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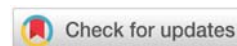
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Short Communication

Air pollution emission from the copper smelter Complex Bor in Serbia

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Abstract

Ever since the industrial revolution, air got significantly polluted by the industry. Air pollution is even more concentrated in cities that have an industrial zone. Especially in these zones, the presence of Sulfur-dioxide (SO₂) and suspended Particles (PM) in the air is very high. Prolonged exposure to SO₂ and PM can cause cancer, cardiovascular and respiratory disorders in humans. The aim of this paper was to review available literature on air pollution by sulfur dioxide and suspended particles in the air region of Bor Copper complex, as well as to determine whether the investigated results are contradictory. Studies from prior years (2004-2015), as well as 2019, indicate rise of SO₂ and PM air pollutants in the atmosphere in the region of the copper smelter of the Bor Complex in Serbia, which can cause serious consequences for human well-being. However, the results of research by different authors for the same years are not in agreement, with that said, a review of the literature indicates significant differences. In addition, no continuous research on any air pollutants has been done for several consecutive years. This can be an interesting question for the scientific public in Serbia. Review of available literature indicates that in Serbia, solving this problem must be taken more seriously.

Introduction

Serbian Bor Copper complex is a copper mining and smelting complex situated in the city of Bor, set in the mountainous part of eastern Serbia (Figure 1). As the amount of rich copper ore deposits is one of the largest in Europe, this area has been regarded as the center for acquiring copper for almost a century, however, the consequence is air pollution. Air pollution in this area has been assessed as one of the major environmental problems in Serbia. Emissions from Cooper Smelter are the largest source of sulfur oxides (SO_x) and trace elements (in PM) such as: Pb, Cd, As, Ni [1-4]. Wind directions in this part of Europe promote air pollution in Bor region. Suspended particles have a pollution scope of 2-3 km, while SO₂ has a range of as much as 15 km [1].

Sulfur-dioxide is a very serious air pollutant that can change climate, degrade visibility and contribute to acid deposition, it has negative influence on the environment, and represents an important health risk [2,5,6]. Sulfur-dioxide is an irritant gas which in high concentrations adversely affects the respiratory

system and skin, as well as the mucous membranes of the throat, eyes and nose [6]. Inhalation of higher concentrations of SO₂ can lead to a buildup of water in the lungs and decrease of oxygen in the blood [7]. In addition, higher concentrations of SO₂ in the air also have a detrimental effect on plants and animals [2].

Due to the application of pyro-metallurgical processes in copper smelters, significant air pollution occurs with suspended particles. These particles contain high concentrations of Lead (Pb), Cadmium (Cd), Nickel (Ni) and Arsenic (As) [1,8,9]. In the case of long-term inhalation of these particles, there is a risk of cancer formation (lungs, kidneys, skin, bladder, prostate, liver) as well as for the development of heart disease, which could increase human mortality [6]. Suspended particles with a diameter of less than 2.5µm ("fine particles" - PM_{2.5}) and particles with a diameter of less than 0.1µm ("ultra-fine particles" - PM_{0.1}) pose a grave danger to human health. Namely, these very tiny particles can enter the airways and lungs quite deeply and the amount of deposition in the respiratory system is very high [1].

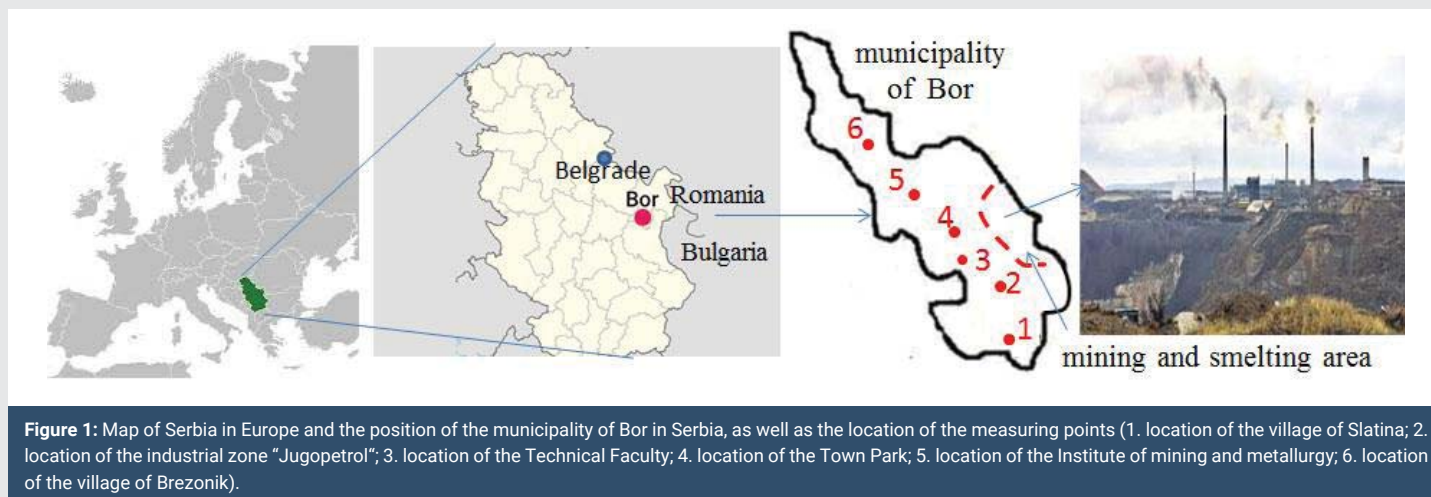


Figure 1: Map of Serbia in Europe and the position of the municipality of Bor in Serbia, as well as the location of the measuring points (1. location of the village of Slatina; 2. location of the industrial zone "Jugopetrol"; 3. location of the Technical Faculty; 4. location of the Town Park; 5. location of the Institute of mining and metallurgy; 6. location of the village of Brezonik).

Due to a negative effect on human health, European Union has limited the concentration of SO_2 in the atmosphere to hourly limit value of $350\mu\text{g}/\text{m}^3$ (concentration must not be greater than this 24 times per year), daily limit is $125\mu\text{g}/\text{m}^3$ (concentration must not be greater than 3 this times per year), and mean annual value is $50\mu\text{g}/\text{m}^3$. For protection of ecosystems annual limit concentration of SO_2 in the atmosphere is $20\mu\text{g}/\text{m}^3$ [10,11]. Daily limit for fine particles ($\text{PM}_{2.5}$) is $25\mu\text{g}/\text{m}^3$ and for PM_{10} particles is $50\mu\text{g}/\text{m}^3$ [11].

At the end of August 1918, the Chinese company Zijin Mining Group was chosen as a strategic partner of the mining and smelting complex Bor. Zijin Mining Group has committed to invest \$ 136 million in ecology and environmental issues. However, Cooper smelter Bor is still one of the major environmental problems in Serbia.

Taking into account the location of this smelting plant (500m from Bor city center) and dominant wind direction these pollutants have heavy impact on people of Bor and surrounding areas. The aim of this paper was to review available literature showing the results of various studies on air pollution by sulfur dioxide and suspended particles in the air of Bor Copper complex. The aim was also to determine whether the investigated results are contradictory.

Methods

Study areas

This research of literature is concentrated on different places in the municipalities of Bor, which are shown in Figure 1.

Analysis of SO_2 and PM concentration

Automatic measuring stations for real-time determination of SO_2 content were located on all measuring points. The content of SO_2 presented in the paper was usually measured by UV-fluorescence method, using reference method EN14212:2005 [12]. The reference method presented in the paper for sampling and measurement of PM_{10} is defined by the protocol EN2341:1999 [13]. The Environmental protection agency of the Republic of Serbia performed the analysis of air

pollution according to Manual Air Quality Monitoring System (AAQMS) [14].

Results and discussion

Annual levels of SO_2 were higher than the allowed limit value, at all the tested sites for the period 2009–2015. On an annual level, concentrations of SO_2 , measured in different places in the zone of the city of Bor, were several times higher than the allowed values for the period 2011, 2012, 2014 and 2015. Daily SO_2 concentrations measured at the suburban zone ($3734\mu\text{g}/\text{m}^3$) were even 187 times higher than the allowable values given by the World Health Organization (Figure 2) [4]. The highest concentration of SO_2 in the air was at the measuring points of the Technical Faculty and Jugopetrol. These locations are placed in the direction of the east and west wind. The second most polluted location was the City Park. The city park is close to the copper smelter and under the influence of east winds. The results of research by Serbula and associates [4] indicate that due to the high concentration of SO_2 the city of Bor could be marked as the most polluted region in this part of the Balkans.

Tasić, et al. [1] reported that, during 2004–2009, concentrations of suspended particles were in direct agreement with the high concentration of SO_2 and inverse agreement with the wind speed. Pollution occurred in episodes. Namely, in different seasons and in a period of several hours during the day there was pollution with PM_{10} particles (max values = $72.7\text{--}393.7\mu\text{g}/\text{m}^3$) higher than the daily allowable limit ($50\mu\text{g}/\text{m}^3$). The share of PM_{10} particles in total suspended particles was generally more than 70 % (Table 1).

The outcomes of research on the degree of air pollution from previous years (2004–2015; Table 1, Figure 2) in the region of the city of Bor, indicate that the concentration of all pollutants is considerably higher. But, the results of research by different authors differ for the same years and do not agree (Table 1). In addition, no continuous research has been done for all pollutants for several consecutive years.

Based on Article No21 of the Law on air protection in the Republic of Serbia, and according to the degree of pollution,



starting from prescribed limit and tolerance values the following air quality categories have been identified:

- 1) First category - clean or lightly polluted air where the values for any pollutant do not exceed the limit;
- 2) Second category - moderately polluted air where the values of nitrogen dioxide exceeded, the limit but the tolerance and the values for other pollutants do not exceed the limit;
- 3) Third category - excessively polluted air where the values for one or more pollutants exceed the limit [14].

According to the data from AAQMS, the mean annual value of SO₂ concentration above the limit value, 50µg/m³, in 2019 year occurred at station Bor-Town Park where it was 54.8µg/m³. Exceeding daily limit value (125µg/m³) was registered at stations Bor-Town Park for 41 days, Bor-Brezonik for 11 days and at Bor-Institut for 8 days. Hourly limit value (350µg/m³) was exceeded more than 24 times at the station Bor-Town Park (235 times), at the station Bor-Brezonik (101 times) and

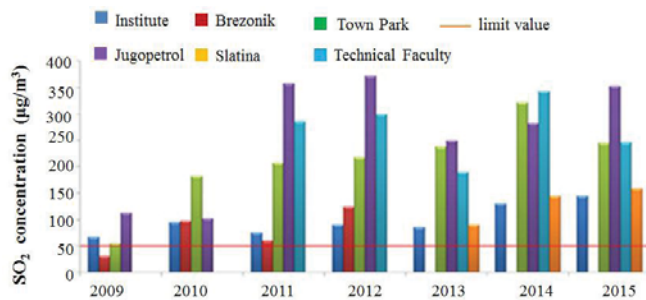


Figure 2: Concentration of SO₂ during the 2009-2015 years in the zone of Bor Copper complex [4].

Table 1: Review of available literature for average annual contents of SO₂ and PM particles in the town of Bor for the 2004-2009 periods (average value; µg/m³).

Location	Year	SO ₂	PM ₁₀	PM _{2.5}	PM ₁	Reference
Town Park	2004	86	41.1	22.7	9.6	[1]
	2005	169	-	-	-	[2]
	2006	227	32.7	14.0	5.7	[1]
		238	-	-	-	
	2007	175	-	-	-	[2]
	2008	105	16	-	-	
	2009	112	32.4	23.7	-	[1]
Institute	2005	66	7	-	-	[2]
	2006	86	8	-	-	
		62	38	16.0	6.7	[1]
	2007	82	8	-	-	
	2008	61	17	-	-	[2]
Jugopetrol	2005	215	-	-	-	[2]
	2006	199	-	-	-	
		178	44.1	19.1	6.9	[1]
	2007	189	-	-	-	
	2008	170	11	-	-	
Brezonik	2005	58	7	-	-	[2]
	2006	104	5	-	-	
		91	5	-	-	
	2007	44	42.5	-	-	
		68	45	-	-	[1]

- no measurements

at the station Bor-Institut (91 times). In the annual report on air pollution for year 2019, the Environmental Protection Agency of the Republic of Serbia did not show the results for PM particles for the city of Bor. But this agency estimated that the air quality in the region of the city of Bor was the third category (Figure 3) [14].

Conclusion

Today, air pollution in Serbia is a serious problem, which has a direct impact on human health. The results of the analysis of the air in Bor Copper complex region show that the concentration of SO₂ and PM particles is above the recommended values at all measurement points. There is no data in the literature on research in the recent period, except for the report of the Ministry of environmental protection of the Republic of Serbia, which indicates a serious problem in this area. Furthermore, the results of scientific tests show significant differences in the results for the same research period. Large pollution intensity for a few hours, one or more times during the day, can lead to an exceedance of the daily average limit value. Meteorological parameters of the wind direction and speed are very important factors for the distribution of particles in the air. Due to the geographical position of Bor smelter, air pollution can also occur in the wider Balkan region (e.g. Bulgaria and Romania). In fact, the current ethical question is being posed to representatives of Bor Copper complex, government officials of Serbia and the scientific community in Serbia - how to solve the serious problem of environmental pollution, which has a great impact on human health?

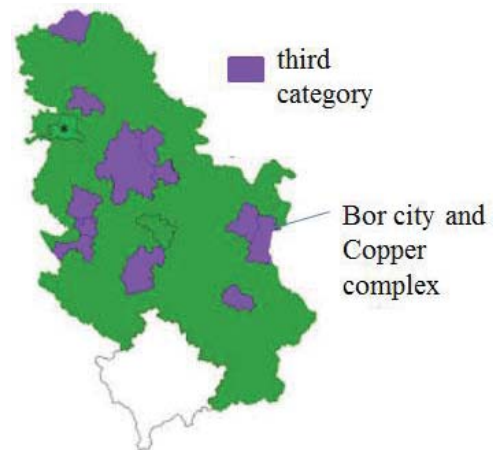


Figure 3: Categories of air quality for 2019 - assessment in accordance with the Law on Air Protection in Republic of Serbia (Environmental Protection Agency of the Republic of Serbia, 2020).

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