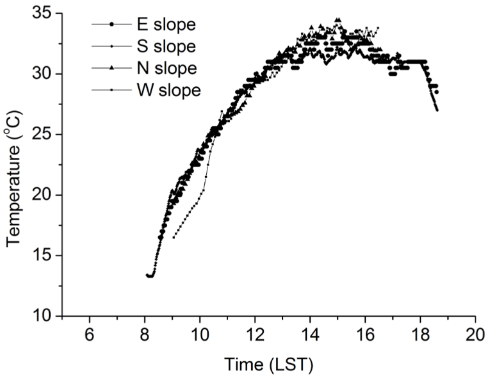

Fig. 4. Temperature on slopes.

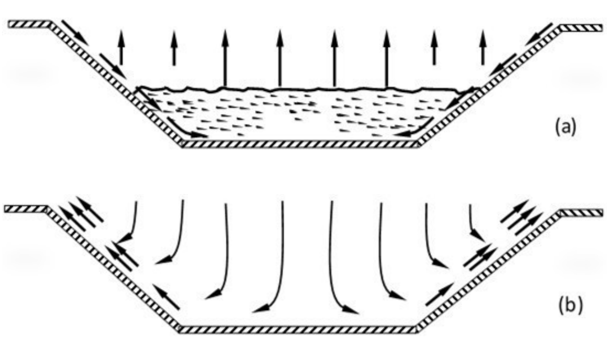

Fig. 5. Air flows in the quarry at night (inversion mode) (a) and during the day (convection mode) (b).

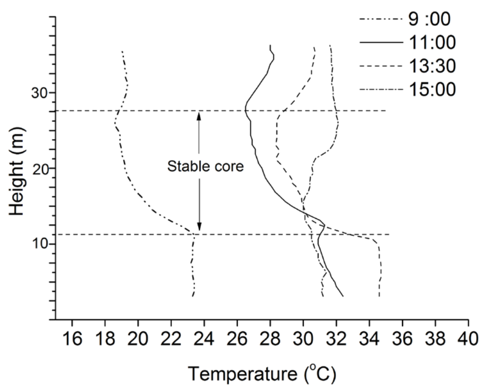

Fig. 6. Vertical temperature profiles stable core.

presence of the so-called mountain-valley circulation is characteristic of such landforms [7]. After sunset, flows of cold air are formed, which descend on the side slopes and fill the volume of the quarry (Fig. 5(a)). In the morning, after sunrise, the gradual heating of the slopes begins and the formation of upward flows of warm air on the slopes of the quarry (Fig. 5(b)). It is the presence of these warm air flows that create conditions for the uniform warming of the air over the slopes, although they are heated differently during different hours of the day.

The vertical profiles of air temperature in the quarry is shown on Fig. 6. From the first profile, taken at 9 a.m., it can be seen that the air temperature in the lower 10-meter layer is about 4oC higher than that at the ground surface (above the upper boundary of the quarry). As the day progressed, this difference remained almost unchanged, and only after 3 p.m., the layer of air above the quarry turned out to be about 2oC warmer.

It is important to note the presence of a raised inversion above the upper boundary of the quarry. The height of the lower inversion border (approximately 25 m) (Fig. 6) remained almost constant until about 1:30 p.m. On the next profile at 3 p.m., the lower border began to sink down.

This configuration of the vertical temperature profiles shows that, in the quarry volume, in the layer between 10 and 25 m, there is a so-called core of cooler air, which is also due to the presence of a raised inversion. In the layer from the bottom of the quarry up to about 10 m, the presence of isotherm is observed, which indicates the existence of a well-developed convective layer. This layer also feeds the warm air currents flowing up the side slopes (Fig. 7).

From the numerous experiments carried out, it has been established that the stable core can be destroyed by the heating of the air in three ways: only from below, by the development of the blending layer; only from above, as the warm air descends and "eats away" its upper border; or by combination of both mechanisms.

In our case, the evolution of the configuration of vertical temperature profiles shows that the destruction of the stable core, formed at night in the atmosphere of the quarry, takes place rather from above, by lowering the bottom end (base) of the raised inversion.

The evolution of the mass concentration and the number of particles in the volume of the quarry is shown on Fig. 8. It can be seen that as the day progresses, the number of particles per unit of volume rapidly decreases. This applies to both the fine fraction (up to 2.5 μm) and the coarse fraction (over 2.5 to 10 μm).

The main reason for the decrease in the concentration of particulate matter is the presence of the aforementioned convective ventilation scheme. After sunrise, the surface of the quarry begins to heat up and

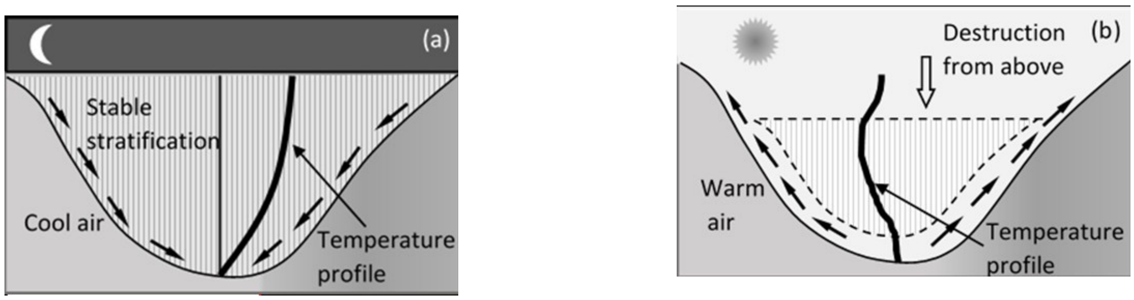

Fig. 7. Characteristic temperature profiles - at night (a) and during the day (b).

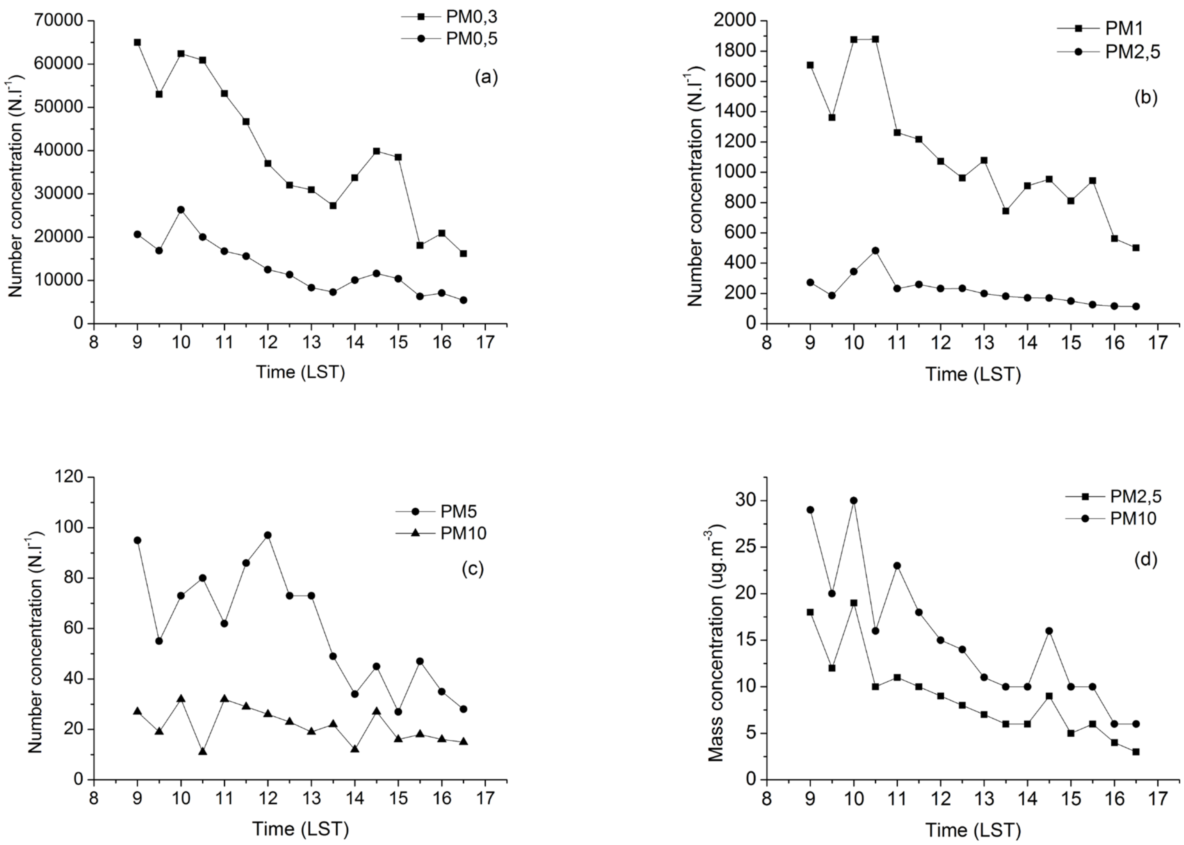

Fig. 8. Numerical (number of particles per liter - N.l-1) and mass (µg.m-3) PM concentrations.

heats the air above it. Flows of warm air are formed on the slopes of the quarry (Fig. 7(b), which carry the pollutants to a height beyond the boundaries of the quarry and thus provide effective ventilation of the air volume inside the quarry space.

It is interesting to note that the reduction of both the fine fraction and the coarse fraction occurs at almost the same rate. At the beginning of the day, the number of particles with a radius of up to 0.3 µm is about 60 000, and in the afternoon, it decreases to about 30 000 (Fig. 8(a)). The same is true for the particles 2,5 µm (from about 200 to 100 - Fig. 8(b) and for 10 µm (from 30 to 15 - Fig. 8(c)).

A similar behavior is also observed in the change of mass concentration of particles in time (Fig. 8(d)). This means that the average density or type of particles in the quarry atmosphere does not change in time.

It is interesting to compare the background aerosol concentration with that in the quarry atmosphere. Graphs of the change of particulate matter concentration on the surface of the quarry are presented on Fig. 9. For better representativeness, the measurements for three

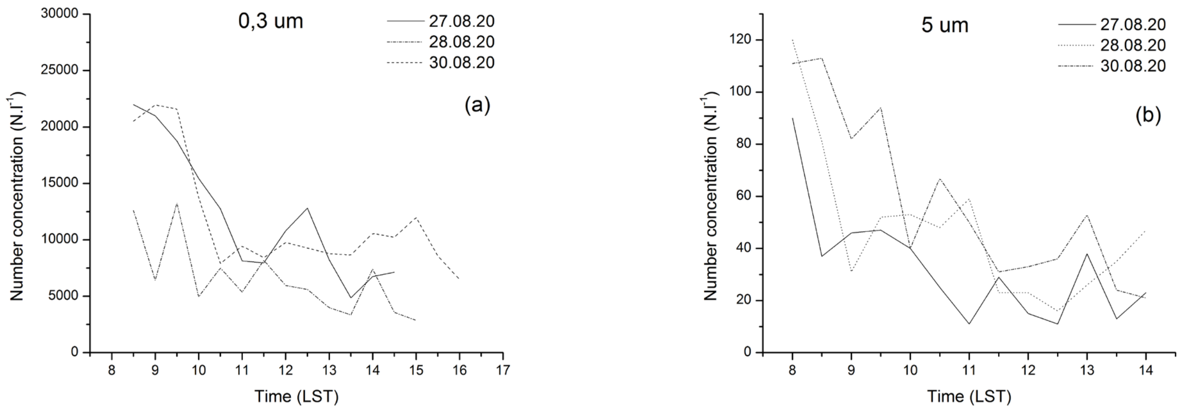

Fig. 9. Background aerosol concentration on quarry surface - for 0.3 μm (a) and 5 μm (b).

days are given, under weather conditions close to those in which measurements in the quarry were made. The figure shows that the fine fraction in the morning hours from about 20 000 particles per liter of air drops to about 5 000. Of the coarse fraction (5 μm), at the beginning of the day, the concentration is about 100 particles per liter, while in the afternoon it drops to about 20 - 30 particles per liter. It can be seen that the concentration in both fractions drops 4 - 5 times during the day. This is due to the fact that the terrain is flat and, apart from the advection of pollutants, substantial vertical convection is generated as well leading to increase in the blending layer volume and, accordingly, to decrease in particulate matter concentration per volume unit [11].

When comparing the graphs of the aerosol concentration in the atmosphere of the quarry, it can be seen that in the fine fraction, at the beginning of the day, the particle concentration is about 3 times higher than the background one, and even in the afternoon it remains relatively high, as only then does it reach values close to the background concentration in the morning hours. For the coarse fraction, however, the behavior is almost uniform over time. The concentration of particles drops from about 100 per liter in the morning hours, to about 20 particles per liter after lunch.

The observed difference in the concentration of particles from the fine fraction could be due to the fact that the density of the predominant particles in the quarry atmosphere compared to those of the background is smaller at the same radius. This means that the mass of these particles is smaller and they are more easily dispersed by wind-induced erosion and slower to settle by gravity. This is logical to assume, because the surface of the quarry is covered with a fine dust of clay, while the surrounding terrain is mainly dominated by particles with a silicate content, which is of higher density.

CONCLUSIONS

From the analysis of the results of the experiment carried out in the atmosphere of the clay quarry, the following can be concluded:

- In the morning, before sunrise, the air in the volume of the quarry is warmer than that on the surface;
- The existence has been established of a stably stratified core in the quarry atmosphere which is only destroyed from above, thus forming raised inversion;
- With the development of the blending layer and generation of vertical flows along quarry slopes, particulate matter concentration exhibits approximately threefold drop during the day;
- Comparison of background and quarry air concentrations shows that particulate matter concentration in the quarry is nearly 3 times higher than the background one.

Acknowledgements

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