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Technical Faculty in Bor

EcoTEK

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Ecological Truth & Environmental Research

Editor

Prof. Dr Snežana Šerbula

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PREFACE

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 focuses on showing the latest research findings and innovations in the field of ecology, environmental protection and sustainable development. The conference will be held in Sokobanja (Serbia) in hotel Sunce in the period of 18–21 June 2024.

The aim of the conference is to connect the experts in various fields in order to transform attitudes and behaviors in everyday practices, as well as in the industry and economy sector which is essential for achieving the desired changes that our society must undergo.

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology; the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica; the University of Zagreb, Faculty of Metallurgy – Sisak; the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Society of Young Researchers – Bor.

These Proceedings encompass 119 papers from the authors coming from the universities, research institutes and industries in 15 countries: Brazil, Norway, USA, Spain, Austria, Libya, Italy, Israel, Slovenia, Croatia, Romania, Bulgaria, Montenegro, Bosnia and Herzegovina, North Macedonia, and Serbia. It is a great honor and pleasure to cordially wish a warm welcome to all the participants of the conference.

As a part of this year's conference, the 6th Student Section – EcoTERS'24 will be held. We appreciate the contribution of the students and their mentors who have also participated in the conference and hope that students will continue to explore and to be curious, since education is a never-ending process, and knowledge is continuously growing.

The organization of the EcoTER'24 conference has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

The support of the Donors and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'24 conference. The organizing committee would like to extend their appreciation and gratitude to the Platinum donors of the conference – Serbia ZiJin Copper doo Bor and HBIS SERBIA, to the Gold donor of the conference – Elixir Group, as well as to the Silver donor of the conference – Serbian Chamber of Engineers.

We would like to express our sincere appreciation to all the authors who have contributed to the Proceedings. We would also like to express our gratitude to the members of the scientific, organizing and honorary committees, reviewers, speakers, chairpersons and all the conference participants for their support of the EcoTER'24. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'24.

Prof. Snežana Šerbula,

President of the scientific and organizing committee



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AIR POLLUTION IN THE BOR REGION FROM 1994 TO 2023

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Abstract

This study considered the historical air pollution data. Assessment of air quality in Bor was done for the period 1994–2023, namely since the installation of monitoring stations for measuring the concentrations of most common air pollutants such as SO₂, PM₁₀ and toxic elements As, Cd and Pb in PM₁₀ samples, at several different locations in relation to the location of the copper smelter. Modernizations of the Flash smelting technology were carried out in 2015 and 2022, which partially affected the reduction of air pollution. The measured concentrations of SO₂, PM₁₀, As in PM₁₀ as well Pb and Cd indicated frequent exceedances of defined annual limit values, both at the national and European levels. The maximum average annual SO₂ concentration reached 372 µg/m³ in 2012 and was 7.5 times higher than the legally prescribed values. Air quality regarding the levels of PM₁₀ and especially As in PM₁₀ was significantly worse after modernization. The annual concentration of As exceeded the annual target value defined by the European and Serbian regulations, at all monitoring sites, with a maximum exceedance of more than 90 times at the suburban location during 2019. Frequent exceedances of the respective annual target values were also noted for Pb and Cd in PM₁₀ samples. The analyzed data pointed out that the Bor region can still be characterized as an ecological hotspot in Serbia and beyond.

Keywords: air pollution, SO₂, PM₁₀, As, Pb, Cd.

INTRODUCTION

Industrial and urban-industrial environments suffer significantly more pollution than typical urban and rural environments, because the largest percentage of pollution comes from industrial activities, mining and metallurgy, combustion of fossil fuels and waste, as well as from traffic [1]. Concentrations of suspended particles in the atmosphere of urban areas range from 60–220 µg/m³. In highly polluted areas, these concentrations can reach up to 2,000 µg/m³ [1].

The European Commission (EC) has determined the allowed limit values (LV) for PM₁₀ as follows: the annual LV is 40 µg/m³, and the daily LV is 50 µg/m³, whereby this value must not be exceeded more than 35 times during the year [2]. The US Environmental Protection Agency (USEPA) for PM₁₀, on a daily basis, defines the LV of 150 µg/m³ [3]. In Serbia, concentration of PM₁₀ defined for inhabited areas is 120 µg/m³ on a daily basis, and 40 µg/m³ on an annual level [4].

Numerous pollutants present in the environment, such as arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), antimony (Sb) and copper (Cu) are classified as PBT elements, i.e. persistent, bioaccumulative and toxic elements [1]. Based on epidemiological

evidence, the International organization for research in the field of cancer (IARC) classified As, Pb and Cd in the group of carcinogenic elements. Apart from being carcinogenic and the most dangerous poison, As is found in copper ore mainly as the mineral arsenopyrite [5]. When copper ore is processed, at all stages of processing, significant amounts of arsenic are emitted in the environment [6].

The aim of this paper is an environmental review of the air quality, which was affected by polluting substances released from the mining and metallurgical facilities for pyrometallurgical copper production, which started 120 years ago in Bor and the surroundings (Eastern Serbia).

MINING AND METALLURGICAL ACTIVITIES IN BOR AND ITS SURROUNDINGS

Bor and its surroundings are known for deposits of copper ore, which are among the largest in Europe [6]. Mining production in Bor has existed for more than 120 years [7]. Mining in Bor began in 1902 with the discovery of copper-rich ore deposits, which were then exploited and processed. Natural hills were disappearing, and artificial hills of mine waste were formed. For years, the copper ore was exploited, so it became poorer over time. The poor copper ore was carried out in flotation, the copper concentrate was melted in the smelter and the flotation tailings formed new artificial lakes with fine sediment, like living mud.

Pyrometallurgical production of copper from sulphide ores (chalcopyrite – CuFeS_2 , chalcosine – Cu_2S , coveline – CuS , arsenopyrite – FeAsS , etc.) was the main source of pollution with SO_2 and PM particles, together with copper ore mining activities. The outdated technology was replaced by flash smelting technology (FST) as an advanced and energy-efficient production method during 2015 [8]. The monitoring of the level of air pollution in the city of Bor is carried out by the Mining and Metallurgical Institute Bor and the Serbian Environmental Protection Agency (SEPA). The measurement of air pollution started way back in 1994, and the levels of air pollution with sulfur dioxide (SO_2), fine suspended particles up to $10\ \mu\text{m}$ (PM_{10}), as well as As, Pb, Cd and Ni in PM_{10} , were determined at several locations in the city of Bor and surrounding settlements, as part of the local and national air quality monitoring networks. The levels of pollutants in the air are accordingly published in the form of annual and monthly reports by the Mining and Metallurgy Institute Bor and are available for public [9].

AIR POLLUTION IN THE AREA OF BOR AND ITS SURROUNDINGS

The area of Bor and its surroundings was under the influence of emissions of SO_2 , sedimentary substances, and suspended particles with a high concentration of arsenic, for many years. Significant exceedances of LVs [4] proposed for these polluting substances have been recorded for many years. Figure 1 shows the average annual concentrations of SO_2 at five measuring sites in the Bor area in the period 1994–2023. The limit value for SO_2 at the annual level is set at $50\ \mu\text{g}/\text{m}^3$ [4] and it is represented by the red horizontal line on the Figure 1. From 1994 to 2010, measurements were provided at three measuring site: Town Park, Institute and Jugopetrol, and later the measuring sites, such as Technical Faculty and

Slatina were also included. Since measurements of air pollution with sulfur dioxide have been carried out, there have always been exceedances of the average annual value of $50 \mu\text{g}/\text{m}^3$, implying that the daily and hourly values were also extremely high. During 2022, the average annual limit value for SO_2 emissions was exceeded only at the measuring site Jugopetrol. The SO_2 concentrations at other four measuring sites were within the defined limits. However, knowing that the reconstruction of the copper smelter, which is located in the very center of the city, was carried out during that year, being out of order for most of that year, then it is understandable that there was no air pollution with sulphur dioxide during 2022. With the reconstruction of the smelter and the introduction of the gas desulphurization process, the limit value of $50 \mu\text{g}/\text{m}^3$ was not exceeded in 2023.

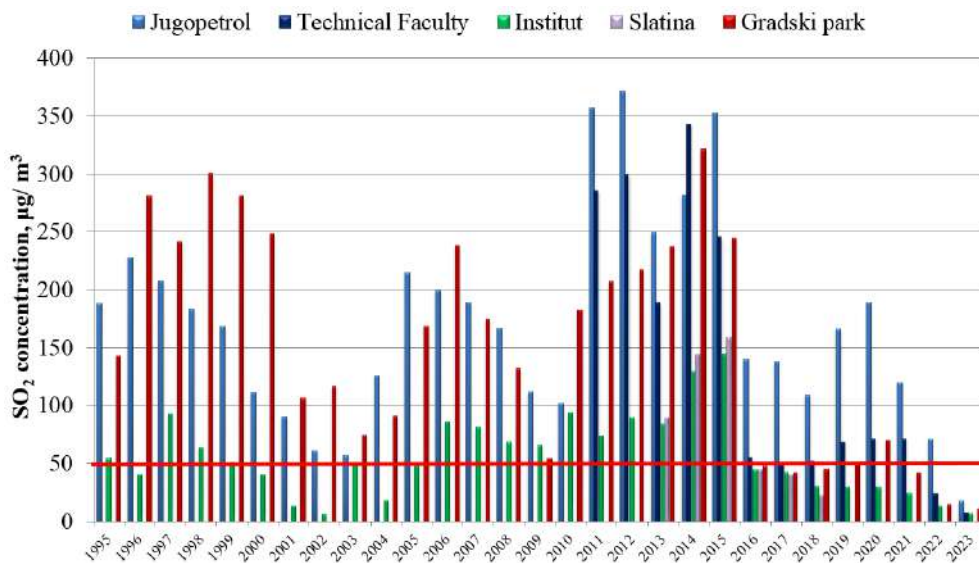


Figure 1 Average annual concentrations of SO_2 at five measuring sites in the Bor area in the period 1994–2023. The limit value (red horizontal line) is defined for SO_2 at $50 \mu\text{g}/\text{m}^3$

The average annual concentrations of total suspended particles (TSP) at all eight measurement sites in the Bor area were around the limit value [4]. The limit value for TSP was $70 \mu\text{g}/\text{m}^3$ until 2013, and after that it was reduced to $40 \mu\text{g}/\text{m}^3$ for PM_{10} , defined by the Regulation of the Republic of Serbia [4]. In both periods, before and after 2013, there were minor exceedances of the defined average TSP and PM_{10} annual values.

The average annual concentrations of As, in suspended particles PM_{10} , were determined at eight sites: Town Park, Jugopetrol, Technical Faculty, Krivelj, Institute, Brezonik, Slatina and Oštrelj during the period from 1994 to 2023, are shown in Figure 2. Over the years, the monitoring of pollutant concentrations was carried out at several other sites, but data for a whole period are not available. The measuring site Town Park is the closest to the copper smelter (0.5 km from the smelter), and is located in the direction of the dominant easterly winds. The measuring site Jugopetrol is located 3.3 km from the copper smelter, where westerly winds bring the pollution from the copper smelter.

During 28 years, the average annual concentrations of arsenic were largely above the LV target value (TV) of $6 \text{ng}/\text{m}^3$ at all three measuring sites (Town Park, Institute and Jugopetrol)

[4]. The high content of As in the air represents a great risk for the entire environment and human health, because As is regarded as a carcinogenic substance [5].

The given concentrations of arsenic in Figure 2, indicate that the urban-industrial zone of Bor is among the most polluted regions in Serbia and in Europe.

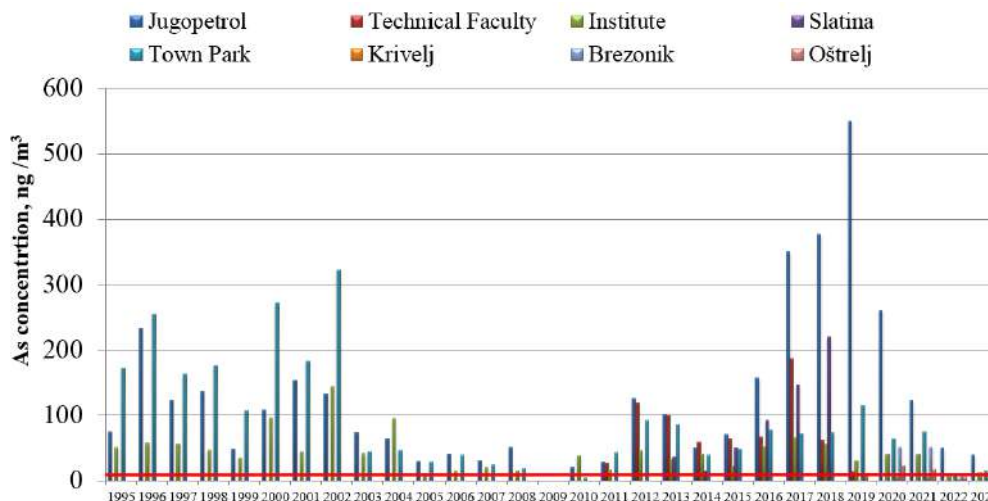


Figure 2 Average annual concentrations of As in suspended PM_{10} particles at eight measuring sites in the Bor area in the period 1994–2023. The target value (red horizontal line) is defined for As at 6 ng/m^3

The annual target value (TV) for Cd content in PM_{10} samples, defined by the Serbian [4], was exceeded at the sites Jugopetrol during the whole analyzed period and Town Park during 2019 (Figure 3). The measuring site Jugopetrol was characterized as the most polluted one with Cd in the Bor area, based on the annual concentrations in PM_{10} samples, during the period from 2010 to 2023. The data indicated that the FST implementation did not significantly contribute to the reduction of Cd emissions.

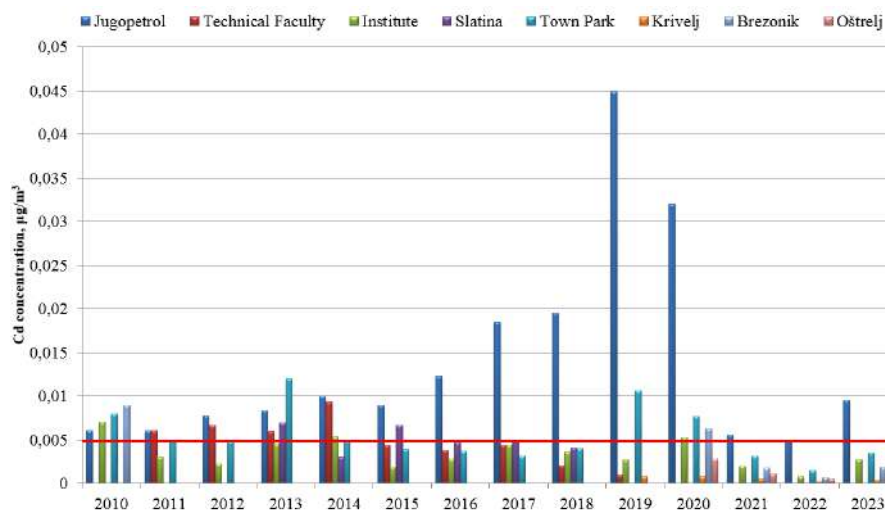


Figure 3 Average annual concentrations of cadmium in suspended PM_{10} particles at eight measuring sites in the Bor area from 1994–2023. The target value (red horizontal line) is defined for Cd at 5 ng/m^3

The annual Pb concentrations in PM₁₀ exceeded the annual LV of 0.5 µg/m³ [4] during 2012 at the measuring sites Jugopetrol and Technical Faculty, during 2013 at the sites Jugopetrol and Town Park, during 2014 at the site Technical Faculty, and during 2016, 2017, 2019 and 2020 at the site Jugopetrol (Figure 4). In the period of the new smelter operation, until 2020, the annual limit values were exceeded at the measuring site Jugopetrol.

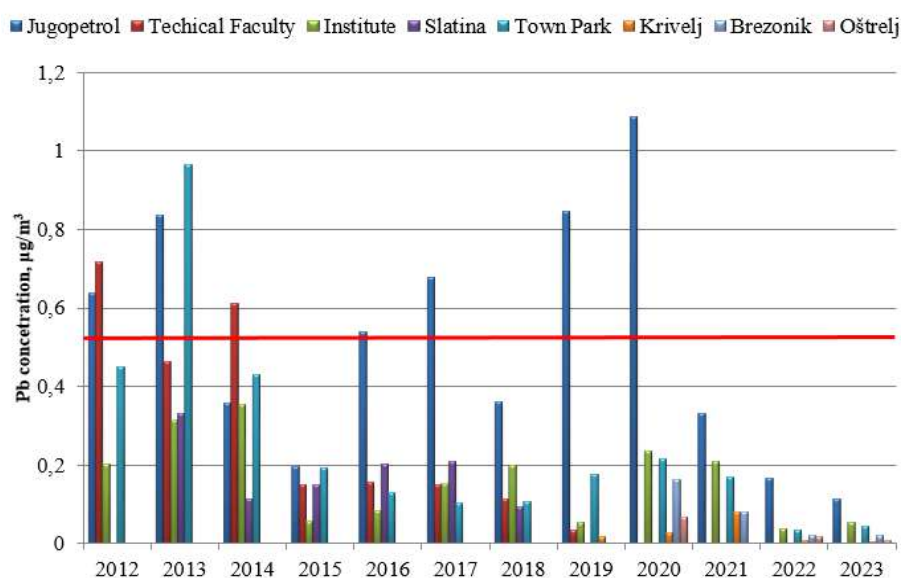


Figure 4 Average annual concentrations of Pb in suspended PM₁₀ particles at eight measuring sites in the Bor area from 2012–2023. The limit value (red horizontal line) is defined for Pb at 0.5 µg/m³

CONCLUSION

Over 120 years of mining and metallurgy in Bor and its surroundings have adversely affected the environment of this region. The natural relief of this area has been totally changed, large amounts of artificial tailings hills have contributed to air, water and soil pollution. The copper smelter located in the very center of the city of Bor, has been the source of increased emissions of sulfur dioxide and polluting particles of the smallest dimensions for decades. PM₁₀ particles, which contain some harmful and carcinogenic substances, such as As and heavy metals (lead, cadmium, nickel, etc.) can cause pollution of the remote areas due to their easy transport by the winds with the most frequently directions.

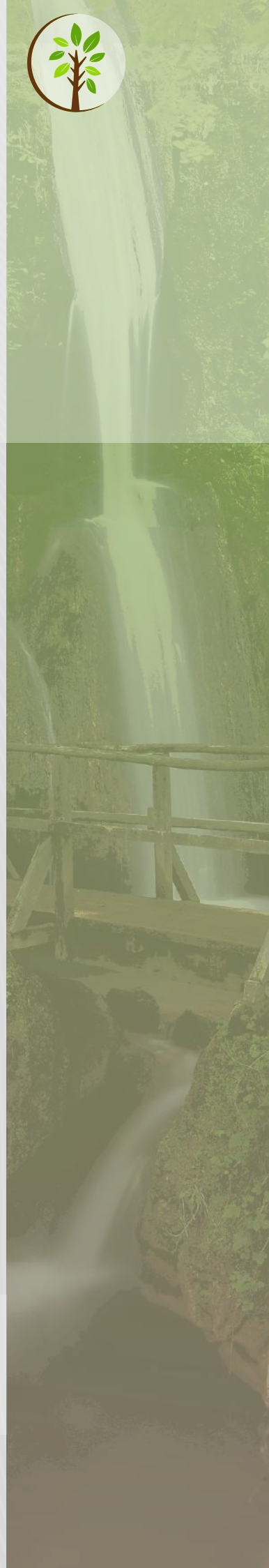
Since 1995, when air quality monitoring began, arsenic levels in the air have never been within the average annual concentration of 6 ng/m³.

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