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Particulate Air Pollution in Central Serbia and some Proposed Measures for the Restoration of Degraded and Disturbed Mining Areas

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KEYWORDS

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ABSTRACT

Mining causes soil degradation, particle emission, and air and water quality deterioration. This study estimates some health risks in districts of Central Serbia affected by surface mining activities, and proposes measures for land restoration. The epidemiological risk assessment was based on data for seven cancers and three cardiovascular diseases during 2010 - 2020. Results showed a statistically significant increase in the incidence of lung and bronchial cancer in critical districts. Borski district stood out with the highest incidence rates for cardiovascular diseases. The suspected role of particulate air pollution from the mining industry in health deterioration calls for intensified air quality monitoring and development of mitigation technologies. A restoration strategy called the Pan-Life-Carpet technology is proposed for the restoration of mining areas and for air and water pollution control.

Introduction

Land is a vital resource for human social and economic wellbeing. However, many parts of land ecosystems are under climatic and anthropogenic pressure. Anthropogenic climate changes accelerate natural and induce anthropogenic land degradation (Talukder et al., 2021). Land degradation leads to the deterioration of terrestrial and aquatic ecosystems and decrease of biodiversity. It presents one of the most severe ecological challenges of today (Perović et al., 2021) that leads to the reduction or loss of the biological or economic productivity and complexity of the land (UNCCD, 1994). Besides natural processes, main causes of land degradation are improper soil and vegetation management, overgrazing, industrial activities, waste deposition and mining, urbanization and infrastructure development, release of airborne pollutants, disturbance of the water cycle (UNDP, 2022), while climate

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change further amplifies the impact of drivers of land degradation (IPBES, 2018).

One of the most visible processes of soil degradation is soil erosion (UNDP, 2022). Soil erosion is a major environmental problem, threatening human safety and global socio-economic development (Sun et al., 2013; Jiang et al., 2019). Soil erosion can affect water and air quality. Erosive and unprotected soil presents a source of particulate pollution, while soil particles can contain other pollutants such as metals and organic pollutants (Goudie, 2014; Giltrap et al., 2021). The global emission of dust from the soil to the atmosphere has been estimated to be 3000 million tons annually (Katra, 2020).

Mining modifies, degrades and pollutes land (Padro et al., 2022). Surface mining induces immediate loss of soil, formation of waste (ash, slag, and tailings) and wastewater resulting from tailing processing (Pavlović et al., 2017). A major problem of mining is the mining waste, i.e. deposits of ash, slag and tailing that are usually disposed of without further utilization (Pavlović et al., 2017). Serbia produces about 40 million tons of mining waste every year (Official Gazette of the Republic of Serbia, No 12/2022). Mining is one of the main processes connected with soil loss and degradation in Serbia (Ličina et al., 2011; Pavlović et al., 2017). Emission of the soil particles to the atmosphere deteriorates air quality of the surroundings and remote areas (Goudie, 2014; Giltrap et al., 2021). Tian et al. (2019) showed that more than half of road dust sieved to 10 μm, collected at different distances to the mine and tailings, originate from the mine.

The primary pollutant produced by surface mining is particulate matter (PM) (Kumar Patra et al., 2016). PM consists of heterogeneous components, formed due to chemical reactions between inorganic and organic substances (soot, dust, soil components, vehicle exhaust gases, combustion products, etc.) (Manisalidis et al., 2020; Matić Savićević, 2020). According to the size PM are divided into three groups: PM10 (coarse particles, between 2.5-10 μm), PM2.5 (fine particles, < 2.5 μm) and PM0.1 (ultrafine particles, < 100 nm) (Franck et al., 2011; USEPA, 2016). The carbon core of PM can adsorb various chemicals such as aromatic and aliphatic compounds, biological allergens, endotoxins, heavy metals (e.g. Pb, As, Cd, Ni) etc. (Matić Savićević, 2020; Knežević et al., 2021) (Figure 1).

PM are associated with various health issues (Kelly & Fussel, 2015), and according to the International Agency for Research on Cancer (IARC) of the WHO, they belong to the Group 1 carcinogens, together with outdoor pollution (Loomis et al., 2013; IARC, 2016). It is estimated that exposure to air pollution, especially PM, results in millions of deaths annually (Kelly & Fussel, 2015; WHO, 2019; 2021). The effect of PM on the human body is determined by size (Valavanidis et al., 2008). Particles larger than 10 μm are generally trapped in the mucous membrane of the nose and throat and can be swallowed (Giltrap et al., 2021). Most PM10 are deposited in the upper airways (Brown et al., 2002) and can get deposited in the lungs where they cause inflammatory processes (Knežević et al., 2021). PM2.5 penetrate deep lung tissue (Giltrap et al., 2021) (Figure 1). Particle shape (International Commission on Radiological Protection, 1995; Sankaran et al., 2023), adsorbed substances (Valavanidis et al., 2008), origin, chemical compositions (Valavanidis et al., 2008; Xing et al., 2016), exposure time (Yang et al., 2019; Orellano et al., 2020), mechanisms of toxicity (Valavanidis et al., 2008) medical condition (e.g. preexisting heart and lung disease, diabetes) and stage of life (elderly and children) (Sacks et al., 2011; Manisalidis et al., 2020) determine the effects of PM on the human body, also.

PM is an important pollution in open mine areas, especially PM10 (Bui et al., 2019). In recent years, the concentration of PM10 in Serbia has been higher than the allowed 50 μg/m³ (WHO, 2019). Mining has a long-standing tradition in the Republic of Serbia with potential to expand (Popović et al., 2015). Kumar Patra et al. (2016) summarized medical evidence of health deterioration due to inhalation of PM pollution from surface mines. Mining impacts cardiovascular and respiratory systems, contributes to the neurological disorders and kidney damages (Ku-

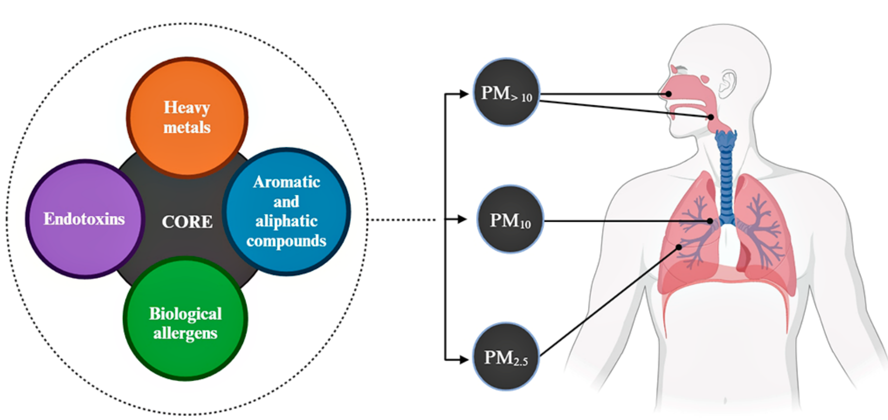

Figure 1. Description of heterogeneity of PM in the air and their impact on the respiratory system depending on the size of the PM (made with https://www.biorender.com/)

mar Patra et al., 2016; da Silva-Rego et al., 2022). One of the Sustainable Development Goals (SDGs) in the Agenda 2030 is to "substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" by 2030 (UN, 2015). Therefore, this work aims to estimate the health risk in the districts of Central Serbia that are affected by surface mining and mining waste disposal, as well as to propose measures for simultaneous mining land restoration, air pollution reduction and health risk decrease.

Data and methods

Databases for epidemiological analyses

The epidemiological risk assessment was based on the incidences of cancers and cardiovascular diseases. According to the Batut definition, standardized incidence and mortality rates represent theoretical values obtained through a specific technical process involving the introduction of a standard population. Typically, this standard population can be the world population (ASR-W), the European population (ASR-E), or a truncated population (ASR-TRUNC). These standardized rates overcome differences (most commonly by sex and age) that exist in different populations, making them suitable for comparisons (Batut, 2023c). The possible relation between PM pollution in degraded/disturbed areas and incidence of cancers and cardiovascular diseases in Central Serbia was based on data published by the Institute of Public Health of Serbia, 'Dr Milan Jovanović Batut' (Batut, 2023, 2023b, 2023c).

The seven examined cancers and three cardiovascular diseases are listed in Table 1, including corresponding abbreviations, as well as their codes from the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD), a medical classification list by the World Health Organization (WHO). The collected data concerning the mentioned diseases covered the period 2010 - 2020. The data included information concerning cancers in both males and females, except for the cancers of pharynx, oral cavity, and larynx, for which data on females was not available.

Table 1. Examined cancers and cardiovascular diseases with abbreviations

Abbr.	ICD - 10 codes	Cancer and cardiovascular diseases
C1	C00 - C14	Malignant neoplasm of lip, oral cavity and pharynx
C2	C32	Malignant neoplasm of larynx
C3	C34	Malignant neoplasm of bronchus and lung
C4	C67	Malignant neoplasm of bladder
C5	C71	Malignant neoplasm of brain
C6	C91 - C95	Leukemia
C7	C00 - C97	Malignant neoplasms
CV1	I21	Acute myocardial infarction
CV2	I20.0	Unstable angina pectoris
CV3	I24.9	Acute coronary syndrome

Source: https://icd.who.int/browse10/2019/en#/C06.9 (Internet 1).

Regional division of Central Serbia

According to the administrative division, Central Serbia has 18 districts. The investigated districts and corresponding abbreviations are presented in Table 2. The incidence of investigated types of cancers and cardiovascular diseases are documented by districts. Thus, it is possible to estimate the occurrence of diseases in degraded mining areas.

Table 2. Investigated districts of Central Serbia and the total number of inhabitants for the period 2010 – 2020 per district

№	District	Average number of inhabitants per district 2010 - 2020
1	Kolubarski	168612
2	Mačvanski	289074
3	Raški	305209
4	Moravički	205360
5	Zlatiborski	276884
6	Rasinski	231362
7	Šumadijski	286174
8	Pomoravski	205571
9	Braničevski	174794
10	Podunavski	192521
11	Zaječarski	113092
12	Borski	118762
13	Nišavski	367036
14	Pčinjski	204323
15	Jablanički	208448
16	Toplički	87473
17	Pirotski	88156
18	Beograd	1541347

Statistical analysis

A division was made into critical and non-critical districts. For critical districts were considered those which are affected by soil degradation and dust pollution from main mining sites of Central Serbia. The minings in Bor, Majdanpek, Kostolac and Kolubara as well as mining waste disposals 'Nikola Tesla A' and 'Nikola Tesla B' were considered as main degraded mining sites (Figure 2, circled). The influence of dominant winds was also considered in districts categorisation. Among the 18 examined districts, ten were critical and represented the first group in the statistical comparison (Beograd city, Podunavski, Borski, Moravički, Kolubarski, Šumadijski, Mačvanski, Braničevski, Zaječarski and Pomoravski). The rest of the districts of Central Serbia were considered as non-critical districts (Pčinjski, Rasinski, Jablanički, Nišavski, Raški, Toplički, Pirotski and Zlatiborski).

The values of the incidences of selected cancers and cardiovascular diseases were statistically analyzed using Student's t-test. Survey results were obtained using statistically significant differences between critical and non-critical districts in Serbia with a reliability of 95% ($p = 0.000 < 0.05$). The normality of the distribution was determined using the Shapiro-Wilk test. Derived values are presented in diagrams in order to visualize possible relationships between the incidences of seven types of cancers and three types of cardiovascular diseases with degraded mining areas which are a source of PM air pollution.

Results

Degraded mining areas in Serbia as particulate matter air pollution source

According to the analysis of the map showing damaged and degraded areas in Serbia with prominent main mining areas (Figure 2), following districts could be considered as most exposed to the PM air pollution from mining areas: Beograd city district, Mačvanski district, Kolubarski district, Moravički district, Šumadijski district, Podunavski district, Pomoravski district, Braničevski district, Borski district and Zaječarski district.

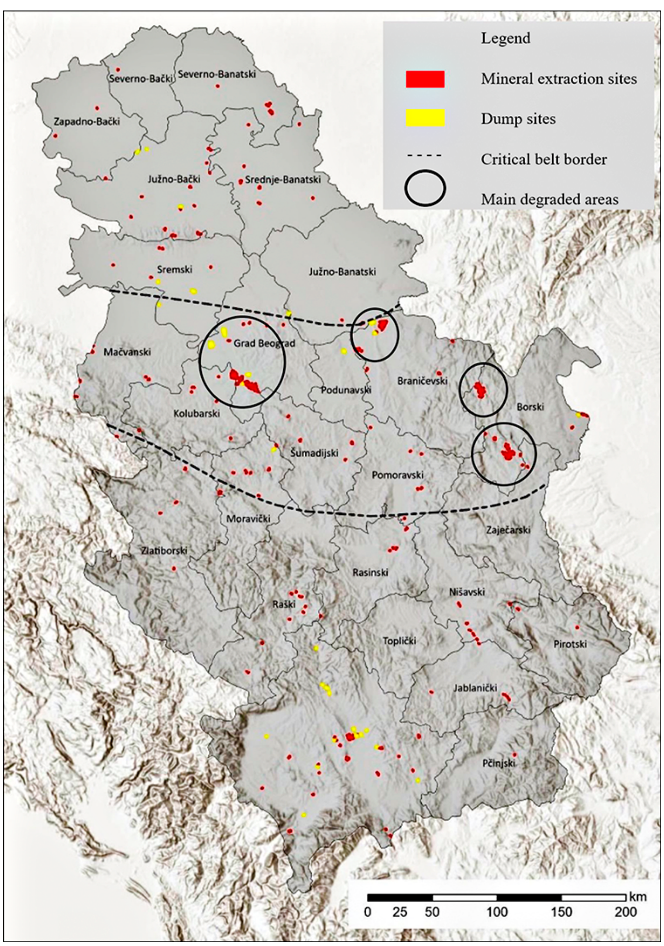

Figure 2. Map of damaged and degraded areas as a source of particulate air pollution in Serbia with ten affected districts in Central Serbia (based on Corine Land Cover 2018 (V2020_20u1), European Environment Agency (EEA))

Epidemiological analyses

The ratio of the incidence of cancer and cardiovascular diseases was determined by district in Central Serbia for the period 2010 - 2020. Critical districts showed a statistically significant association with an increased incidence of lung and bronchial cancer compared to the non-critical districts ($p = 0.027$, $p < 0.05$) (Figure 3a). The highest mean incidence of lung and bronchial cancer was determined in the following critical districts: the Beograd city (75.86) and Podunavski (70.15) districts. Statistical analyses showed the association of critical districts with an increased incidence of cancer of the oral cavity and pharynx (cavitas and pharynx) was marginally significant ($p = 0.086$, $0.05 \leq p < 0{,}1$) (Figure 3b). However, incidence analysis for other investigated cancers (C2, C4, C5, C6, C7) showed that there is

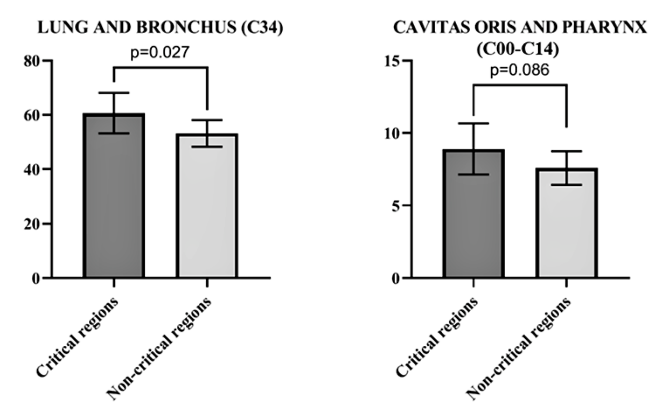

Figure 3. Incidence of lung and bronchial cancer (a), oral cavity and pharynx cancers (b) in Central Serbia for the period 2010 – 2020

no statistically significant difference between the critical and non-critical districts.

The incidence analysis for the examined cardiovascular diseases (CV1, CV2, CV3) showed that there is no statistically significant difference between the selected critical and non-critical districts. Due to the fact that cardiovascular diseases are the most common cause of death in Serbia in 2019 (Vasić et al., 2022), the incidence values among all districts in Central Serbia were compared, whereby the Borski district stood out in particular. Based on the incidence values, this district took the first place in the case of acute coronary syndrome, the second place in the case of unstable angina pectoris, and the third place in the case of acute myocardial infarction. Owing to the fact that this district is the most affected by soil (surface) degradation, the incidence values of the Borski district in the period from 2010 - 2020. years were compared with each district individually as well. Analyses proved that there is no statistically significant difference between the Borski district on one side and the districts with the highest incidence values.

Acute coronary syndrome disease in Borski district, with a standardized incidence rate of 200.768 per 100,000 inhabitants, ranks this district with the highest incidence compared to other districts (Figure 4). Statistical processing of the data did not show statistical significance difference in comparison with Zaječarski district that belongs to the group of critical districts as well ($p = 0.466$).

In the case of unstable angina pectoris, the Borski district, with standardized incidence rate values of 64.077 per 100,000 inhabitants in the observed period, ranked second in terms of the incidence, after the Nišavski district (incidence value = 76.064) and ahead with the Zaječarski district (incidence value = 58.732) (Figure 5). Statistical analyses show no significant difference between the Borski district and Nišavski ($p = 0.426$), Zaječarski ($p = 0.574$) and the Beograd city district ($p = 0.505$) on the other side. Results show that Borski, Zaječarski and the Beograd city districts, belonging to critical districts, are among the leading districts for unstable angina pectoris according to incidence values.

In the case of acute myocardial infarction, the Borski district, with standardized incidence rate values of 135.964 per 100,000 inhabitants in the observed period, ranked third in incidence, after Šumadijski and Raški districts with incidence values of 146.305 and 137.084 respectively (Figure 6). There is no statistically significant difference in the incidence values for the acute myocardial infarction between Borski and some other critical districts: Šumadijski ($p = 0.615$), Raški ($p = 0.327$), Rasinski ($p = 0.515$), Toplički ($p = 0.557$), Zaječarski ($p = 0.484$), Pčinjski ($p = 0.405$), Pirotski ($p = 0.420$), Mačvanski ($p = 0.346$) and Kolubarski ($p = 0.283$). Still, Borski district stood out as the district with the leading high incidence for analyzed cardiovascular disease in the observed period.

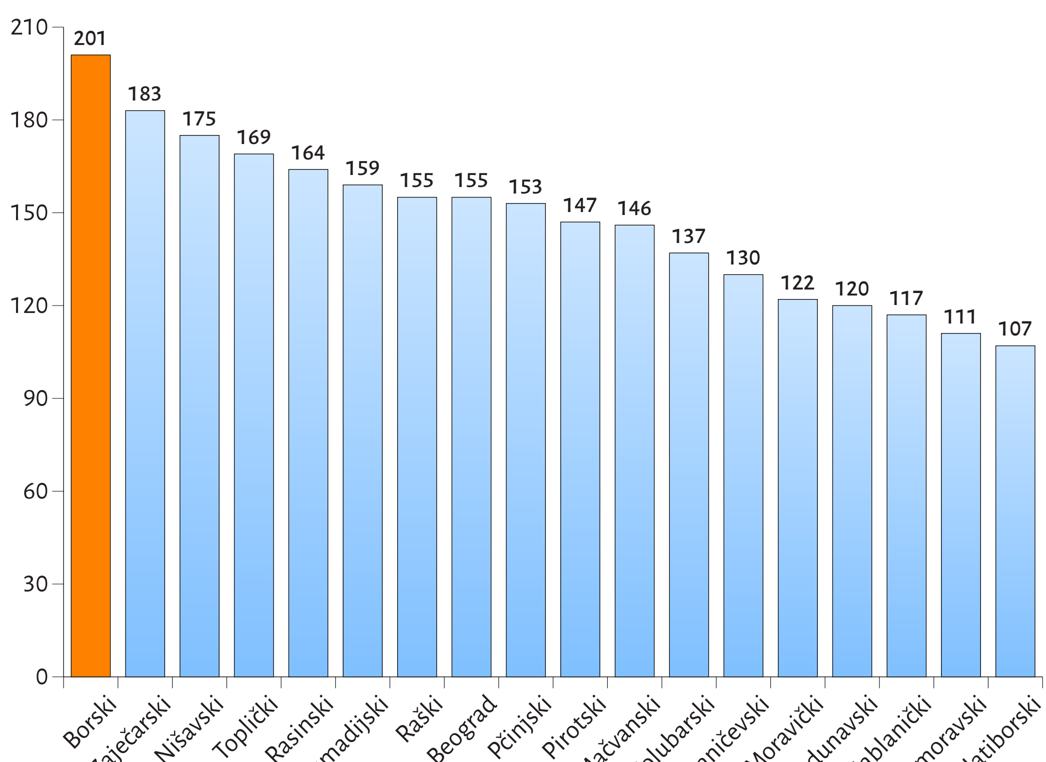

Figure 4. Standardized incidence rates (per 100,000 inhabitants) of acute coronary syndrome disease in Central Serbia for the period 2010 – 2020

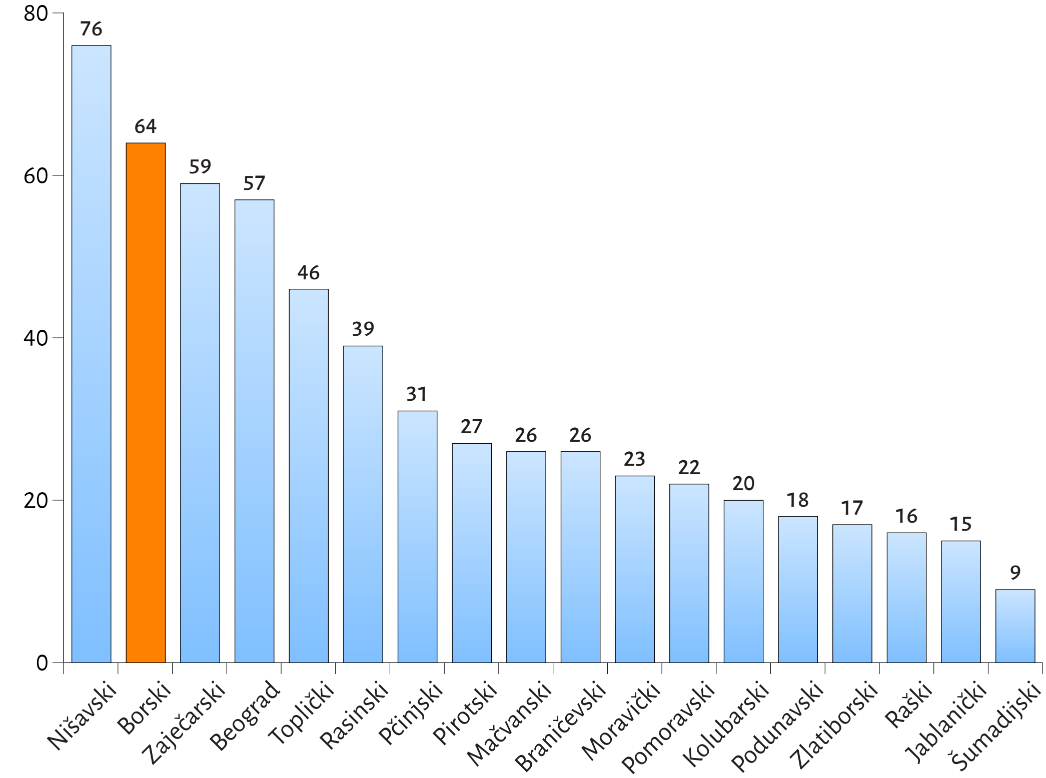

Figure 5. Standardized incidence rates (per 100,000 inhabitants) of unstable angina pectoris in Central Serbia for the period 2010 – 2020

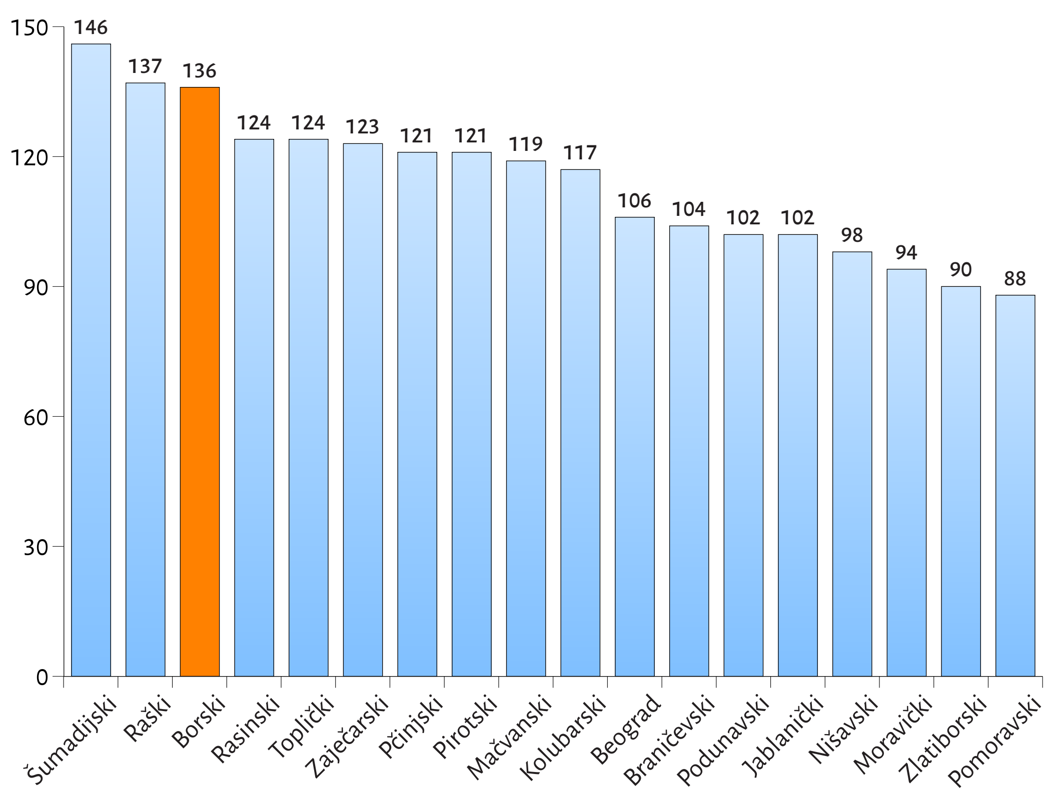

Figure 6. Standardized incidence rates (per 100,000 inhabitants) of acute myocardial infarction in Central Serbia for the period 2010 – 2020

Discussion

Mining activities as a health risk in Central Serbia

Land degradation is a world-wide problem. Serbia is under a high risk of land degradation and associated consequences, with an expected increase in the future (Pavlović et al., 2017; UNDP, 2022). The most pronounced process of soil degradation in Serbia and many other European countries is soil erosion (Pavlović et al., 2017; SEPA, 2018). Degraded soil presents a source of air pollution (Giltrap et al., 2021). Soil degradation by mining activities and tailings and waste disposals plays an important role in the generation of atmospheric dust with respect to the quantity of the particulates generated (Csavina et al., 2012). Based on the map of damaged and degraded areas in Serbia (Figure 2), districts around the main mining areas in Central Serbia could be considered as the most exposed districts suffering from PM air pollution from surface mining activities, and thus they have been regarded as critical districts in this study. Regardless of the presence of the surface mines in Vojvodina, this region was not taken into consideration in this study due to high industrialization and agricultural areas. Agricultural areas in Serbia are mostly located in Vojvodina, where more than 60% of the area is in the category of hazardous sensitivity and 36% in the category of medium sensitive to wind erosion (Baumgertel et al., 2019). Mines in Bor and Majdanpek (Figure 2, circled) are one of the main surface mining areas in Serbia. They are located in the borderline of Borski district with surrounding Zaječarski, Pomoravski and Braničevski districts. Kostolac mine (Figure 2, circuled) is located in Braničevski district, close to Podunavski district. Kolubara mine (Figure 2, circled) and 'Nikola Tesla A' and 'Nikola Tesla B' mine waste disposals (Figure 2, circled) in Beograd city district are surrounded by Mačvanski, Kolubarski, Moravički, Šumadijski and Podunavski districts. The geographical positions of the mentioned districts, in relation to mines and mine waste disposals, indicate their exposure to mine-originating PM air pollution. Therefore, the mentioned districts form a potential critical belt with the increased risk of exposure to PM air pollution from degraded mining lands and mining waste disposal sites.

Statistical analyses indicated a statistically significant association between an increased incidence of lung/bronchial cancer in the critical districts for the period 2010 - 2020 (Figure 3a). Beograd city district showed the highest incidence of lung and bronchial cancer during the observed period of 11 years compared to other districts of Central Serbia. Main mining and degraded areas impacted Beograd city district are Kolubara coal basin with total area of about 600 km^2 (Milanović et al., 2017) and thermal power plant ash disposal sites 'Nikola Tesla A' with an area of 400 ha (Gajić, 2014) and 'Nikola Tesla B' with an area of 600 ha (Nišić et al., 2015). Opencast coal mines in Serbia are mainly located in areas of fertile alluvial soils and occupy about 12,000 ha, with an expected increase of 200 ha each year (Pavlović et al., 2017). The eight thermal power plants in Serbia produce 8 Mt of ash annually (Electric Power Industry of Serbia, Technical Report 2010), while only 2.7% of the ash in Serbia is utilized for other purposes, mainly in the construction industry (Pavlović et al., 2017). Mining waste that is not subjected to further utilization is usually deposited in the open air (Pavlović et al., 2017). Large areas of deposited mining waste and opencast mines are exposed to the environmental erosive forces, e.g. wind erosion. Wind directions reported for the meteorological stations Beograd and Valjevo (Republic Hydrometeorological Service of Serbia) can contribute to the dispersion of particles from ash disposals and the Kolubara mine degraded land (Figure 7). Studies have shown increased lung cancer risk among miners with exposure to coal dust (Une et al., 1995; Hosgood et al., 2012; Tomaskova et al., 2012). Minowa et al. (1988) showed a higher lung cancer mortality in administrative units with coal mines in Japan. Fly coal ash has also been recognised as a health risk factor for lung cancer development (Whiteside & Herndon, 2018). Thus, the results of this study and current knowledge of the role of coal dust and fly ash in lung cancer development indicate that district Beograd city, where Kolubara coal mine and ash disposals ('Nikola Tesla A' and 'Nikola Tesla B') are located as, well as surrounding districts could be considered as risk areas for lung cancer development. Besides cancers, coal mine dust (Ross & Murray, 2004; Laney & Weissman, 2014) and fly ash (Shrivastava et al., 2015) are promoting other respiratory diseases in the affected areas. Tomaskova et al. (2012) showed increased lung cancer risk in coal miners with pneumoconiosis, compared to those without pneumoconiosis. This indicates a greater susceptibility to developing lung cancer in people with an already impaired immune system. Examining the health status of the population in the territory of the municipality of Lazarevac, district affected by Kolubara mining activities, Muratović (2015) pointed out the importance of air pollution of the mining areas in the development of respiratory diseases such as bronchitis, asthma and pneumonia. This study did not include the mentioned diseases due to the lack of official data. Therefore, monitoring and future research should cover a wider spectrum of respiratory diseases in relation to target districts due to the significant contribution of mine activities to air pollution.

This study showed that there is a statistically significant but marginal association between elevated incidence of cancer of the oral cavity and pharynx in the male population and critical districts. Due to lack of data, this study did not include the female population in examining the association of cancer of the oral cavity and pharynx in the critical districts. There are studies that showed the association of pharynx cancer with exposure to coal dust (Goldberg et al., 1997; Laforest et al., 2000). Thus, the contribution of PM air pollution from mine sites in development of this cancer should not be underestimated, but deserves more attention in further research.

According to the World Health Organization, particulate air pollution is significantly associated with cardiopulmonary diseases and mortality (WHO, 2021). Cardiovascular diseases are one of the main causes of death in Serbia (Vasić et al., 2022) and world-wide (Gaziano, 2001; Gaidai et al., 2023; Samuel et al., 2023; Woodruff et al., 2024). This study showed that there is no statistically significant difference between the selected critical and non-critical districts in analyzed cardiovascular diseases. One of the reasons could be that the development of cardiovascular diseases is influenced by an array of factors (Dahlöf, 2010), and not only by air pollution originating from surface mining activities. Still, among all districts in Central Serbia, Borski district has the leading high incidence for analyzed cardiovascular disease. Most of the land degraded by surface mining in Serbia is located in Borski district and it is caused by copper mining in Majdanpek and Bor (Pavlović et al., 2017). The mining activity has degraded areas of about 1110 ha in Bor and 12,060 ha in Majdanpek which is about 60% of the total agricultural land (Pavlović et al., 2017). Wind directions measured from the meteorological station Crni Vrh (Republic Hydrometeorological Service of Serbia) in Borski district indicate possible contribution of wind to the emission of particles from mine degraded lands to neighbor and remote sites (Figure 7). Bor is one of the most air polluted regions in Serbia and beyond. Air quality monitoring for Bor showed that annual arsenic concentrations exceeded the proposed limit value at all measuring sites and annual lead and cadmium concentrations frequently exceeded the proposed limit value for the period from 2009 to 2015 (Serbula et al., 2017). Mining activities in Majdanpek also negatively impacted the environment, and consequently air quality (Ilić Krstić et al., 2020). Study conducted by Nkosi et al. (2016) showed that elderly people exposed to pollution arising from mine dumps in South Africa had a significantly higher prevalence of cardiovascular and respiratory diseases and that living close to mine dumps was significantly associated with asthma, hypertension, pneumonia, emphysema, arrhythmia, and myocardial infarction. Higher mortality rates from chronic cardiovascular disease compared to non-mining areas have also been observed in mining areas of Central Appalachian States (Esch & Hendryx, 2011). Based on the known negative impact of air pollution from mining areas on the cardiovascular system (e.g. Esch & Hendryx, 2011; Nkosi et al., 2016.) and results of this study, mining activities and consequent heavy metal pollution should be considered as important risk factors for development of cardiovascular diseases.

Despite the existence of the Kostolac mine in Braničevski district, the low incidence of analyzed diseases can be

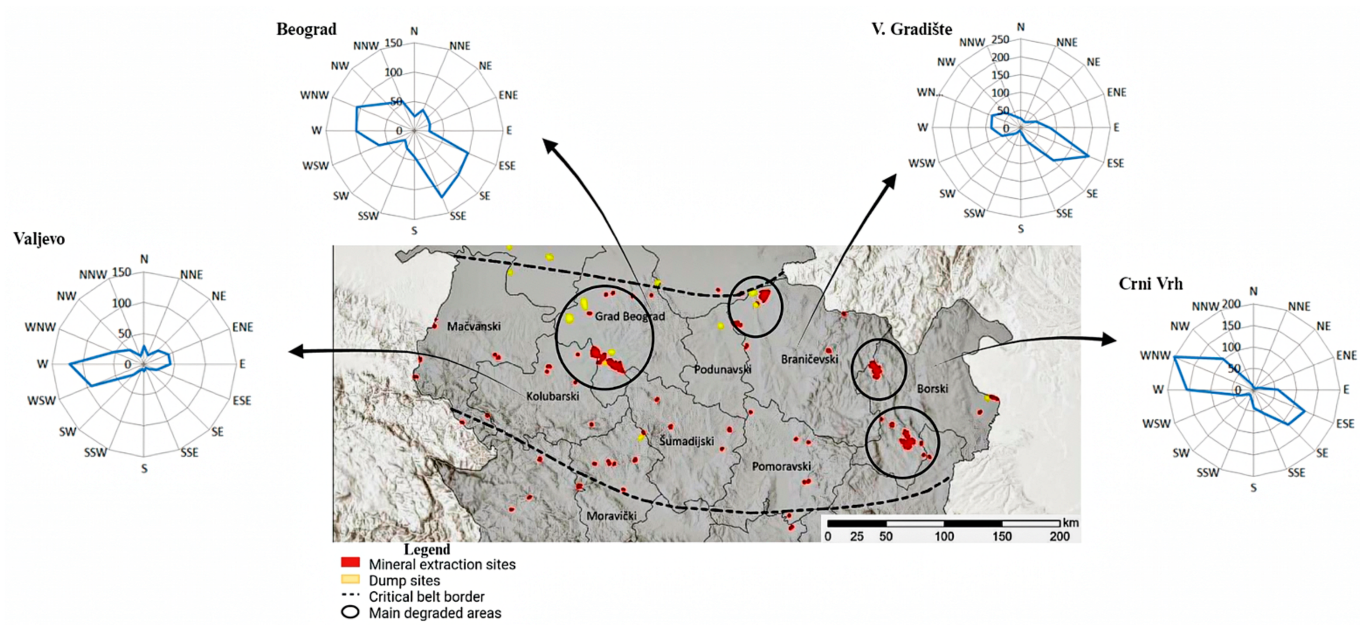

Figure 7. Representative relative frequencies of wind directions in per mille (1981 - 2010) for critical belt: Borski district (meteorological station Crni Vrh), Braničevski district (meteorological station V. Gradište), Begrad city district (meteorological station Beograd) and Kolubara district (meteorological station Valjevo) (based on Corine Land Cover 2018) (V2020_20u1), European Environment Agency (EEA), (Republic Hydrometeorological Service of Serbia)

due to its position in the border zone and the dominant east-southeast wind (ESE wind, Veliko Gradište meteorological station) (Republic Hydrometeorological Service of Serbia) (Figure 7).

Mining activities such as excavation, crushing, grinding, separation, smelting, refining, and tailings are important sources of contaminated dust that can be wind-transported to neighbour places (Serbula et al., 2010; Csavina et al., 2012; Zanetta-Colombo et al., 2022). Local copper mining activities in northern Chile are connected to the increased metal concentrations in dust collected from roofs and windows of indigenous villages (Zanetta-Colombo et al., 2022). However, in Serbia there is an insufficient monitoring of particle pollution (Matić Savićević & Stojanović, 2019), even though air pollution harms the economy of the country through lower labour output (World Bank, 2016), increased health expenses, damage to crops and infrastructure, and costs related to climate change and environmental protection (WHO, 2021). Total treatment costs in 2017 were 30% higher compared to 2010, and amounted to circa €1.7 billion and €1.4 billion, respectively. The modern way of living is considered to have a huge impact on the increase in the cost of treating cardiovascular diseases. According to the WHO, particulate air pollution is significantly associated with cardiopulmonary diseases and mortality, and other health conditions (WHO, 2021).In studies from other countries (Minowa et al., 1988; Une et al., 1995; Goldberg et al., 1997; Laforest et al., 2000; Ross & Murray, 2004; Esch & Hendryx, 2011; Hosgood et al., 2012; Tomaskova et al, 2012; Laney & Weissman, 2014; Shrivastava et al., 2015; Nkosi et al., 2016; Whiteside & Herndon, 2018) and this study from the Republic of Serbia indicate the role of the particulate air pollution from the mine industry in health deterioration. Thus, intensified monitoring of PM air pollution originating from mining activities, assessment of their influence on the health and combating particulate air pollution is of environmental, health, economic and social importance in Serbia and world-wide.

Proposed measures for restoration of degraded and disturbed mining areas to combat particulate air pollution

Even though there have been made certain efforts towards improving restoration practice in Serbia, restoration activities in Serbian mining basins are considered poorly applied in practice (Ranđelović et al., 2017). Natural recovery of the vegetation cover could take a long time and the success of land restoration by higher plants in these environments could be limited. The process of natural recovery of satisfactory vegetation cover on mine wastes could last from 50 to 100 years (Bradshaw, 1997). Restoration of the mine tailings and waste deposits by recultivating higher plants is limited because of adverse environmental factors present in these environments, such as water and nutrient deficiency, high temperatures, adverse chemical properties of the substrates (Pavlović & Mitrović, 2013; Pavlović et al., 2017; Li & Liber, 2018). Li & Liber (2018) study showed that low levels of soil moisture and available nitrogen were the major limiting factors affecting plant community development on the coal gob pile, not metal toxicity.

Dominant biological cover in the environments where development of higher vegetation is hindered is represented by biological soil crusts (biocrusts) (Veste, 2005). Biocrusts are bio-sedimentary complexes of organisms (cyanobacteria, mosses, lichens, fungi and bacteria) and soil particles (Eldridge & Green, 1994; Williams et al., 2012). This community is highly tolerant to desiccation and long-term drought (Veste, 2005). Biocrust characterizes successional development that begins with cyanobacterial colonization of the soil (Lan et al., 2012; Williams et al., 2012). Several cyanobacteria genera are nitrogen fixers within biocrusts (Belnap & Lange, 2003). They produce protective layers of exopolysaccharides that have multiple roles in the biocrust community such as binding the soil particles, retaining water and nutrients (Colica et al., 2014; Rossi & De Philippi, 2015; Mugnai et al., 2017). Cyanobacteria and their exopolysaccharides form a complex protective network with incorporated soil particles over the soil surface (Dulić et al., 2017; Palanački Malešević et al., 2021). They trap (Malam Issa et al., 2001; Williams et al., 2012; Svirčev et al., 2013; 2019; Dulić et al., 2017; Palanački Malešević et al., 2021), metabolize and stabilize the airborne particles (Dulić et al., 2017; Palanački Malešević et al., 2021; Svirčev et al., 2013; 2019). Accordingly, colonization of the surface of the substrate by biocrusts provides essential ecosystem functions. They control water and nutrient availability and soil stability in the environment (Chamizo et al., 2016; 2018; Palanački Malešević et al., 2021).

Artificially induced biocrusts have been proposed to fight land degradation in adverse environmental conditions, and cyanobacterial inoculation have been introduced as a potential solution (e.g. Wang et al., 2009; Rossi et al., 2017; Chamizo et al., 2018; Antoninka et al., 2020; Rossi, 2020). Some of the latest studies employing cyanobacteria for the restoration of degraded land and the mitigation of adverse environmental conditions are reviewed in the study by Palanački Malešević et al. (2024). The importance of biocrusts and cyanobacteria in the land restoration after soil disturbance induced by mining has been recognized (Doudle & Williams, 2010; Doudle et al., 2011; Williams et al., 2019). Cyanobacterial inoculation induces biocrusts development on mine tailings, which further mitigates wind erosion and enhances tailing fertility enabling establishment of vegetation cover (Rezasoltani et al., 2023). However, biocrusts development in the field conditions can be hindered by adverse environmental factors. Water is a primary factor affecting biocrust growth (Bu et al., 2014) and drought is common in most mine environments (Zhu et al., 2022). Dew enables physiological activity of cyanobacteria and maintenance of biocrust biomass, but for biocrust biomass growth a higher amount of water than dew is needed (Rao et al., 2009). Since the restoration process could take a long time due to the lack of moisture during the initial phase of biocrust development, it is necessary to find strategies for acceleration of the biocrusts establishment and further growth. Assisted development of artificially induced biocrusts through mitigation of key limiting factors could provide promotion of inoculum viability and growth rate. Biocrust carpet engineering could enable quick, sustainable and environmentally friendly solutions to mining land restoration.

The role of biocrust carpet engineering, through assisted development of artificially induced biocrusts, in the restoration of mine tailings and waste deposits of mining to control air pollution should not be neglected. To provide a quick, sustainable, and environmentally friendly solution, some requirements must be met:

– Providing ***interaction of dust particles with cyanobacteria*** would lead to particle capture into the sticky cyanobacterial biofilm and their further entrapment in this community during dry and wet environmental conditions (Svirčev et al., 2013; 2019; Palanački Malešević et al., 2021). Inoculation of cyanobacterial biomass in the affected environments would promote this interaction.
– Providing an ***extended wet period*** would enable longer metabolic activity of cyanobacteria and thus active collection of air particles by sticky biofilm. During wet environmental conditions, metabolically active cyanobacteria trap, metabolize and deposit airborne particles as part of their life strategy in providing minerals for biocrusts growth (Williams et al., 2012; Svirčev et al., 2013; 2019). Polysaccharide support to cyanobacterial inoculum could improve water availability, provide extended wet period, and promote cyanobacterial metabolic activity and biocrusts growth. There are studies that indicate the potential of superabsorbent polymer (Park et al., 2014) and nanocomposite (Chi et al., 2020; Li et al., 2021) as soil fixing and water retention agents in promoting biocrust growth.

Attention should be paid to the technical feasibility of the polysaccharide-supported inoculation of cyanobacteria in the field. A physical support to the polysaccharide-cyanobacterial carpet should be engineered to enable easier carpet applicability at the field. This polysaccharide-cyanobacterial carpet with physical support creates microenvironmental conditions for the accelerated initiation and growth of biocrusts. This technology could be called the Pan-Life-Carpet (PLC) concept, i.e. a carpet for the initiation of life on mining and other degraded land areas.

Degraded land is a source for dust emission and precondition for sediment erosion. Such land directly causes air pollution by dust emission to the atmosphere and water pollution by soil and sediment erosion to neighboring water bodies (Figure 8a). Airborne particles from polluted air are carried by the wind to distant regions and very often end up in water ecosystems. In this way, water bodies are also indirectly polluted by airborne particles from polluted air. Therefore, there is a need for sustainable solutions to the problems of land degradation and consequent air and water pollution in such challenging environments. Cyanobacteria and their sticky exopolysaccharides, that are part of PLC technology, are known to capture, accumulate and stabilize airborne particles (Svirčev et al., 2013; 2019; Palanački Malešević et al., 2021). Implemented PLC technology and consequent accelerated biocrust development stabilize soil surface, prevent dust emission and sediment erosion, providing land restoration and prevention of air and water pollution, respectively (Figure 8b). The sticky structure of PLC provided by cyanobacterial exopolysaccharide

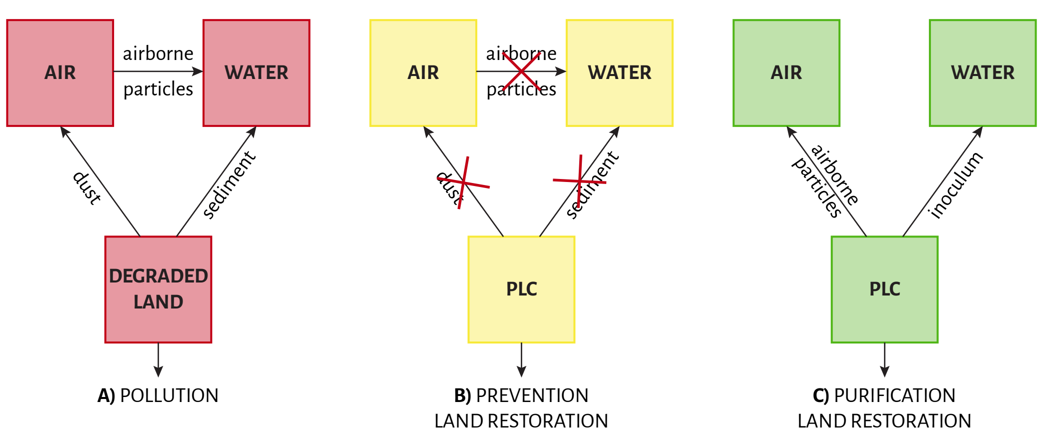

Figure 8. The role of Pan-Life-Carpet (PLC) in land restoration, prevention of air and water pollution as well as air and water purification (made with https://www.biorender.com/)

captures airborne particles from polluted air, decreases their concentration in the air and thus provides air purification (Figure 8c). Cyanobacterial biomass from polluted water bodies can be taken away from water ecosystems and used as inoculum for PLC development, which further contributes to water purification (Figure 8c).

The PLC technology thus exhibits a double impact on air quality: 1) by stabilizing substrate surfaces it prevents dust particle emission to the atmosphere and thus prevents air pollution (Figure 8b); 2) by capturing and further stabilizing airborne particles it purifies already polluted air (Figure 8c). The PLC technology exhibits similar benefits for the water ecosystems: 1) by preventing air pollution and purifying air it prevents indirect pollution of water ecosystems Figure 8b; 2) the use of cyanobacterial biomass from eutrophic lakes for PLC preparation purifies water ecosystems, as well (Figure 8c). Thus, biocrust carpet engineering, i.e. the PLC concept, by providing land restoration, air and water pollution prevention as well as air and water purification addresses global environmental problems of land degradation and air and water pollution.

Conclusion

The present study addressed the health risk assessment in districts of Central Serbia due to exposure to PM pollution originating from degraded mining areas. Epidemiological estimation was based on the incidence of seven types of cancers and three types of cardiovascular diseases in 18 districts of Central Serbia for the period 2010 – 2020. Locations of surface mines, mine disposals and ash disposal sites, as well as frequencies of wind directions, were also observed.

The obtained results showed a statistically significant increase in lung and bronchial cancer incidence in critical districts affected by soil degradation and dust pollution from main mining sites compared to non-critical districts. Among them, Beograd city had the highest incidence due to the proximity and wind impact from thermal power plant ash disposal sites 'Nikola Tesla A', 'Nikola Tesla B', and Kolubara coal basin. Based on the incidence values, the Borski district, where most of the land was degraded by copper mining (Bor and Majdanpek), stood out among the top three districts for examined diseases.

According to the results of the study, intensified monitoring of air pollution originating from mining areas, as well as mitigation technology for restoration of such degraded land, are necessary. Pan-Life-Carpet technology based on artificially induced biocrusts, with the dominance of cyanobacteria, has been proposed as a potential quick, sustainable, and environmentally friendly solution for mining land restoration and air and water pollution control. The PLC concept is becoming ready for field testing and expected to facilitate processing of degraded land surfaces.

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References

Antoninka, A., Faist, A., Rodríguez-Caballero, E., Young, K. E., Chaudhary, V. B., Condon, L. A., & Pyke, D. A. (2020). Biological soil crusts in ecological restoration: emerging research and perspectives. *Restoration Ecology*, 28(S2), 3-8. https://doi.org/10.1111/rec.13201

Batut (2023). Institute of Public Health of Serbia 'Dr Milan Jovanović Batut' https://www.batut.org.rs/index.php?content=186 (04.10.2023).

Batut (2023b). Institute of Public Health of Serbia 'Dr Milan Jovanović Batut' https://www.batut.org.rs/index.php?content=1413 (10.10.2023).

Batut (2023c). Internet 3: Institute of Public Health of Serbia 'Dr Milan Jovanović Batut' https://www.batut.org.rs/index.php?category_id=109 (23.10.2023).

Baumgertel, A., Lukić, S., Belanović Simić, S., & Kadović, R. (2019). Identifying Areas Sensitive to Wind Erosion—A Case Study of the AP Vojvodina (Serbia). *Applied Sciences*, 9(23), 5106. 10.3390/app9235106

Belnap, J., & Lange, L.O. (2003). Biological soil crusts: Structure, function, and management. In *Ecological studies*. 10.1007/978-3-642-56475-8

BioRender. (2024). https://www.biorender.com/ (01.02.2024).

Bradshaw, A. (1997). Restoration of mined lands—using natural processes. *Ecological Engineering*, 8(4), 255 – 269. https://doi.org/10.1016/s0925-8574(97)00022-0

Brown, J. S., Zeman, K. L., & Bennett, W. D. (2002). Ultrafine particle deposition and clearance in the healthy and obstructed lung. *American Journal of Respiratory and Critical Care Medicine*, 166(9), 1240 – 1247. 10.1164/rccm.200205-399oc

Bu, C., Wu, S., Yang, Y., & Zheng, M. (2014). Identification of factors influencing the restoration of Cyanobacteria - Dominated biological soil crusts. *PloS One*, 9(3), e90049. https://doi.org/10.1371/journal.pone.0090049

Bui, X. N., Lee, C. W., Nguyen, H., Bui, H., Long, N. Q., Le, Q., . . . Moayedi, H. (2019). Estimating PM10 Concentration from Drilling Operations in Open-Pit Mines Using an Assembly of SVR and PSO. *Applied Sciences (Basel)*, 9(14), 2806. 10.3390/app9142806

Chamizo, S., Cantón, Y., Rodríguez-Caballero, E., & Domingo, F. (2016). Biocrusts positively affect the soil water balance in semiarid ecosystems. *Ecohydrology*, 9(7), 1208 - 1221. 10.1002/eco.1719

Chamizo, S., Mugnai, G., Rossi, F., Certini, G., & De Philippis, R. (2018). Cyanobacteria inoculation improves soil stability and fertility on different textured soils: gaining insights for applicability in soil restoration. *Frontiers in Environmental Science*, 6. https://doi.org/10.3389/fenvs.2018.00049

Chi, Y., Li, Z., Zhang, G., Zhao, L., Gao, Y., Wang, D., Wu, Z. (2020). Inhibiting desertification using aquatic cyanobacteria assisted by a nanocomposite. *ACS Sustainable Chemistry & Engineering*, 8(8), 3477 – 3486. https://doi.org/10.1021/acssuschemeng.0c00233

Colica, G., Li, H., Rossi, F., Li, D., Liu, Y., & De Philippis, R. (2014). Microbial secreted exopolysaccharides affect the hydrological behavior of induced biological soil crusts in desert sandy soils. *Soil Biology & Biochemistry*, 68, 62 – 70. 10.1016/j.soilbio.2013.09.017

Csavina, J., Field, J. A., Taylor, M. P., Gao, S., Landázuri, A. C., Betterton, E. A., & Sáez, A. E. (2012). A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. *Science of the Total Environment*, 433, 58 – 73. 10.1016/j.scitotenv.2012.06.013

Da Silva Rêgo, L. L., De Almeida, L. A., & Gasparotto, J. (2022). Toxicological effects of mining hazard elements. *Energy Geoscience*, 3(3), 255 – 262. 10.1016/j.engeos.2022.03.003

Dahlöf, B. (2010). Cardiovascular disease risk factors: Epidemiology and risk assessment. *The American Journal of Cardiology*, 105(1), 3A - 9A. https://doi.org/10.1016/j.amjcard.2009.10.007

Doudle, S., & Williams, W. (2010). Can we kick-start mining rehabilitation with cyanobacterial crusts?. In D.J. Eldridge, & C. Waters (Eds), *Proceedings of the 16th Biennial conference of the Australian rangeland society.* Bourke: Australian Rangeland Society, Perth.

Doudle, S., Williams, W. & Galea, V. (2011). Improving rehabilitation outcomes using biocrusts. *Eight International Heavy Minerals Conference* 2011 (pp.85-97), Perth, WA, Australia, 5-6 October 2011. Carlton South, VIC, Australia: Australasian Institute for Mining and Metallurgy (AusIMM).

Dulić, T., Meriluoto, J., Palanački Malešević, T., Gajić, V., Važić, T., Tokodi, N., . . . Svirčev, Z. (2017). Cyanobacterial diversity and toxicity of biocrusts from the Caspian Lowland loess deposits, North Iran. *Quaternary International*, 429, 74 – 85. https://doi.org/10.1016/j.quaint.2016.02.046

Eldridge, D.J., & Greene, R.S. (1994). Microbiotic soil crusts: A review of their roles in soil and ecological processes in the rangelands of Australia. *Australian Journal of Soil Research*, 32(3), 389 – 415. 10.1071/SR9940389

Electric Power Industry of Serbia - EPS. (2010). Technical Report. https://www.eps.rs/eng/Documents/yearreports/EPS%20Annual%20report%202010.pdf (23.09.2024).

Esch, L., & Hendryx, M. (2011). Chronic cardiovascular disease mortality in mountaintop mining areas of central Appalachian states. *The Journal of Rural Health*, 27(4), 350 – 357. https://doi.org/10.1111/j.1748-0361.2011.00361.x

European Environment Agency - EEA. (2018). Corine Land Cover V2020_20u1.

Franck, U., Odeh, S., Wiedensohler, A., Wehner, B., & Herbarth, O. (2011). The effect of particle size on cardiovascular disorders - The smaller the worse. *Science of the Total Environment*, 409(20), 4217 – 4221. 10.1016/j.scitotenv.2011.05.049

Gaidai, O., Cao, Y., and Laginov, S. (2023). Global Cardiovascular Diseases Death Rate Prediction. *Current Problems in Cardiology*, 48(5), 101622. https://doi.org/10.1016/j.cpcardiol.2023.101622

Gajić, G., (2014). *Ekofiziološke adaptacije odabranih vrsta zeljastih biljaka na deponiji pepela termoelektrane 'Nikola Tesla A' u Obrenovcu.* (Ecophysiological adaptations of selected species of herbaceous plants at the ash dump of the thermal power plant 'Nikola Tesla A' in Obrenovac) Belgrade: University of Belgrade.

Gaziano, J.M. (2001) Global burden of cardiovascular disease. In R. Zorab. (Ed.), Heart Disease. *A textbook of cardiovascular medicine* (pp. 1 - 18). Philadelphia: W.B. Saunders Company.

Giltrap, D., Cavanagh, J., Stevenson, B., & Ausseil, A. (2021). The role of soils in the regulation of air quality. *Philosophical Transactions of the Royal Society B*, 376(1834), 20200172. 10.1098/rstb.2020.0172

Goldberg, P., Leclerc, A., Luce, D., Morcet, J-F., & Brugère, J. (1997). Laryngeal and hypopharyngeal cancer and occupation: results of a case control-study. *Occupational* *and Environmental Medicine*, 54(7), 477 – 482. https://doi.org/10.1136/oem.54.7.477

Goudie, A.S. (2014). Desert dust and human health disorders. *Environment International*, 63, 101 – 113. https://doi.org/10.1016/j.envint.2013.10.011

Hosgood, H. D., Chapman, R. S., Wei, H., He, X., Tian, L., Liu, L. Z., … Lan, Q. (2012). Coal mining is associated with lung cancer risk in Xuanwei, China. *American Journal of Industrial Medicine*, 55(1), 5 – 10. 10.1002/ajim.21014

Ilić Krstić, I., Malenović Nikolić, J., & Janaćković, G. (2020). Ecological security in Majdanpek mining area – a case study. *Facta Universitatis*, 17(1), 65 - 74. https://doi.org/10.22190/fuwlep2001065i

International Agency for Research on Cancer (IARC) (2016). Outdoor Air Pollution: IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Vol. 109. Lyon, France: IARC.

International Commission on Radiological Protection - ICRP. (1995). *Human Respiratory Tract Model for Radiological Protection*. Elsevier Health Sciences, 66.

Internet 1. International Statistical Classification of Diseases and Related Health Problems https://icd.who.int/browse10/2019/en#/C06.9 (25.09.2023).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2018). Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In R. Scholes, L. Montanarella, A. Brainich, N. Barger, B. ten Brink, & M. Cantele… (eds). IPBES secretariat: Bonn, Germany.

Jiang, C., Zhang, H., Wang, X., Yu, F., & Labzovskii, L. (2019). Challenging the land degradation in China's Loess Plateau: Benefits, limitations, sustainability, and adaptive strategies of soil and water conservation. *Ecological Engineering*, 127, 135 – 150. 10.1016/j.ecoleng.2018.11.018

Katra, I. (2020). Soil erosion by wind and dust emission in Semi-Arid soils due to agricultural activities. *Agronomy (Basel)*, 10(1), 89. https://doi.org/10.3390/agronomy10010089

Kelly, F. J., & Fussell, J. C. (2015). Air pollution and public health: emerging hazards and improved understanding of risk. *Environmental Geochemistry and Health*, 37(4), 631 – 649. 10.1007/s10653-015-9720-1

Knežević, J., Jović, B., Marić Tanasković, L., Mitrović-Josipović, M., Ljubičić, A., Stamenković, D., Dimić, B. (2021). *Annual report on the state of air quality in the Republic of Serbia in 2020.* Serbian Ministry of Environmental Protection.

Kumar Patra, A., Gautam, S., & Kumar, P. (2016). Emissions and human health impact of particulate matter from surface mining operation - A review. *Environmental Technology and Innovation*, 5, 233 – 249. 10.1016/j.eti.2016.04.002

Laforest, L., Luce, D., Goldberg, P., Bégin, D., Gérin, M., Demers, P.A., Brugère, J., Leclerc, A. (2000). Laryngeal and hypopharyngeal cancers and occupational exposure to formaldehyde and various dusts: a case-control study in France. *Occupational and Environmental Medicine*, 57(11), 767 – 773. 10.1136/oem.57.11.767

Lan, S., Wu, L., Zhang, D., & Hu, C. (2012). Successional stages of biological soil crusts and their microstructure variability in Shapotou region (China). *Environmental Earth Sciences*, 65(1), 77 – 88. https://doi.org/10.1007/s12665-011-1066-0

Laney, A.S., & Weissman D.N. (2014). Respiratory Diseases Caused by Coal Mine Dust. *Journal of Occupational and Environmental Medicine*, 56(0 10), S18 - S22. 10.1097/JOM.0000000000000260.

Li, S., & Liber, K. (2018). Influence of different revegetation choices on plant community and soil development nine years after initial planting on a reclaimed coal gob pile in the Shanxi mining area, China. *Science of the Total Environment*, 618, 1314 – 1323. 10.1016/j.scitotenv.2017.09.252

Li, Z., Chen, C., Gao, Y., Wang, B., Wang, D., Du, Y., . . . Cai, D. (2021). Synergistic effect of cyanobacteria and nano-sand-stabilizer on biocrust formation and sand fixation. *Journal of Environmental Chemical Engineering*, 9(1), 104887. https://doi.org/10.1016/j.jece.2020.104887

Ličina, V., Nešić, Lj., Belić, M., Hadžić, V., Sekulić, P., Vasin, J., & Ninkov, J. (2011). The soils of Serbia and their degradation. *Ratarstvo i Povrtarstvo*, 48(2), 285–290.

Loomis, D., Grosse, Y., Lauby-Secretan, B., El Ghissassi, F., Bouvard, V., Benbrahim-Tallaa, L., … Straif, K. (2013). The carcinogenicity of outdoor air pollution. *The Lancet Oncology*, 14(13), 1262 – 1263. 10.1016/s1470-2045(13)70487-x

Malam Issa, O., Le Bissonnais, Y., Défarge, C., & Trichet, J. (2001). Role of a cyanobacterial cover on structural stability of sandy soils in the Sahelian part of western Niger. *Geoderma*, 101(3–4), 15 – 30. https://doi.org/10.1016/s0016-7061(00)00093-8

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and Health Impacts of Air Pollution: A review. *Frontiers in Public Health*, 8. 10.3389/fpubh.2020.00014

Matić Savićević B. & Stojanović M. (2019). *Zagađenost urbanog vazduha na teritoriji Republike Srbije merena u mreži institucija javnog zdravlja u 2018. godini* [Urban air pollution in the territory of the Republic of Serbia measured in the network of public health institutions in 2018]. Beograd: Institut za javno zdravlje Srbije 'Dr Milan Jovanović Batut'.

Matić Savićević, B. (2020). *Zagađenost urbanog vazduha na teritoriji Republike Srbije merena u mreži institucija javnog zdravlja u 2020. godini* [Urban air pollution in the territory of the Republic of Serbia measured in the network of public health institutions in 2020]. Beograd: Institut za javno zdravlje Srbije 'Dr Milan Jovanović Batut'.

Milanović, M., Tomić, M., Perović, V., Radovanović, M., Mukherjee, S., Jakšić, D., Petrović, M., & Radovanović, A. (2017). Land degradation analysis of mine-impacted zone of Kolubara in Serbia. *Environmental Earth Sciences*, 76(16). 10.1007/s12665-017-6896-y

Minowa, M., Stone, B.J., & Blot, W.J. (1988) Geographic pattern of lung cancer in Japan and its environemtal correlation. *Japanese Journal of Cancer Research*, 79, 1017 - 1023.

Mugnai, G., Rossi, F., Felde, V. J.M.N.L., Colesie, C., Büdel, B., Peth, S., . . . De Philippis, R. (2017). Development of the polysaccharidic matrix in biocrusts induced by a cyanobacterium inoculated in sand microcosms. *Biology and Fertility of Soils*, 54(1), 27 – 40. https://doi.org/10.1007/s00374-017-1234-9

Muratović, E. (2015). Životna sredina, zdravstveno stanje stanovništva i teritorijalni razvoj opštine Lazarevac [Environment, population health and teritorial development of the Lazarevac muncipality]. In: *Zbornik radova mladih istraživača, Planska i normativna zaštita prostora i životne sredine.* Palić-Subotica.

Nišić, D. D., Knežević, D.N. & Pantelić, U.R., (2015). Klasifikacija deponije pepela Termoelektrane 'Nikola Tesla B' po stepenu rizičnosti. *Tehnika*, 70(5), 769 - 776. 10.5937/tehnika1505769N

Nkosi, V., Wichmann, J., & Voyi, K. (2016). Comorbidity of respiratory and cardiovascular diseases among the elderly residing close to mine dumps in South Africa: A cross-sectional study. *South African Medical Journal*, 106(3), 290 - 297. https://doi.org/10.7196/samj.2016.v106i3.10243

Orellano, P., Reynoso, J., Quaranta ,N., Bardach, A., & Ciapponi, A. (2020). Short-term exposure to particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), and ozone (O3) and all-cause and cause-specific mortality: Systematic review and meta-analysis. *Environment International*, 142, 105876. 10.1016/j.envint.2020.105876

Padró, J. C., Cardozo, J., Montero, P., Ruiz-Carulla, R., Alcañiz, J. M., Serra, D., & Carabassa, V. (2022). Drone-Based identification of erosive processes in Open-Pit mining restored areas. *Land*, 11(2), 212. https://doi.org/10.3390/land11020212

Palanački Malešević, T., Dulić, T., Obreht, I., Trivunović, Z., Marković, R., Kostić, B., . . . Svirčev, Z. (2021). Cyanobacterial Potential for Restoration of Loess Surfaces through Artificially Induced Biocrusts. *Applied Sciences (Basel)*, 11(1), 66. https://doi.org/10.3390/app11010066

Palanački Malešević, T., Meriluoto, J., Mihalj, I., Važić, T., Marković, R., Jurca, T., Codd, G.A., Svirčev, Z. (2024). Restoration of damaged drylands through acceleration of biocrust development. *CATENA*, 244, 108265. https://doi.org/10.1016/j.catena.2024.108265

Park, C. H., Li, X., Jia, R.L., & Hur, J. S. (2014). Effects of superabsorbent polymer on cyanobacterial biological soil crust formation in laboratory. *Arid Land Research and Management*, 29(1), 55 – 71. https://doi.org/10.1080/15324982.2014.928835

Pavlović, P., & Mitrović, M, (2013). Thermal power plants in Serbia—the impact of ash on soil and plants. In: Anđelković, M. (ed) *Energy and the environment, scientific meetings, Book 4.* Serbian Academy of Sciences and Arts (SANU), Belgrade, pp 429 – 433 (in Serbian).

Pavlović, P., Kostić, N., Karadžić, B., & Mitrović, M. (2017). The soils of Serbia. In *World soils book series*. 10.1007/978-94-017-8660-7

Perović, V., Kadović, R., Djurdjević, V., Pavlović, D., Pavlović, M., Čakmak, D., … Pavlović, P. (2021). Major drivers of land degradation risk in Western Serbia: Current trends and future scenarios. *Ecological Indicators*, 123, 107377. 10.1016/j.ecolind.2021.107377

Popović, V., Živanović Miljković, J., Subić, J., Jean-Vasile, A., Nedelcu, A., & Nicolăescu, E. (2015). Sustainable land management in mining areas in Serbia and Romania. *Sustainability (Basel)*, 7(9), 11857 – 11877. https://doi.org/10.3390/su70911857

Ranđelović, D. (2017). Reclamation methods and their outcomes in Serbian mining basins. *2nd International and 14th National Congress of Soil Science Society of Serbia-Solutions and Projections for Sustainable Soil Managemen*t.25-28th September 2017, (pp. 40-48). Novi Sad, Serbia.

Rao, B., Liu, Y., Wang, W., Hu, C., Li, D., & Lan, S. (2009). Influence of dew on biomass and photosystem II activity of cyanobacterial crusts in the Hopq Desert, northwest China. *Soil Biology & Biochemistry*, 41(12), 2387 – 2393. https://doi.org/10.1016/j.soilbio.2009.06.005

Rezasoltani, S., Champagne, P., & Mann, V. (2023). Improvement in mine tailings biophysicochemical properties by means of cyanobacterial inoculation. *Waste and Biomass Valorization*, 15, 1689-1699. https://doi.org/10.1007/s12649-023-02195-4

Ross, M. H., & Murray, J. (2004). Occupational respiratory disease in mining. *Occupational Medicine*, 54(5), 304 – 310. https://doi.org/10.1093/occmed/kqh073

Rossi, F. (2020). Beneficial biofilms for land rehabilitation and fertilization. *FEMS Microbiology Letters*, 367(21). https://doi.org/10.1093/femsle/fnaa184

Rossi, F., & De Philippis, R. (2015). Role of cyanobacterial exopolysaccharides in phototrophic biofilms and in complex microbial mats. *Life*, 5(2), 1218 – 1238. https://doi.org/10.3390/life5021218

Rossi, F., Li, H., Liu, Y., & De Philippis, R. (2017). Cyanobacterial inoculation (cyanobacterisation): Perspectives for the development of a standardized multifunctional technology for soil fertilization and desertification reversal. *Earth-Science Reviews*, 171, 28 –43. https://doi.org/10.1016/j.earscirev.2017.05.006

Sacks, J. D., Stanek, L.W., Luben, T.J., Johns, D.O., Buckley, B.J., Brown, J.S., & Ross, M. (2011). Particulate Matter–Induced health effects: Who is susceptible? *Environmental Health Perspectives*, 119(4), 446 – 454. 10.1289/ehp.1002255

Samuel, P.O., Edo, G.I., Emakpor, O.L., Oloni, G.O., Ezekiel, G.O., Essaghah, A.E.A., Endurance Agoh, E., Agbo, J.J. (2023). Lifestyle modifcations for preventing and managing cardiovascular diseases. *Sport Sciences for Health*, 20, 23-36. https://doi.org/10.1007/s11332-023-01118-z

Sankaran, G., Tan, S.T., Yap, R., Chua, M.L., Ng, L.C., & George, S. (2023). Characterization of size-differentiated airborne particulate matter collected from indoor environments of childcare facilities. *Chemosphere*, 340, 139670. 10.1016/j.chemosphere.2023.139670

Serbian Environmental Protection Agency - SEPA. (2018). Report on soil conditions in the Republic of Serbia. Ministry of Environmental Protection, Belgrade.

Serbula, S. M., Antonijević, M. M., Milošević, N., Milić, S., & Ilic, A. A. (2010). Concentrations of particulate matter and arsenic in Bor (Serbia). *Journal of Hazardous Materials (Print)*, 181(1 – 3), 43 – 51. https://doi.org/10.1016/j.jhazmat.2010.04.065

Serbula, S. M., Milosavljević, J., Radojević, A. A., Kalinović, J. V., & Kalinović, T. S. (2017). Extreme air pollution with contaminants originating from the mining–metallurgical processes. *Science of the Total Environment*, 586, 1066 – 1075. https://doi.org/10.1016/j.scitotenv.2017.02.091

Shrivastava, S., Sahu, P., Singh, A., & Shrivastava L. (2015) Fly ash disposal and diseases in nearby villages (A Survey). *International Journal of Current Microbiology and Applied Sciences*, 4(2), 939 - 946.

Sun, W., Shao, Q., & Liu, J. (2013). Soil erosion and its response to the changes of precipitation and vegetation cover on the Loess Plateau. *Journal of Geographical Sciences*, 23(6), 1091 – 1106. 10.1007/s11442-013-1065-z

Svirčev, Z., Dulić, T., Obreht, I., Codd, G. A., Lehmkuhl, F., Marković, S. B., . . . Meriluoto, J. (2019). Cyanobacteria and loess—an underestimated interaction. *Plant and Soil*, 439(1 – 2), 293 – 308. https://doi.org/10.1007/s11104-019-04048-3

Svirčev, Z., Marković, S. B., Stevens, T., Codd, G. A., Smalley, I., Simeunović, J., . . . Hambach, U. (2013). Importance of biological loess crusts for loess formation in semi-arid environments. *Quaternary International*, 296, 206 – 215. https://doi.org/10.1016/j.quaint.2012.10.048

Talukder, B., Ganguli, N., Matthew, R. A., vanLoon, G. W., Hipel, K. W., & Orbinski, J. (2021). Climate change–triggered land degradation and planetary health: A review. *Land Degradation & Development*, 32(16), 4509 – 4522. 10.1002/ldr.4056

Tian, S., Liang, T., & Li, K. (2019). Fine road dust contamination in a mining area presents a likely air pollution hotspot and threat to human health. *Environment International*, 128, 201 – 209. 10.1016/j.envint.2019.04.050

Tomášková, H., Jirák, Z., Šplíchalová, A., & Urban, P. (2012). Cancer incidence in Czech black coal miners in association with coalworkers' pneumoconiosis. International *Journal of Occupational Medicine and Environmental Health*, 25(2). 10.2478/s13382-012-0015-9

U.S. Environmental Protection Agency - USEPA. (2016). Particulate matter (PM) basics. Available at: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics (23.09.2024.)

Une, H., Esaki, H., Osajima, K., Ikui, H., Kodama, K., & Hatada, K. (1995). A Prospective Study on Mortality among Japanese Coal Miners. *Industrial Health*, 33(2), 67 – 76. 10.2486/indhealth.33.67

United Nations (UN). (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. Resolution Adopted by the General Assembly on 25 September 2015. https://sustainabledevelopment.un.org/content/documents/21252030 %20Agenda%20for%20Sustainable%20Development%20web.pdf (13.09.2024).

United Nations Convention to Combat Desertification (UNCCD) (1994). *United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification Particularly in Africa*. United Nations: Paris, France.

United Nations Development Programme - UNDP. (2022). *Soil Degradation and Climate Change in Serbia*. ISBN 978-86-7728-356-8.

Valavanidis, A., Fiotakis, K., & Vlachogianni, T. (2008). Airborne particulate matter and human health: toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic mechanisms. *Journal of Environmental Science and Health, Part C*, 26(4), 339 – 362. 10.1080/10590500802494538

Vasić, A., Vasiljević, Z., Mickovski-Katalina, N., Mandić-Rajčević, S., & Soldatović, I. (2022). Temporal Trends in Acute Coronary Syndrome Mortality in Serbia in 2005 – 2019: An Age–Period–Cohort Analysis Using Data from the Serbian Acute Coronary Syndrome Registry (RAACS). *International Journal of Environmental Research and Public Health*, 19, 14457. 10.3390/ijerph192114457

Veste, M. (2005). Importance of biological soil crusts for rehabilitation of degraded arid and semi-arid ecosystems. *Science of Soil and Water Conservation*, 3(4), 42 - 47.

Wang, W., Liu, Y., Li, D., Hu, C., & Rao, B. (2009). Feasibility of cyanobacterial inoculation for biological soil crusts formation in desert area. *Soil Biology & Biochemistry*, 41(5), 926 - 929. https://doi.org/10.1016/j.soilbio.2008.07.001

Waste Management Program of the Republic of Serbia for the period of 2022 - 2031. Official Gazette of the Republic of Serbia, No 12/2022. https://www.ekologija.gov.rs/

Whiteside, M., & Herndon, J. M. (2018). Coal fly ash aerosol: risk factor for lung cancer. *Journal of Advances in Medicine and Medical Research*, 25(4), 1 – 10. 10.9734/jammr/2018/39758

Williams, A. J., Buck, B. J., & Beyene, M. (2012). Biological Soil Crusts in the Mojave Desert, USA: Micromorphology and Pedogenesis. *Soil Science Society of America Journal*, 76(5), 1685 – 1695. https://doi.org/10.2136/sssaj2012.0021

Williams, W., Chilton, A., Schneemilch, M., Williams, S., Neilan, B., & Driscoll, C. (2019). Microbial biobanking – cyanobacteria-rich topsoil facilitates mine rehabilitation. *Biogeosciences*, 16(10), 2189 – 2204. https://doi.org/10.5194/bg-16-2189-2019

Woodruff, R. C., Tong, X., Khan, S. S., Shah, N. S., Jackson, S. L., Loustalot, F., & Vaughan, A. S. (2024). Trends in cardiovascular disease mortality rates and excess deaths, 2010–2022. *American Journal of Preventive Medicine*, 66(4), 582–589. https://doi.org/10.1016/j.amepre.2023.11.009

World Bank, 2016. *The cost of air pollution: strengthening the economic case for action*. World Bank Group. Washington, D.C.

World Health Organization - WHO. (2019). Health Impact of ambient air pollution in Serbia. A call to action. World Health Organization. Regional Office for Europe.

World Health Organization - WHO. (2021). WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva.

Xing, Y. F., Xu, Y. H., Shi, M. H., & Lian, Y. X. (2016). The impact of PM2.5 on the human respiratory system. *Journal of Thoracic Disease*, 8(1), E69 – E74. 10.3978/j.issn.2072-1439.2016.01.19

Yang, Y., Ruan, Z., Wang, X., Yang, Y., Mason, T.G., Lin, H., & Tian, L. (2019). Short-term and long-term exposures to fine particulate matter constituents and health: A systematic review and meta-analysis. *Environmental Pollution*, 247, 874 – 882. 10.1016/j.envpol.2018.12.060

Zanetta Colombo, N. C., Fleming, Z. L., Gayó, E. M., Manzano, C., Panagi, M., Valdés, J., & Siegmund, A. (2022). Impact of mining on the metal content of dust in indigenous villages of northern Chile. *Environment International*, 169, 107490. https://doi.org/10.1016/j.envint.2022.107490

Zhu, S. C., Zheng, H. X., Liu, W. S., Liu, C., Guo, M. N., Huot, H., . . . Tang, Y. T. (2022). Plant-Soil Feedbacks for the restoration of degraded mine lands: a review. *Frontiers in Microbiology*, 12. https://doi.org/10.3389/fmicb.2021.751794