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HYDROGEOLOGICAL ANALYSIS OF THE EXISTING STATE OF DRAINAGE WITH A NEW SYSTEM OF WELLS FOR LOWERING THE GROUNDWATER LEVEL OF THE RTH FLOTATION TAILING DUMP IN BOR[**]

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Abstract

After conducting the geotechnical and hydrogeological explorations of the RTH flotation tailing dump and determining the stability of slopes for the overhanging purposes, the zone with the observed instability, an elevated and unfavorable gradient of the groundwater level, was determined and located. Due to these reasons, further design of the groundwater level regulation system was started. The hydrodynamic analysis of the task determined that in order to achieve the effects of lowering and regulating the level of underground water, it is necessary to construct fourteen wells.

Keywords: *flotation tailing dump, groundwater level, hydrodynamic analysis*

1 INTRODUCTION

The RTH tailings dump was built from materials of anthropogenic origin, at the location where the Bor River used to flow before the formation of the open pit. After the artificial diversion of the river, the mining activities were started, where on one side, the mineral raw materials were excavated and mine waste was disposed so that after completion, the excavated area would be used for disposal of flotation material. Before the actual disposal of flotation material and during disposal, a higher overhang was carried out by forming the dams and embankments, in order to prevent it from protruding outside the land fill. The last applied geotechnical explorations were carried out in 2022. As part of them, the hydrogeological investigations of the location in question were carried out. Since there was a need to define a technical solution for lowering and regulating the level of underground water in a pre-defined area of the tailing dump, the continuation of numerical interpretation of the collected and presented exploration results with the analysis of various technical solutions was started. This paper presents the basic concept and technical solution of groundwater level regulation and expected effects of the system operation.

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2 PRESENTATION OF RESEARCH RESULTS PERFORMED EXPLORATION RESULTS

The geological foundations of the field, planned for overhang the tailing dump, were obtained on the basis of results of the existing and supplementary explorations [1]. A total of 20 wells were drilled on the field, and piezometer structures were installed in 19. After washing, they are included in observation the groundwater level regime. Geotechnical and hydrogeological mapping was performed on the extracted core. Determination of the layers, defined by the origin and period of origin, was carried out as follows:

- Parent rock,
- Parent rock (deluvium),
- Mine waste - landfills,
- Smelter slag,
- Flotation tailings - dust and sludge,
- Flotation tailings - sand,
- Embankments of heterogeneous composition,
- New perimeter embankment.

In addition to mapping the core and defining the lithological composition and belonging to a specific (determined) formation, the samples were taken for the grain-size analysis on a certain number of samples. Based on the results of the grain-size analyses, and for the purposes of defining the hydrogeological function of individual lithological members, the filtration coefficient was calculated according to the empirical patterns. The affiliation of formations was defined by synthesis of all results according to the hydrogeological function. The hydro-geological function of individual lithological members by wells is shown in Figure 1.

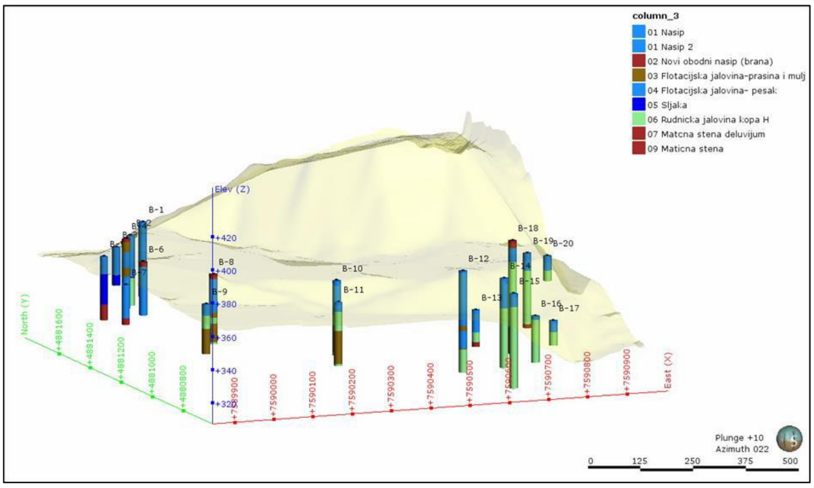

Figure 1 *3D view of wells with hydrogeological interpretation of the well core*

Based on the presented results of exploratory drilling, installation of the piezometer construction and backfilling of the piezometer, observation of the underground water level and mapping of the field, and as a part of the very complex hydrogeological conditions of formation, it can be stated that an outcrop with a free level is formed on the entire area, where it can be classified according to the type of porosity in the following way:

- compact type of outcrop with good water permeability,
- compact type of outcrop with lower water permeability,
- complex type of porosity with lower water permeability,
- conditionally dry part of the field.

By synthesis all the results from exploratory drilling, installation of piezometers, groundwater level measurement to the field mapping, a hydrogeological map of the RTH flotation tailing dump, shown in Figure 2, was made.

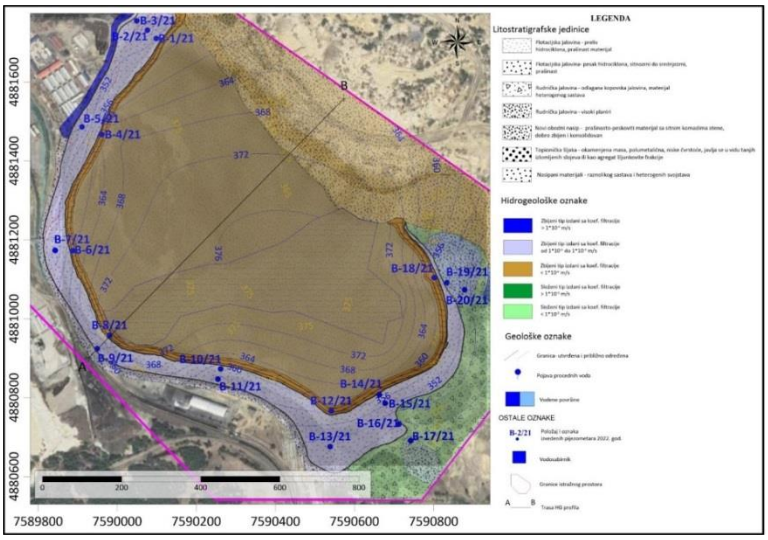

Figure 2 *Hydrogeological map of the RTH flotation tailing dump*

3 DEVELOPMENT OF A HYDRODYNAMIC (MATHEMATICAL) MODEL

To define the concept of groundwater level regulation, a mathematical model of the flotation tailing dump was developed. For the purposes of development a hydrodynamic (mathematical) model [2], the finite difference method (MODFLOW) was used.

Regarding the model layers as well as the filtration characteristics, it was used that the model layer 1 is flotation sand and the model layer 2 is flotation sludge. Other hydrogeological members that have a subvertical transition are defined by the filtration coefficient within the limits of their distribution. The base of the model consists of the parent rock, which is assumed to have no groundwater flow and does not affect the groundwater balance within the RTH tailing dump body.

The external and internal boundary conditions were used as the boundary conditions of the hydrodynamic model of the RTH tailing dump. The external boundary conditions define the current domain. A DRN (Drain) type condition was used, where a special attention was paid to the character and manner of lateral outflow from the model. As an internal boundary condition, the boundary type CHD was used, which reflects the elevation of vertical recharge of the tailing dump.

During realization of the applied geotechnical explorations, fifteen horizontal drains were made, namely six drains near Dam 1 and nine drains near Dam 2, whose effect is incorporated into the model. What is known is the position of the drain beginning and length of its installation. It was assumed in the model that direction is assumed and drain is completely horizontal.

Using the MODFLOW package, that is, the GMG solver. The modeling results are shown on the map in Figure 3, where the hydroisohypses, obtained by the mathematical model and residual difference between the calculated groundwater level and measured groundwater level on the piezometers, are shown.

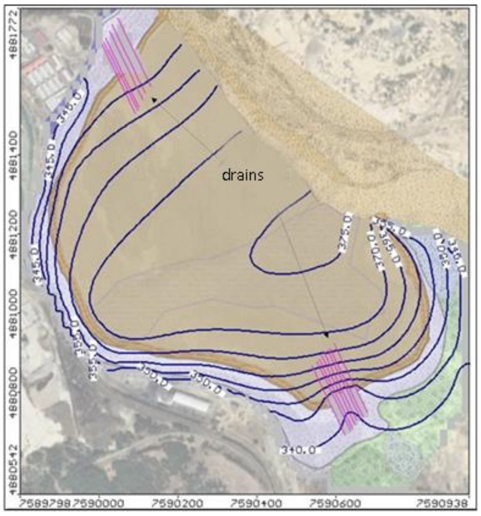

Figure 3 *Hydrodynamic model of the RTH tailing dump*

The model calculates the amount of water that flows out of horizontal drains was calculated on a model. At Dam 1, Q = 46,018 m^3/day = 0.53 l/s; while at Dam 2 Q = 182.36 m^3/day = 2.11 l/s. It was concluded that the effect was achieved by creating the horizontal drains, lowering the groundwater level by about 2 m.

4 DEFINING THE CONCEPT OF THE GROUNDWATER LEVEL REGULATION SYSTEM

In order for local instability to be regulated, it is necessary to lower the groundwater level by 4-5 m in the subject area. For the need to dimension the level lowering system, the presented hydrodynamic model will be used.

What is important to note, and for the purposes of dimensioning the technical solution for lowering and regulating the level of underground water, is the fact that there is flotation sand in the area of interest, from the surface of the terrain. It has a relatively homogeneous granulometric composition, with a filtration coefficient of $1x10^{-6}$ m/s. The mine waste is in the foothills with extremely heterogeneous filtration characteristics, and filtration coefficients from $1x10^{-5}$ to $1x10^{-7}$ m/s.

Since it was not possible to define the boundary of the mine waste, based on the filtration characteristics on the basis of the exploratory wells, the filtration characteristics must be monitored indirectly during well drilling [3].

The values of filtration coefficients mostly range from $1x10^{-6}$ to $1x10^{-5}$ m/s and more. This indicates that the underground water moves freely (gravitationally from higher to the lower potential), i.e., vertical wells of small diameter are an adequate method for lowering and regulating the level.

The individual capacity of the well, depending on the filtration coefficient, and for the conditions of the underground water regime, according to the various criteria, ranges in the interval as shown in Table 1[4].

Table 1 *Permissible speeds of water reaching the well under different criteria*

Different criteria	**Filtration coefficients (m/s)**		
	1.00E-07	**1.00E-06**	**1.00E-05**
Zihart criterion	Vd = 2.11E-05	Vd = 6.67E-05	Vd = 2.11E-04
Modified Zihard criterion	Vd = 1.05E-05	Vd = 3.33E-05	Vd = 1.05E-04
Abramov criterion	Vd = 1.55E-04	Vd = 3.33E-04	Vd = 7.18E-04
Kovac criterion	Vd = 4.22E-05	Vd = 9.09E-05	Vd = 1.96E-04
Kovac critical speed	Vkr = 1.61E-05	Vkr = 3.66E-05	Vkr = 8.30E-05
Q (l/s)	**0.43**	**1.36**	**3.39**

Under the most unfavorable conditions, and assuming that the well is well constructed, the smallest

expected capacity of each well is 0.43 l/s. Using the hydrodynamic model, in order to lower the level of 4-5 m in the analyzed area, it is necessary to build fourteen wells. Their effect in depth and in terms of the radius of effect of the group of wells is shown in Figure 4.

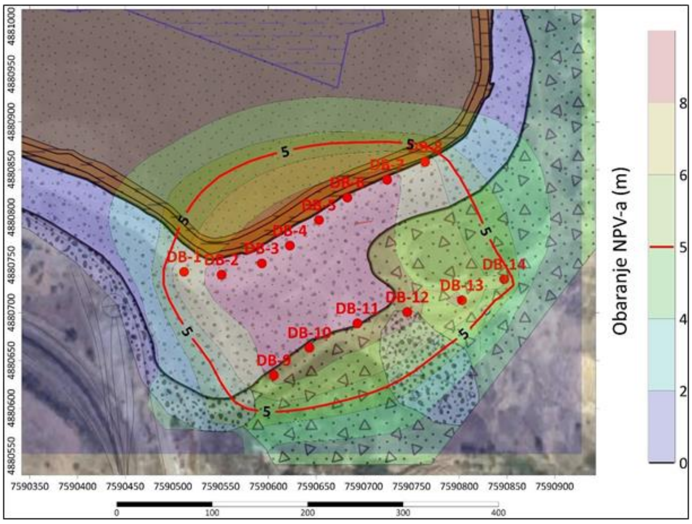

Figure 4 *Expected effect of operation of fourteen wells with the position shown*

The designed position and expected depth of the well is shown in Table 2.

Table 2 *Designed wells*

Well label	Y	X	Prognostic depth (m)
DB-1	7590512	4880743	50
DB-2	7590551	4880740	50
DB-3	7590593	4880752	50
DB-4	7590622	4880770	50
DB-5	7590653	4880797	60
DB-6	7590683	4880821	60
DB-7	7590724	4880839	50
DB-8	7590764	4880858	50
DB-9	7590606	4880635	50
DB-10	7590643	4880664	40
DB-11	7590693	4880689	40
DB-12	7590746	4880701	50
DB-13	7590803	4880713	50
DB-14	7590847	4880735	50

CONLUSION

Based on the results of the conducted hydrogeological and geotechnical explorations of the RTH flotation tailing dump in Bor, a hydrodynamic model of the tailing dump was created. In order to achieve the necessary lowering of the underground water level at the Dam 2 of the landfill, for the purpose of stabilization and rehabilitation the facility, it was necessary to find an adequate technical solution. Through hydrodynamic analysis, it was determined that fourteen wells must be constructed in order to achieve the effects of lowering and regulating the level of underground water. Their position and achieved effects of their installation were modeled and determined.

After completion of the field works on installation the well structures, and based on the report on the construction and testing the wells, it is necessary to purchase and equip the well with the well pumps, electrical and mechanical equipment, as well as a suitable drainage system to the receiver that is not in hydraulic connection with the underground water at microlocation. Based on the pumping test, determine the actual exploitation capacity of the well and put the system into operation. Since there is a piezometer network at the location where the wells in question are being drilled, it will be possible to determine the actual effects of the system operation directly in the field. After six months of the system operation and continuous monitoring of exploitation on wells and level measurements on piezometers, it is necessary to recalibrate the hydrodynamic model and give an assessment of the achieved effects in relation to the designed one.

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Original Scientific Paper
Environmental
protection engineering

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AMBIENT AIR QUALITY AT THE PISKANJA BORON MINERAL DEPOSIT NEAR BALJEVAC ON THE IBAR RIVER

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Abstract

This paper presents the results of the ambient air quality in the area of Piskanja boron mineral deposits, located in the eastern part of the Jarandol Tertiary Basin, on the right bank of the Ibar River. The analysis included samples from four measuring points, sampled during the summer and winter months of 2018-2019. The total atmospheric deposition, pH value, and heavy metal content (Pb, Cd, Zn, As) in the total atmospheric deposition were measured at all four measuring points. In addition, sulfur dioxide, nitrogen dioxide, soot, and PM_{10} particulate matter were analyzed at two measuring points. Considering the obtained results and applicable legal regulations, the tested air samples were found to be within the prescribed limit values by the analyzed parameters, except for the measured PM_{10} concentrations (particulate matter less than 10 µm). The obtained test results should contribute to determining the direct impact of future exploitation of boron minerals on air quality.

Keywords: *ambient air, boron minerals, Piskanja deposit, Jarandol basin*

1 INTRODUCTION

The Piskanja boron mineral deposit is located on the right bank of the Ibar River, in the eastern part of the Jarandol Basin in the immediate vicinity of the Baljevac settlement, municipality of Raška. The Jarandol Tertiary Basin is divided by the Ibar River into two parts: eastern - Piskanja, encompassing the Piskanja boron deposit, and western - Jarandol, with the Bela stena and Borovak magnesite deposits, Jarando coal deposit, boron mineral deposit in Pobrđe and boron mineralization occurrences in Raspopovići. In genetic terms, the Piskanja deposit was formed in the Neogene, sedimentary series of the Jarandol Basin, in the immediate vicinity of which there are larger massifs of volcanic andesitic, dacite and phenodacite rocks. Given the sedimentary series covered with the alluvial formations and humus, these rocks are mostly inaccessible to a direct observation in surface terrain [1, 2].

The beginning of boron mineral research in this deposit dates back to 1987 when the "Ibarski rudnici" company drilled a 3.5 m thick layer of boron minerals at a depth of 306.7 to 310.2 m. Ever since, a detailed geological exploration has been carried out on several occasions to define the quantity and quality of the useful component. Based on the obtained results, the potential borate reserves in the Piskanja deposit are estimated at over 7,500,000 tons of quality boron minerals (colemanite, ulexite, probertite), with the average content of useful component of about 36% B_2O_3 [3]. Due to the high useful component content, the deposit exploitation is planned. In order

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to determine the direct impact of the future mine on the quality of the main environmental parameters, the environment was "as is" tested in the deposit area [4].

As a part of these tests, the ambient air quality was analyzed from four different locations in the subject deposit area. The results of these tests are presented in this paper. Figure 1 shows the sampling site location.

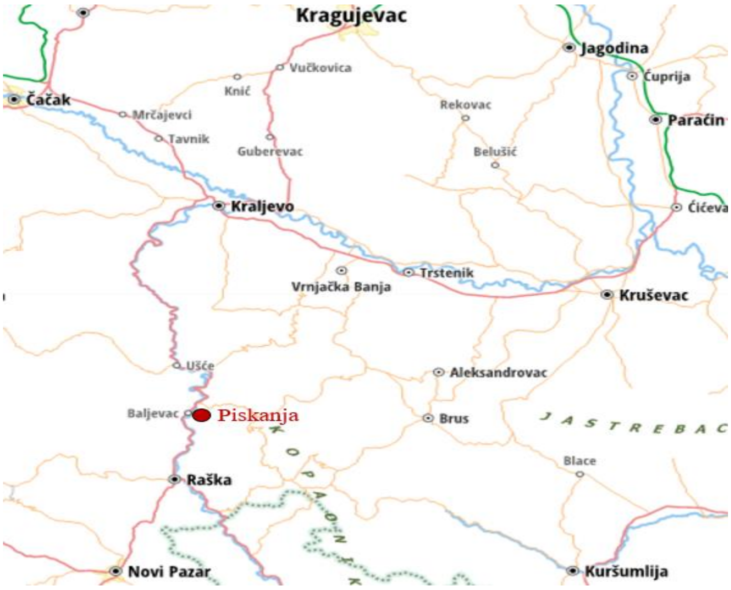

Figure 1 *Location of sampling*

2 TEST MATERIAL AND METHODS

The ambient air quality in the Piskanja boron mineral deposit area was tested in the summer (June 4, 2018 - July 4, 2018) and winter (January 17, 2019 - February 16, 2019) periods.

Sampling was performed at four measuring points, taking into account the population and the spatial coverage of the deposit area (Table 1).

Table 1 *Description and coordinates of sampling point*

Marking of measuring/sampling points	Sampling point	Coordinates	
		N	E
MM6	Family house of Milinka Mihajlović	43 23 14.50	20 39 00.37
MM7	Family house of Zvezdan Jovanović	43 22 52.50	20 38 55.80
MM8	Family house of Milica Todorović	43 22 44.90	20 39 16.90
MM9	Family house of Vidosava Radosavljević	43 22 42.57	20 38 38.25

At all four measuring points, the total atmospheric deposition and pH values were measured by monthly sampling. In addition, the heavy metal content (Pb, Cd, Zn, As) was determined in the total atmospheric deposition. During the testing period, at two measuring points (MM6, MM7), sulfur dioxide, nitrogen dioxide, and soot were analyzed by the 24-hour sampling, while PM_{10} particulate matter was measured 15 days a month.

Locating, sampling and measuring parameters in the field and laboratory conditions were performed by the Belgrade Mining Institute. Heavy metal content in sediments was determined by the Institute Mol d.o.o. Stara Pazova. The air samples were analyzed according to the standards and using the accredited methods.

Following laws and bylaws regulate the protection of air from pollution in Serbia: the Air Protection Act [5] and Decree on Conditions for the Air Quality Monitoring and Requirements [6] which defines, among other things, the measurement conditions and concentration limits of pollutants harmonized with the EU requirements. In the particulate matter limit values guidelines, the World Health Organization (WHO) did not prescribe a lower particulate matter concentration threshold below which there is no impact on human health, but gave the certain guidelines and recommendations. The guidelines offer the recommended levels of exposure to PM_{10} and $PM_{2.5}$, ozone, nitrogen dioxide, and sulfur dioxide, as well as measures to encourage a progressive improvement in the air quality and reduce the impact of pollution on health [7, 8].

3 RESULTS AND DISCUSSION

Figures 2–8 show the results of measuring the tested parameters for the summer and winter seasons, while the statistical indicators are given in Tables 2–5. In the same tables, GV (limit values) are given for comparison purposes, the concentrations of which are defined by the Decree on Conditions for Air Quality Monitoring and Requirements [6].

The average daily concentrations of sulfur dioxide at the MM6 and MM7 measuring points do not exceed the limit values, and no extremely high concentrations were recorded, see Figures 2 and 3.

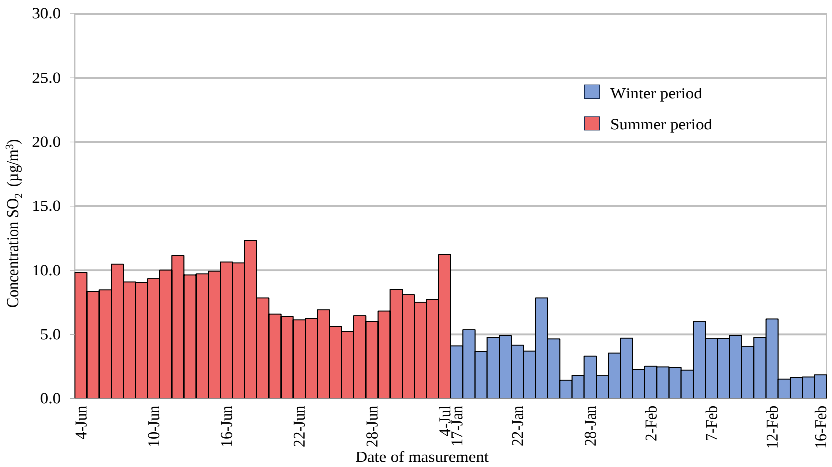

Figure 2 *Average daily concentrations of SO_2 at the MM6 measuring point i n summer and winter periods*

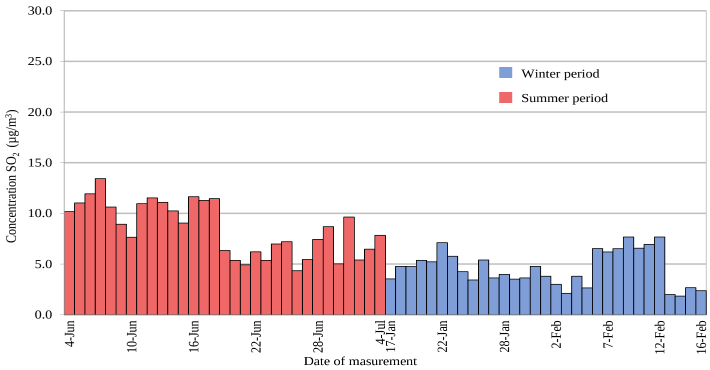

Figure 3 *Average daily concentrations of SO_2 at the MM7 measuring point in summer and winter periods*

Table 2 *Statistical indicators of SO_2 at the MM6 and MM7 measuring points in summer and winter periods*

Marking of measuring/ sampling points	Summer period			Winter period		
	C_{av}	C_{min}	C_{max}	C_{sr}	C_{min}	C_{max}
MM6	< 10.0	< 10.0	12.3	< 10.0	< 10.0	< 10.0
MM7	< 10.0	< 10.0	13.4	< 10.0	< 10.0	< 10.0
LV(C_{24}) = 85 µg/m³						

Analyzing the obtained results, it can be concluded that the maximum values of SO_2 concentration were measured in the summer period. The maximum daily concentrations of 13.4 µg/m³ and 12.3 µg/m³ were recorded at MM7 and MM6 measuring points, respectively. The elevated concentrations in the summer period are associated with polluter located near the subject deposit. This primarily refer to the coal separation in Baljevac and landfill of small, waste coal containing about 42% of ash [9].

During the entire measuring period, the average daily concentrations of nitrogen dioxide were significantly below the limit values prescribed by the Decree [6].

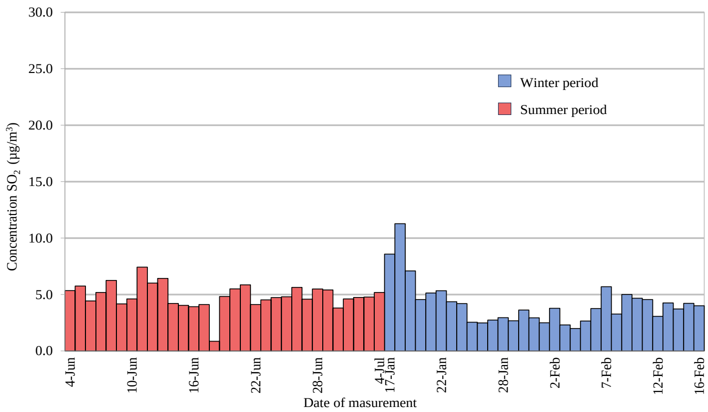

Figure 4 *Average daily concentrations of NO_2 at the MM6 measuring point in summer and winter periods*

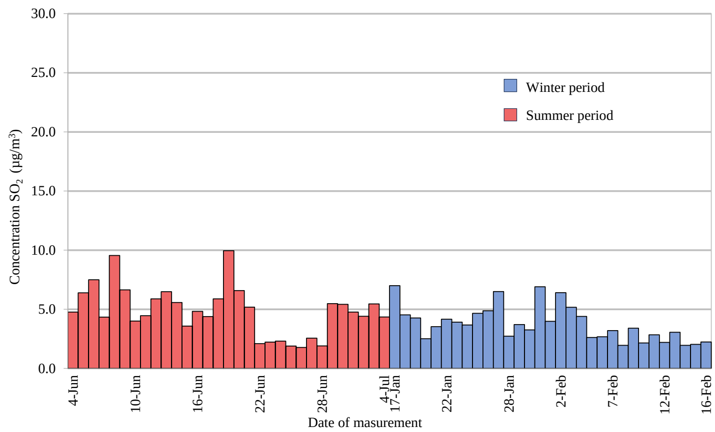

Figure 5 *Average daily concentrations of NO_2 at the MM7 measuring point in summer and winter periods*

Table 3 *Statistical indicators of NO_2 at the MM6 and MM7 measuring points in summer and winter periods*

Marking of measuring/ sampling points	Summer period			Winter period		
	C_{av}	C_{min}	C_{max}	C_{sr}	C_{min}	C_{max}
MM6	4.9	< 3.0	7.4	4.2	< 3.0	11.3
MM7	4.9	< 3.0	10.0	3.8	< 3.0	7.0
LV(C_{24}) = 85 μg/m^3						

The maximum average daily concentration was measured at the MM6 measuring point as 11.3 μg/m^3 in winter and 10.0 μg/m^3 in summer, while the other values were significantly lower.

The average daily concentrations of soot at the MM6 and MM7 measuring points do not exceed the maximum allowed concentrations in any measuring period, see Figures 6 and 7.

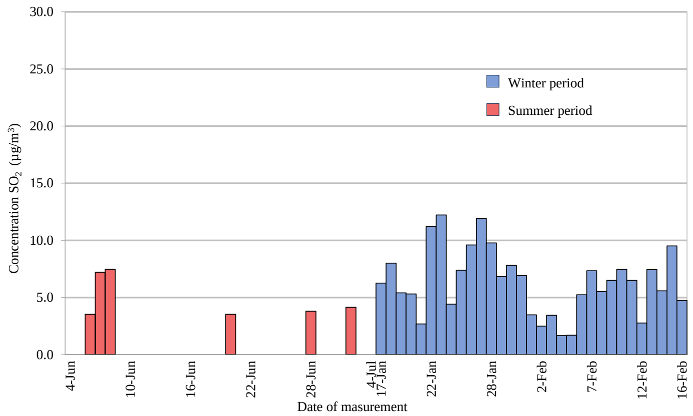

Figure 6 *Average daily concentrations of soot at the MM6 measuring point in summer and winter periods*

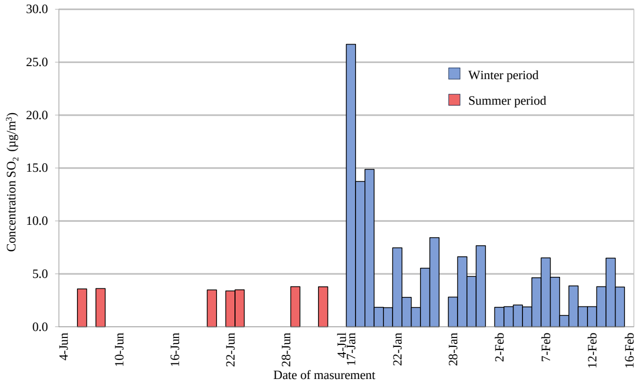

Figure 7 *Average daily concentrations of soot at the MM7 measuring point in summer and winter periods*

Table 4 *Statistical indicators of soot at the MM6 and MM7 measuring points in summer and winter periods*

Marking of measuring/ sampling points	Summer period			Winter period		
	C_{av}	C_{min}	C_{max}	C_{sr}	C_{min}	C_{max}
MM6	< 2.0	< 2.0	7.5	< 2.0	< 2.0	12.2
MM7	< 2.0	< 2.0	3.8	4.9	< 2.0	26.7
MAC **(C_{24}) = 50µg/m³**						

The maximum daily concentration of 26.7 µg/m³ was recorded in winter at the MM7 measuring point, which is still within the permitted values. It can also be concluded that significantly higher soot concentrations were recorded in winter that is explained by the combustion of organic matter in individual furnaces.

Concentrations of PM_{10} during the summer period, at both measuring points, were below the prescribed limit values. The analysis of the results showed that during the winter period the daily limit value of PM_{10} was exceeded for three days at the MM6 measuring point and six days at the MM7 measuring point, see Figures 8, 9. The maximum concentration was measured at MM7 measuring point and was 85.3 µg/m³.

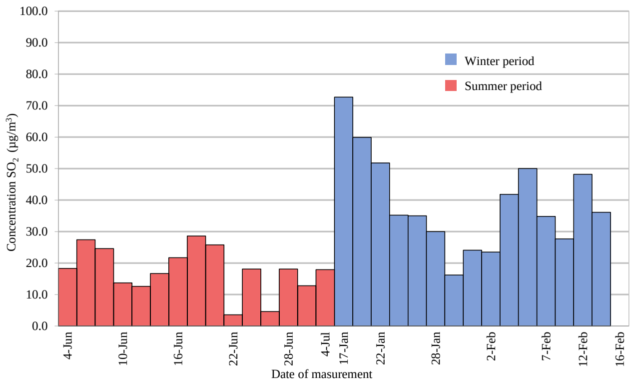

Figure 8 *Average daily concentrations of PM_{10}, at the MM6 measuring point in summer and winter period*

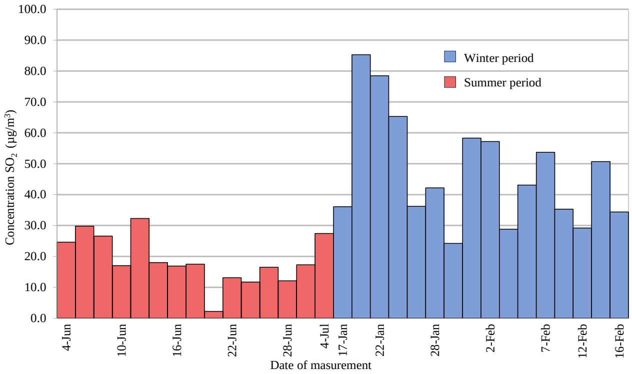

Figure 9 *Average daily concentrations of PM_{10} at the MM7 measuring point in summer and winter period*

The elevated measured values of PM_{10} in the winter period at this location are mostly precipitated from the ashes of individual household furnaces. Therefore, they are directly related to the combustion of organic fuels in households. The value of PM_{10} emission also depends on air currents, i.e., wind speed [10].

Table 5 *Statistical indicators for particulate matter at the MM6 and MM7 measuring points in summer and winter periods*

Marking of measuring/ sampling points	Summer period			Winter period		
	C_{av}	C_{min}	C_{max}	C_{sr}	C_{min}	C_{max}
MM6	17.6	3.6	28.6	39.1	16.2	72.7
MM7	19.9	2.2	36.1	48.2	24.2	85.3
GV **(C_{24}) = 50µg/m^3**						

Table 6 shows the measurement results at all four measuring points of the following parameters: pH value, total atmospheric deposition (TAD), heavy metal content (Zn, Pb, Cd, As) in the total atmospheric deposition. Within the same table, the maximum allowable concentrations (MAC) for the total atmospheric deposition are given.

Table 6 *Results of pH, TAD and heavy metal in the TAD measurements*

Marking of meas-uring/ sampling points	Summer period						Winter period					
	pH	TAD	Zn	Pb	Cd	As	pH	TAD	Zn	Pb	Cd	As
MM6	7.47	94.1	14.64	3.44	<0.07	0.92	6.12	61.3	8.56	4.43	<0.07	0.92
MM7	7.03	85.5	10.68	6.63	<0.07	0.77	5.98	51.1	12.99	5.42	<0.07	0.77
MM8	5.93	153.4	7.73	5.03	<0.07	1.59	5.18	49.0	4.38	3.48	<0.07	1.59
MM9	5.61	107.1	5.60	1.59	<0.07	0.82	5.4	42.0	8.41	2.44	<0.07	0.82
MAC (1 month) = 450 mg/m^{2}day												

The value of the total atmospheric deposition in the subject area was within the limits prescribed by the Decree on Conditions for Air Quality Monitoring and Requirements [6]. During the measurement period, at all four measuring points, the concentration of atmo-spheric deposition ranged from 42.0 - 61.3 mg/m^2 per day in winter and 85.5 - 153.4 mg/m^2 per day in summer. The Decree on Conditions for Air

Quality Monitoring and Requirements does not prescribe the maximum allowable quantity of these metals in the total atmospheric deposition [6]. The obtained values can be used to monitor the impact of future exploitation on the area air quality.

4 CONCLUSION

To manage the air quality in an area, it is necessary to monitor the concentrations of pollutants, characteristic of the sources of pollution in that area. The environmental impact of a project cannot be determined without study the environment quality before the start of the project. Due to this reason, the air quality was tested in the area of the Piskanja boron mineral deposit before exploitation. Sampling was performed during the summer and winter seasons with four measuring points arranged so as to cover the entire deposit area. The analysis included the following parameters: sulfur dioxide, nitrogen dioxide, soot, PM_{10} and total atmospheric deposition. The content of Zn, Pb, Cd and As heavy metals was also determined in the total atmospheric deposition.

The test results showed that the ambient air of subject area was not burdened with excessive concentrations of the measured parameters in the examined period. Except for the measured PM_{10} concentration, the analyzed parameters do not exceed the limit values prescribed by the Decree on Conditions for Air Quality Monitoring and Requirements. The elevated PM_{10} content for several days during the winter period, at both measuring points, is associated with the combustion of organic fuel in the individual furnaces. The measurements carried out are aimed to be used in monitoring the impact of future exploitation of boron minerals at the Piskanja deposit on the air quality to prevent or minimize the adverse effects of exploitation.

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