

Supplementary resources

**on the Impact of Waste Disposal
on Air Pollution and Human Health
in Serbia**

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and Human Health in Serbia**

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Supplementary resources on the Impact of Waste Disposal
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These Supplementary resources offer wider perspective for reader’s deeper understanding of the interlinkages between unsustainable waste management practices and resulting air pollution with a severe impact to human health.

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1.1.

An Overview of Pollutants Released from Landfills into Various Environmental Media during Fires

PM particles (PM_{10} and $PM_{2.5}$)

A key indicator of air quality is the concentration of suspended particles (PM), since these particles are the most common air pollutants. Total suspended particles (TSP) are particles or aerosols that comprise a complex mixture of organic and inorganic substances (hydrocarbons, metal oxides, carcinogens, etc.), with a diameter less than 100 μm . Suspended particles of different sizes (PM_{10} , $PM_{2.5}$, PM_1) are released during open incineration (Estrellan CR, lino F 2010; Lemieux PM et al. 2004; US EPA, 2021b). Particle size is directly related to their potential to cause health problems. Particles smaller than 10 micrometers in diameter are of greatest concern, as they can reach deep into the lungs, and some even into the bloodstream (US EPA, 2021b).

Carrying out an effective fire impact assessment requires a factor less specific to particular burning materials, one which is emitted during all fires. PM_{10} is emitted during the combustion of any type of material, which is why all factors critical for assessing landfill fires should take PM_{10} concentrations into account.

Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs), partially oxidized PAHs (oxy-PAHs) and soot are the main pollutants released by outdoor combustion. PAHs and oxy-PAHs are carcinogens and they also impact the endocrine system (Estrellan CR, lino F 2010).

PAHs are a large group of organic compounds containing two or more fused aromatic (benzene) rings.

Benzo(a)pyrene is considered to be a major representative of this group of compounds, with proven cytotoxic, genotoxic, carcinogenic, teratogenic and immunotoxic effects (Zasadowski A, Wysocki A 2002; Tang D et al. 2008). According to the World Health Organization (WHO), the most toxic of this group of compounds are: benzo(a)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, fluoranthene, indeno (1,2,3-c,d) pyrene and benzo(g,h,i)perylene (UNEP, ILO, WHO; International Program on Chemical Safety, EHC 202, Selected Non-heterocyclic Polycyclic Aromatic Hydrocarbons. Geneva, 1989) (<https://incchem.org/documents/ehc/ehc/ehc202.htm>).

B(a)P is widely distributed through by-products of incomplete combustion (including municipal and industrial waste incineration) and carbon fossil fuel pyrolysis (organic matter). After release into the environment, B(a)P can be detected in ambient air, drinking water, waste water and food treated by burning charcoal. The degree of emission and molecular structure are directly related to the type of material being burnt, where B(a)P is primarily emitted into the air, binding mainly to $PM_{2.5}$ particles (Jovičić SN et al. 2013; Gianelle V et al. 2013). EU Directive 2004/107/EC proposes B(a)P as a marker for carcinogenic risk originating from exposure to PAHs in ambient air, setting a target value of 1.0 ng/m^3 , as a mean annual value (EU Directive 2004/107/EC).

According to national regulations, in Serbia B(a)P is monitored at measuring points within the state network of measuring points, as well as local networks for air quality monitoring. According to the

findings of the Report by the Institute of Public Health of Serbia entitled “Urban Air Pollution in the Republic of Serbia Measured within the Network of Public Health Institutions in 2020” (PHIS, 2021), in 2020, B(a)P was monitored in 28 urban units/settlements, of which 14 measuring points are on the territory of the city of Belgrade (the jurisdiction of the City Institute for Public Health). The annual mean concentration in 2020 was 2.21 ng/m³; at 24 of the 28 sites, the concentration was above the recommended 1.0 ng/m³ (87%), indicating the need to treat exposure to this group of compounds from the perspective of protecting public health among exposed vulnerable groups. It should be emphasized that the concentration of benzo(a)pyrene in PM₁₀ shows a pronounced seasonal dependence, with maximum values during the winter months (from December to March) at all measuring points.

As one of the conclusions in the recently published paper “Presence of B(a)P in PM₁₀ in Urban Ambient Air in Serbia - Neglected Risk to Public Health among the Exposed Population (Matić B et al. 2022) the presence of B(a)P in PM₁₀ registered by the automatic measuring station JKP Vinča is indicated to originate from the landfill in Vinča and its constant self-ignition (the measuring station is located 3 km from the Vinča landfill), as well as from home fireplaces in this rural area. The paper also concludes that the number of measuring points where PM₁₀ concentrations and B(a)P content are measured in Serbia is not insignificant, which provides a good basis for further research and the adoption of methodology for assessing the impact of this fraction of PAHs on the health of the exposed population within the Network of Public Health Institutions.

Heavy metals

Heavy metals are one of the most important pollutants found in landfills. However, outdoor combustion results in limited discharge of heavy metals from landfills due to the high boiling points of almost all relevant metals and metal oxides, with the exception of mercury and methylated compounds of arsenic, tin or bismuth. (Feldmann J, Hirner AV 1995; Dopp E et al. 2011). Metal compounds can be released through particles during open combustion and distributed in the environment. However, the main way heavy metal compounds are released is through leachate, which can lead to ground and surface water contamination (Baun DL, Christensen TH 2004).

PCDD/PCDFs and other unintentional POPs

The main source of PCDD/PCDFs release in developing countries and countries in transition today is open waste incineration (UNEP, 2017d). With the formation of PCDD/PCDFs, other unintentional POPs (uPOPs) such as polychlorinated biphenyls (PCBs), polychlorinated naphthalenes (PCNs), hexachlorobenzene (HCB) or pentachlorobenzene (PeCB) are formed and released together (Weber R et al. 2001). The TEQ for released PCDD/PCDFs is approximately two orders of magnitude higher than that of PCBs or PCNs (Sakurai T et al. 2003).

The main trigger for the formation of PCDD/PCDFs in open waste incineration is PVC. The combustion of PVC increases emissions by several orders of magnitude (Ikeguchi T, Tanaka M 1999). Most PVC is disposed of in landfills and dumps which are a source of chlorine for increased dioxin/uPOP emissions. Also, dioxin precursors in waste such as wood or leather treated with PCP, triclosan, or PCBs cause a significant release of PCDD/PCDFs during open waste incineration (Ikeguchi T, Tanaka M 1999; Buser HR et al. 1978; Launhard TH et al. 1998; Weber R 2007; Doudrick KD et al. 2010).

Prolonged release of PCDD/PCDFs from open incineration in landfills can contaminate surrounding soil. The land around some landfills in Africa contained several 100 ng/kg with a maximum contamination of 3340 ng/kg near the landfill in Sierra Leone (Martinez-Guijarro K et al. 2019). On the other hand, soil samples near landfills in South Africa (Martinez-Guijarro K et al. 2019) and Poland (Gworek B et al. 2013) showed background PCDD/F levels below 2 ng TEQ/kg, indicating the absence or a low PCDD/F release at these landfills.

The level of PCDD/PCDFs in soil that can lead to concentrations in eggs rising above EU maximum levels is below 5 ng TEQ/kg (Weber R et al. 2018b; 2019). Therefore, PCDD/PCDFs soil contamination around landfills where open incineration processes occur is sufficient to contaminate eggs (Petrlik J et al. 2022). Moreover, poultry and cattle may be fed in landfills and collect ash. Sampled eggs around landfills exceeded the EU prescribed limit value in Kenya (7.6 times), Pakistan (1.5 times) and Senegal (11 times) (DiGangi J, Petrlik J 2005).

A well-documented case of large-scale contamination of food-producing animals, as well as milk and cheese, including mozzarella, due to frequent open waste incineration in landfills leading to environmental contamination with PCDDs/PCDFs, is the Campania region of Italy (Neugebauer F et al. 2009; Esposito M et al. 2010; Mazza A et al. 2018). This shows that long-term outdoor waste burning can contaminate large areas including land, food and people (IZSdM, 2021).

PCDD/PCDFs deposited in sanitary landfills are usually not released as air emissions due to their low vapor pressure (Gotz R et al. 2013). However, open burning can facilitate the atmospheric release of PCDD/PCDFs adsorbed on waste, as shown in the incineration of waste wood (Prange JA et al. 2003).

Open burning (e.g. in gardens, yards or along streets) can lead to local PCDD/F contamination, especially when materials with the potential to form PCDD/PCDFs are used. These are, for example:

- Incineration of treated waste wood (treated with PCP or treated with copper salts).
- Incineration of PVC waste with other household waste (e.g. agricultural foil/ irrigation pipes, construction waste and demolition waste).
- Open incineration of e-waste or end-of-life vehicle waste.
- Co-incineration of pesticide containers.

In the assessment of chicken eggs around landfills and dumps 80% of eggs had PCDD/PCDFs and PCBs levels above EU regulatory limits (Petrlik J et al. 2022). With such open burning, land in gardens or farms can become contaminated with PCDD/PCDFs. The level of contamination has been documented in the Netherlands where more than 50% of domestic eggs from 62 hen breeders were above the maximum allowed EU limit values for TEQ PCDD/PCDFs-PCBs (Hoogenboom LA et al. 2016) indicating widespread soil contamination in gardens and farms where chickens were raised. In addition to open burning, the spread of contaminated ash originating from household heating (or other sources) or the earlier use of pesticides containing PCDD/PCDFs (PCP, 2,4-D or 2,4,5-T) may be a source of such contamination even if these pesticides were used several decades earlier, as PCDD/PCDFs persist in soil (Weber R et al. 2018b; Petrlik J et al. 2022).

Polybrominated and brominated/chlorinated dibenzo-p-dioxins and dibenzofurans (PBDD/PBDF and PXDD/PXSDF)

On average, open waste incineration in landfills in Mexico emitted large amounts - 823 ng PCDD/F TEQ/kg of carbon burned (Gullett BK et al. 2010). Emissions of polybrominated compounds such as PBDD/F were close to the amounts for similar chlorinated compounds (PCDD/F), averaging 470 ng TEQ/kg of carbon burned. PBDD/Fs can be formed as combustion reaction products of flame retardants - polybrominated diphenyl ethers (PBDE) or by thermal desorption from the material itself (Gullett BK et al. 2010).

In addition to PCDD/F contamination, e-waste or auto waste incineration sites have high concentrations of brominated and brominated-chlorinated PXDD/F (Yu X et al. 2008; Fujimori T et al. 2016; Tue NM et al. 2016).

Eggs sampled at the Agbogbloshie e-waste site in Accra (Ghana, Africa) had 1156 pg TEQ/g of fat (sum of PCDD/PCDFs, PBDD/PBDF, and dl-PCBs), and therefore the highest dioxin contamination ever measured (Petrlik J et al. 2019a). An adult eating a single egg per day from free-range hens in the Agbogbloshie area would consume 405 times the tolerable weekly intake (TWI) of 2 pg TEQ/kg of fat of PCDD/F and dl-PCBs. Eggs sampled in Thailand at locations where e-waste was recycled with open incineration had PCDD/F levels of 84 pg TEQ/g of fat and 20 pg TEQ/g of fat of brominated PBDD/Fs (Petrlik J et al. 2017). PCDD/F levels in these eggs were 33 times above the EU limit of 2.5 pg TEQ/g of fat. In the third case in China, eggs sampled near the incinerator had a PBDD/PBDF-TEQ of 29 pg/g of fat, which is more than PCDD/F-TEQ (12.2 pg TEQ/g of fat) and PCBs TEQ (4 pg TEQ/g of fat) (Weber R et al. 2015). There are cases that show that outdoor combustion of plastics treated with brominated flame retardants from e.g. electrical and electronic waste can lead to relevant contamination of eggs with PBDD/PBDF. However, even in these cases, PCDD/PCDFs contamination was even higher because these compounds are also formed at such sites (Yu X et al. 2008), and lower molecular weight PCDD/PCDFs are likely to have a higher transfer factor from soil to eggs compared to brominated aromatic compounds of higher molecular weight (Hoogenboom LA et al. 2006; Oloruntoba K et al. 2021).

Polychlorinated biphenyls (PCBs)

A large portion of industrial PCBs in Germany have been disposed of in landfills (Weber R et al. 2018a). PCBs are poorly volatile compounds and can migrate and contaminate the environment. Concentrations of dioxin-like PCBs of 3 to 6 ng TEQ/kg were measured in the soil around these landfills, which is too high for safe egg production, and pooled egg samples from two chicken breeders were above the EU limits for food near the landfill (Weber R et al. 2015). Also eggs around landfills in the study of IPEN contained high levels of PCBs.

Additionally, sediments and fish downstream from landfills are affected by leachate and can have very high PCBs concentrations where concentrations in fish are above EU regulatory limit values (Haarstad K, Borch H 2008; Zennegg M et al. 2010; Weber R et al. 2018b).

Pesticides

In countries which have failed to establish an adequate waste management system, POPs pesticides and other pesticides are partially disposed of in illegal landfills, as well as in unsanitary landfills/

dumps for industrial and municipal waste. In addition, empty pesticide containers are often disposed of in unsanitary landfills and illegal dumps (Huici O et al. 2017).

Pesticides are thus released into the environment and pollute it (Dvorska A et al. 2012; Toichuev RM et al. 2017a). Additionally, pesticides incinerated in the open increase PCDD/PCDFs emissions (UNEP, 2013).

Sediments and fish downstream from landfills are affected by leachate. Leachate can lead to very high levels of POPs pesticides in fish (Haarstad K, Borch H 2008; Wycisk P et al. 2013) or contaminate or even lead to the death of livestock (Toichuev RM et al. 2017a).

Polybrominated diphenyl ethers (PBDE) and other brominated flame retardants (BFR) as well as phosphorus-containing flame retardants (PFR)

Monitoring of PBDE emissions from open waste incineration at two illegal landfills in Mexico averaged 724 mg/kg of burned carbon (Gullett BK et al. 2010). Emissions of PBDE and other halogen flame retardants from landfills in Canada have also been documented via seagull sampling (Sorais M et al. 2020).

Significant concentrations of PBDE were present in the soil near landfills and illegal dumping grounds in different regions of Canada, indicating atmospheric release and deposition of PBDE from landfills (Danon-Schaffer MN et al. 2008; Danon-Schaffer MN 2010). Further, PBDE and other BFRs and PFRs are released in leachate affecting groundwater, surface water, sediments, or by treatment of wastewater and sludge (Oliaei F et al. 2002; Osako M et al. 2004; Weber R et al. 2011, Odusanya DO et al. 2009). By monitoring fifty-six samples of free-range chicken eggs and cow's milk around two landfills where open waste incineration occurs, as well as in places where landfills were considered not to affect contamination, a high level of PBDE was found in eggs, from 262.3 to 313.4 (ng/g lw of total Σ PBDE) which is at least two orders of magnitude higher compared to PBDE concentrations in supermarket eggs in industrialized countries and Nigeria (Oloruntoba K et al. 2019). Also, the concentrations of PBDE in milk from cows in the vicinity of the two illegal dumping grounds were 49.1 and 81.5 ng/g lw. These concentrations are significantly higher than the concentrations in other studies, such as the mean concentrations measured in the USA (12 ng/g lw), the United Kingdom (0.25 ng/g lw), Spain (0.63 ng/g lw), Ireland (0.40 ng/g lw); and Switzerland (0.20 ng/g lw) (Oloruntoba K et al. 2019). A comparison of PBDE concentrations in soil around two landfills and PBDE concentrations in hen eggs shows that the presence of PBDE in soil is sufficient to explain concentrations of these compounds in hen eggs with a reasonable transfer rate for PBDE of 0.28 on average (Oloruntoba K et al. 2021).

Also, eggs near other locations where open incineration took place in Africa contained very high concentrations of PBDE, especially when electrical and electronic waste was burned at those sites (Petrlik J et al. 2019a). Chicken eggs around a plastic incineration site in Indonesia were contaminated with PBDE and other POPs compounds (Petrlik J et al. 2019b).

Contamination of groundwater with flame retardants, especially phosphorus-based PFR flame retardants soluble in landfill/dumping ground water, can also contaminate nearby drinking water wells (Buszka PM et al. 2009). Additionally, sediments and fish downstream of landfills may be affected by leachate and fish may have very high concentrations of PBDE (Haarstad, Borch H 2008).

Chlorinated paraffins

Since the use of chlorinated paraffins (CP) began in the 1930s, large amounts of waste containing short-chain chlorinated paraffins (SCCP) and other CPs have already been disposed of in landfills and illegal dumps (ESWI, 2011; UNEP, 2019b; Guida Y et al. 2020). Short-chain chlorinated paraffins (SCCP) in the soil around landfills on the Tibetan Plateau indicate that landfills represent local sources of CP.

SCCP and other CPs are detected in leachate from landfills, with concentrations up to 614 mg/l (Nordic Council of Ministers, 2006; Guida Y et al. 2020). Elevated SCCP concentrations have also been detected in the land around landfills in China (Li J et al. 2021)

Chicken eggs near a plastic incineration site in Indonesia have been contaminated with SCCP and other POPs compounds (Petrlik J et al. 2019b). Eggs in the vicinity of open incineration sites in Africa also contained high concentrations of SCCP and other POPs compounds when the waste contained electrical and electronic waste (Petrlik J et al. 2019a).

Per- and polyfluorinated alkyl substances (PFAS)

Because PFAS do not degrade in landfills or groundwater and many of them being water-soluble, the accumulated amount of PFAS deposited in landfills for centuries, and probably longer, poses a major threat to the environment. PFAS are essentially filtered from all sanitary and non-sanitary landfills in industrialized and developing countries (Busch J et al. 2010; Gallen C et al. 2017; Lang JR et al. 2017; Kim JW et al. 2013).

The population around landfills is at risk due to exposure, especially if they use groundwater as drinking water or as irrigation water. Further, if drinking water wells or aquifers used to produce drinking water for the general population are near illegal landfills, then the general population may be exposed to PFAS from leachate from those landfills.

Open incineration in landfills and illegal dumps could increase the release of PFAS from landfills via two mechanisms: 1) thermal evaporation of PFAS and 2) degradation of fluoropolymer side chains and further into groundwater. These compounds are found in consumer products, as they are used for surface treatment of textiles, furniture and paper, accounting for 90% of total PFOS use in the EU in 2000 (Fricke M, Lahl U 2005).

Bisphenol A (BPA) and its derivatives

Bisphenol A (BPA) is mostly used as a composite monomer of polycarbonate and epoxy resins, as well as to a lesser extent as a dye developer in thermal paper (European Chemicals Bureau, 2009). Polycarbonates are widely used for hard plastic products such as CDs, home appliances, medical devices and utensils. BPA is also used as a plastic additive as an antioxidant for polyvinyl chloride (PVC) (Kawanaka Y et al. 2000; European Chemicals Bureau, 2009; Wang H et al. 2021). Other different bisphenols (BPS, BPB, BPF or BPZ) are used as alternatives, and BPS is the main substitute for BPA. BPA is a potent endocrine disruptor (EFSA, 2021). BPA is released in large quantities during open incineration of polycarbonate plastics (Estrellan CR, Iino F 2010). Furthermore, BPA is the main pollutant in landfill leachate and can have a major impact on groundwater and surface water pollution (solubility 100 to 300 mg/L). BPA is released from landfills in leachate in high concentrations even from old landfills closed 30 to 60 years ago (Propp VR et al. 2021). The conclusion of a recent

study in Japan is that former and existing landfills are the main sources of BPA inflow into rivers from wastewater treatment plants (158 ng/L) which received leachate from landfills, and that the concentration in river water was up to 70 ng/L. (Gomi M et al. 2022). Given the long-term release, which originates from the degradation of polycarbonates and BPA resin (Gomi M et al. 2022), the thousands of tons of polycarbonates and BPA resin being dumped in Serbia are huge reserves for the long-term release of BPA, probably for centuries.

A recent re-evaluation of the tolerable daily intake (TDI) for BPA by the European Food Safety Authority found that the TDI was 0.04 ng/kg body weight/day (EFSA, 2021). The EFSA report states that the values of the estimated dietary exposure to BPA (mean and 95th percentile) are as much as two to four orders of magnitude higher than the TDI, including infants and children. A reevaluation will result in changes to the limit values for BPA in drinking water and groundwater, during which an assessment of exposure to BPA of the population supplied with water from groundwater or surface water mixed with leachate from landfills or illegal dumps will be taken into account. These facts are included in the US EPA action plan for BPA (US EPA, 2010).

Pharmaceutical and personal care products

The release of pollutants from pharmaceuticals and personal hygiene products from landfills raises great concern due to their water solubility and impact on surface water biota, but also the risk of human exposure due to contamination of groundwater and water reservoirs (Peng X et al. 2014). Open incineration is likely to destroy less persistent pharmaceuticals and pesticides. However, some of the dioxin precursors, such as triclosan, facilitate the formation and release of PCDD/PCDFs during open incineration (Halden RU et al. 2017). The incineration of waste containing triclosan and its derivatives is estimated to significantly contribute to total dioxin emissions in the United States (Doudrick KD et al. 2010).

2.1.

AIR QUALITY INDICES

An Air Quality Index is a mechanism through which timely and general real-time air quality information can be made available to the general public in a simple way, in order to raise environmental awareness. The European Environment Agency, via its European Air Quality Index webpage (<https://airindex.eea.europa.eu/Map/AQI/Viewer/>) presents a visual categorization of air quality, forming 6 quality groups: Good, Fair, Moderate, Poor, Very Poor and Extremely Poor. These categories are defined as ranges of mean hourly (SO₂, NO₂ and O₃) or “sliding” mean twenty-four-hour (PM_{2.5} and PM₁₀) values of concentrations of individual pollutants (Table 1).

Table1. European Air Quality Index (EEA)

Matter	Aggregate.	Good	Fair	Moderate	Poor	Very Poor	Extremely Poor
PM _{2.5}	24h	0-10	10-20	20-25	25-50	50-75	75-800
PM ₁₀	24h	0-20	20-40	40-50	50-100	100-150	150-1200
NO ₂	1h	0-40	40-90	90-120	120-230	230-340	340-1000
O ₃	1h	0-50	50-100	100-130	130-240	240-380	380-800
SO ₂	1h	0-100	100-200	200-350	350-500	500-750	750-1250

State institutions in the Republic of Serbia in charge of monitoring the state of air quality (National network of automatic stations for air quality monitoring: <http://amskv.sepa.gov.rs>; the City Public Health Institute of Belgrade: www.beoeko.rs), use CAQI (Common Air Quality Index), an index created within the project “Air Quality in Europe” which was completed in 2016 (www.airqualitynow.eu). This air quality index uses only the mean hourly values of concentrations for the categorization of air quality into 5 categories: Excellent, Good, Acceptable, Polluted and Heavily Polluted (Table 2). It is indicative that in the original definition of the index available on the project portal, there are defined limit values of classes for both levels of aggregation (1 hour and 24 hours) and that the “best” categories are called “Very Low” and “Low” in terms of air pollution. Our institutions have merely opted for hourly categorization, i.e. for the affirmative labels “Excellent” and “Good”.

Table 2. Common Air Quality Index (CAQI) used by state institutions in RS

Matter	Aggregate.	Excellent	Good	Acceptable	Polluted	Heavily polluted
PM _{2.5}	1h	0 - 15	15 - 30	30 - 55	55 - 110	> 110
PM ₁₀	1h	0 - 25	25 - 50	50 - 90	90 - 180	> 180
NO ₂	1h	0 - 50	50 - 100	100 - 150	150 - 400	> 400
O ₃	1h	0 - 60	60 - 120	120 - 180	180 - 240	> 240
SO ₂	1h	0 - 50	50 - 100	100 - 350	350 - 500	> 500

It is to be expected that widely used applications for mobile and desktop devices such as IQ Air (known as Air Visual), Air Care, WAQI and others, use several different indices that the user may choose from: the Index accepted by the U.S. Environmental Protection Agency (US AQI), the above mentioned EU Index (EU AQI) and others.

Confusion is heightened by the fact that US AQI uses a numerical representation that is the product of a complex calculation, which includes concentrations of all five key pollutants, while EU AQI is simply a selection of the worst-ranked concentrations of the same five substances and has no numerical determinant. This often leads to confusion because the interested public, including decision-makers, compares the “calculated” index with the actual concentrations.

For example, at a given time, the calculated US AQI may be 53, which puts air quality into the “Medium” category, whereas this value is in fact a consequence of the calculation based on a concentration of PM_{2.5} particles of 13 µg/m³, which the domestic version of the CAQI index would rate as “Excellent”. One need hardly point out that it is unnecessary to compare the index itself with the concentration.

2.2.

List of the Most Important Serbian Regulations Related to the Present Study

General

Law on Ratification of the Convention on Access to Information, Public Participation in Decision-Making and the Right to Legal Protection in Environmental Matters (Official Gazette of RS - International Agreements, No. 38/09);

Law on Environmental Protection (Official Gazette of RS, No. 135/2004, 36/2009, 36/2009 - other law, 72/2009 - other law, 43/2011 - decision US, 14/2016, 76/2018 and 95/2018 - other Law);

Law on Nature Protection (Official Gazette of RS, No. 36/2009, 88/2010, 91/2010 - amended, 14/2016 and 95/2018 - other Law);

Law on Environmental Impact Assessment (Official Gazette of RS, No. 135/2004 and 36/2009);

Law on Strategic Environmental Assessment (Official Gazette of RS, No. 135/2004 and 88/2010);

Regulation on determining the List of projects for which an impact assessment is mandatory and the List of projects for which an environmental impact assessment may be required (Official Gazette of the RS, No. 114/2008);

Law on Integrated Prevention and Control of Environmental Pollution (Official Gazette of RS, No. 135/04, 25/15 and 109/21);

Regulation on types of activities and plants for which integrated permits are issued (Official Gazette of RS, No. 84/05);

Law on Fire Protection (Official Gazette of RS, No. 111/09, 20/15, 87/18 and 87/18-other law);

Law on Disaster Risk Reduction and Emergency Management (Official Gazette of RS, No. 87/18);

Law on Planning and Construction (Official Gazette of RS, No. 72/09, 81/09 - correction, 64/10 - US, 24/11, 121/12, 42/13 - US, 50/13 - US, 98 / 13 - US, 132/14, 145/14, 83/18, 31/19, 37/19 - state law, 9/20 and 52/21);

Air

Law on Air Protection (Official Gazette of RS, No. 36/09, 10/13 and 26/21 - other law);

Regulation on monitoring conditions and air quality requirements (Official Gazette of RS, No. 11/10, 75/10 and 63/13);

Regulation on Measuring Emissions of Pollutants into the Air from Stationary Pollution Sources (Official Gazette of RS, No. 5/16);

Regulation on Limit Values for Emissions of Pollutants into the Air from Stationary Pollution Sources, Except for Combustion Plants (Official Gazette of RS, No. 111/15 and 83/21);

Regulation on determining the air quality control program within the state network (Official Gazette of RS, No. 58/11);

Regulation on Designating Zones and Agglomerations (Official Gazette of RS, No. 58/11)

Water

Regulation on Limit Values for Emissions of Pollutants into Waters and Deadlines for Reaching Them (Official Gazette of RS, No. 67/11, 48/12 and 1/16);

Rulebook on the manner and conditions for measuring the quantity and testing of wastewater quality and the content of the report on the performed measurements (Official Gazette of RS, No. 33/16);

Regulation on limit values of pollutants in surface and groundwater and sediment and deadlines for their reaching them (Official Gazette of RS, No. 50/12);

Regulation on limit values of priority hazardous substances polluting surface waters and deadlines for reaching them (Official Gazette of RS, No. 24/14).

Land

Law on Agricultural Land (Official Gazette of RS, No. 62/06, 65/08 - other law, 41/09, 112/15, 80/17 and 95/18-state law);

Law on Land Protection (Official Gazette of RS, No. 112/15);

Regulation on Limit Values of Pollutants, Harmful and Dangerous Substances in Soil (Official Gazette of RS, No. 30/18 and 64/19);

Regulation on the systematic monitoring of the condition and quality of land (Official Gazette of RS, No. 88/20);

Rulebook on the content of remediation and reclamation projects (Official Gazette of RS, No. 35/19);

Rulebook on the list of activities that may cause soil pollution and degradation, procedure, data content, deadlines and other requirements for land monitoring (Official Gazette of RS, No. 68/19).

Waste

Law on Waste Management (Official Gazette of RS, No. 36/09, 88/10, 14/16 and 95/18 – state Law);

Regulation on waste disposal in landfills (Official Gazette of RS, No. 92/10);

Rulebook on the methodology for collecting data on the composition and quantities of municipal waste on the territories of local self-governments (Official Gazette of RS, No. 61/10);

Rulebook on categories, testing and classification of waste (Official Gazette of RS, No. 56/10, 93/19, 39/21).

List of the Most Important EU Directives Related to the Present Study

General

Convention on access to information, public participation in decision-making and access to justice in environmental matters done at Aarhus, Denmark, on 25 June 1998;

Regulation (EU) 2021/1767 of the European Parliament and of the Council of 6 October 2021 amending Regulation (EC) No 1367/2006 on the application of the provisions of the Aarhus Conven-

tion on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters to Community institutions and bodies;

Council Directive 2008/1 / EC, of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control;

Directive 2004/35 / CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage (ELD);

Directive 85/337 / EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (EIA), amending Directive 2011/92 / EU on the assessment of the effects of certain public and private projects on the environment; amending Directive 2014/52 / EU of the European Parliament and of the Council of 16 April 2014;

Directive 2010/75 / EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

Regulation (EU) No 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants (POPs Regulation)

Air

1979 Convention on long-range transboundary air pollution;

Council Decision of 19 February 2004 concerning the conclusion, on behalf of the European Community, of the Protocol to the 1979 Convention on Long Range Transboundary Air Pollution on Persistent Organic Pollutants ;

Council Decision of 14 October 2004 concerning the conclusion, on behalf of the European Community, of the Stockholm Convention on Persistent Organic Pollutants ;

Directive 2008/50 / EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe;

Directive 2004/107 / EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air;

Directive 2010/75 / EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

Water

Directive 2000/60 / EC a framework for the Community action in the field of water policy or, for short, the EU Water Framework Directive (WFD);

Directive 2006/118 / EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration;

Directive 2013/39 / EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60 / EC and 2008/105 / EC as regards priority substances in the field of water policy.

Land

Directive 2010/75 / EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

Waste

Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98 / EC on waste;

Council Directive 1999/31 / EC of 26 April 1999 on the landfill of waste;

COMMISSION IMPLEMENTING DECISION (EU) 2018/1147 of 10 August 2018 establishing best available techniques (BAT) conclusions for waste treatment, under Directive 2010/75 / EU of the European Parliament and of the Council

2.3.

GAP ANALYSIS: Review and Comparison of EU and RS Regulations Defining Requirements for Monitoring Pollutants in Environmental Media within the Present Study

EU regulations	RS regulations	Comments / conclusions / additional information
Air		
<p>Directive 2008/50 / EC on ambient air quality and cleaner air for Europe and amendments, as of 18.09.2015.</p> <p>Art.5</p> <ul style="list-style-type: none"> • SO2 • NO2 and NOx, expressed as NO2 • PM10 • PM2.5 • Pb • Benzene • CO <p>Art.9 and Art. 10</p> <ul style="list-style-type: none"> • Ozone <p>This directive does not mention the monitoring of unintentionally produced POPs.</p> <p>Directive 2004/107 / EC relating to As, Cd, Hg, Ni and PAHs in ambient air.</p>	<p>Law on Air Protection (Official Gazette of RS, No. 36/09, 10/13 and 26/21 - other law)</p> <p>Art.8 Pollutants for which air quality is assessed:</p> <ul style="list-style-type: none"> • SO2 • NO2 and NOx, expressed as NO2 • PM10 • PM2.5 • Pb • Benzene • CO • Ground-level ozone • As, Cd, Ni • Benzopyrene <p>Regulation on monitoring conditions and air quality requirements (Official Gazette of RS, No. 11/10, 75/10 and 63/13):</p> <p>Art.7</p> <ul style="list-style-type: none"> • SO2 • NO2 and NOx, expressed as NO2 • PM10 • PM2.5 • Pb • Benzene • CO • Ground-level ozone • As, Cd, Ni, Hg • Benzopyrene <p>Art.8a In order to measure the concentration of benzo(a)pyrene in the air, concentrations of other significant polycyclic aromatic hydrocarbons must be monitored at a small number of measuring points and locations for sampling benzo(a)pyrene. As a minimum, concentrations of the following must be measured: benzo (a) anthracene, benzo(b) fluoranthene, benzo (j) fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene and dibenzo(a, h)anthracene. Unintentionally produced POPs: Article 3 of the Law on Air Protection provides a definition of unintentionally released persistent organic pollutants emitted from stationary and mobile sources of pollution, such as PCDF and PCDD/F, PAHs, hexachlorobenzene and PCBs. The law mentions that the Air Quality Information System contains data from the National Inventory of Unintentionally Released Persistent Organic Pollutants.</p>	<p>All pollutants prescribed by the EU regulations for monitoring within the regular monitoring of ambient air have been transposed into domestic regulations. The limit values provided by the domestic Regulation on monitoring conditions and air quality requirements are fully harmonized with EU legislation and prescribed standards, except in the case of annual concentrations of PM2.5, for which the limit value in the EU has been 20 µg/m³ since 1.1.2020, and which, according to domestic Regulation, will be applied in the Republic of Serbia from 1.1.2024. EU Directive 2008/50, as well as the Regulation on conditions for monitoring and air quality requirements, do not define the need to monitor ambient air quality at municipal waste landfill sites, or in their immediate vicinity.</p>

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Waste		
EU Directive 2018/851 amending Directive 2008/98 / EC on waste	Law on Waste Management (Official Gazette of RS, No. 36/09, 88/10, 14/16 and 95/18 – state law) Partially transposed Directive. Separate chapters of the Law include the management of special waste streams - waste containing PCBs and POPs.	A Draft Waste Management Strategy for the period 2019-2024 has been prepared. The Waste Management Program in the Republic of Serbia for the period 2022 – 2031 has been adopted. The adoption of the Action Plan for the period from 2022 to 2024 is expected.
Council Directive 1999/31/EC on landfills and amendments, as of 04.07.2018.	Regulation on waste disposal in landfills (Official Gazette of RS, No. 92/10)	Both the Directive and the Regulation on waste disposal in landfills define the dynamics of testing emissions of gasses (CH ₄ , CO ₂ , O ₂ , H ₂ S, H ₂ , etc.), leachate, surface water and groundwater at landfills. Data on gas emission monitoring at sanitary landfills are submitted to the Environmental Protection Agency of the RS only for some of the sanitary landfills, which is an obligation under Article 27 of the Regulation on waste disposal at landfills, while these are not submitted for unsanitary landfills. As part of the monitoring of gas emissions at sanitary landfills, CH ₄ , H ₂ S, CO ₂ and O ₂ are measured, as well as CO, which is considered to be the most sensitive indicator of underground fires.
Water		
Directive 2000/60 / EC: Water Framework Directive (WFD)	Law on Waters (Official Gazette of RS, No. 30/10, 93/12, 101/16, 95/18 and 95/18 - state Law) Partially transposed directive.	A new amendment to the Law on Waters, announced for 2019, is expected. Plans to protect water from pollution in RS have not been adopted.
	Regulation on ELV of Pollutants into Waters and Deadlines for reaching them (Official Gazette of RS, No. 67/11, 48/12 and 1/16)	The Regulation on ELV of Pollutants into Waters and Deadlines for Reaching Them also recognizes wastewater whose pollution primarily originates from waste disposal on the surface and from the purification of waste gasses generated by waste incineration. The test parameters do not include PCDD, PCDF and PCBs. In the case of wastewater from the treatment of waste gasses generated by waste incineration, before mixing with other wastewaters, the ELV for dioxins and furans is defined as the sum of individual dioxins and furans, max 0.3 ng/l. The deadline for reaching the ELV is 31.12.2025.
	Regulation on Limit Values of Pollutants in Surface and Groundwater and Sediment and Deadlines for Reaching them (Official Gazette of RS, 50/12)	Environmental quality standards for Group I priority substances include PCBs in surface waters, and Group II lists dioxins and dioxin-like compounds PCDD, PCDF and PCBs-DL, with a deadline according to the Plan for protection of water from pollution, but without AMC and MAC .

Supplementary resources

<p>Directive 2013/39 / EU amending Directives 2000/60 / EC and 2008/105 / EC as regards priority substances in the field of water policy</p>	<p>Regulation on Limit Values of Priority Hazardous Substances Polluting Surface Waters and Deadlines for reaching them (Official Gazette of RS, 24/14)</p> <p>Partially transposed Directive.</p>	<p>The Directive supplements the list of priority substances which may not be introduced into water with another 12 substances (45 in total), some of which are characterized as priority hazardous substances and include PAHs and dioxins and dioxin-like compounds (PCDDs, PCDFs and PCBs). The section Environmental Quality Standards lists all 45 substances (for the sum of PCDD + PCDF + PCBs-DL 0.0065µg/kg TEQ, for biota (fish)).</p> <p>The RS Regulation needs to be harmonized, as it lists 35 priority hazardous substances in Group I, and 25 in Group II. The monitoring did not encompass all water bodies and all substances, nor did it establish all limits for detection and qualification for all substances.</p>
<p>Directive 2006/118/EC on the protection of groundwater against pollution and deterioration</p> <p>In Annex II, Part B:</p> <p>The minimum indicator includes the parameters: As, Cd, Pb, Hg, NH₄⁺, Cl⁻, SO₄²⁻ trichloroethene, tetrachloroethene, as well as electrical conductivity, which indicates the intrusions of saline or other intrusions (or sulfate and chloride content).</p> <p>It does not specify quality parameters for sediment.</p>	<p>Regulation on Limit Values of Pollutants in Surface and Groundwater and Sediment and Deadlines for Reaching Them (Official Gazette of RS, No. 50/12)</p> <p>Partially transposed Directive</p> <p>The Regulation defines that the direct and indirect discharge of pollutants from Lists I and II into groundwater, including carcinogenic, mutagenic and teratogenic substances is prohibited, but without specifying the compounds.</p> <p>Annex 3: Limit values for sediment quality assessment</p> <p>The LV assesses the sediment status and quality trend for PCBs (sum of PCBs 28, 52, 101, 118, 138, 153 and 180) of 20 µg/kg as a target value, and 200 µg/kg as MAC. The LV for the assessment of sediment quality when dredging sediment from watercourses defines a target value of 0.02 mg/kg, and a verification level of 0.2 mg/kg (its disposal is not allowed without special protection measures, it must be stored in controlled conditions with special protection measures, so as to prevent the spread of pollutants into the environment).</p>	<p>There is a partial difference when it comes to the requirements of the Regulation on LV Pollutants in Surface and Groundwater and Sediment and the Deadlines for reaching them.</p> <p>The Directive also sets quality standards, which are identical to those in the Regulation.</p>

Land		
<p>Directive 2010/75 / EU on industrial emissions (IPPC) Refers to waste incinerators, but does not include land pollution as a consequence of fires</p>	<p>Law on Land Protection (Official Gazette of RS, No. 112/15)</p>	<p>Regulates land protection, the systematic monitoring of soil condition and quality, improvement, remediation and reclamation measures, inspection and other issues of importance for the protection and preservation of land as a natural resource of national interest, and is under the authority of the Ministry of Environmental Protection.</p>
	<p>Regulation on limit values of pollutants, harmful and dangerous substances in soil (Official Gazette of RS, No. 30/18 and 64/19), in force since 01.01.2020.</p>	<p>Defines the Maximum (MV) and Remediation limit values (RV) of pollutants, harmful and dangerous substances in the soil and remediation values (RV) in the aquifer. Specific MV and RV (for PCBs and PAHs in soil and groundwater) are listed. In the case of RV, the sum of polychlorinated biphenyl congeners is taken into account: PCBs 28, 52, 101, 118, 138, 153 and 180; and for MV, the sum of the same congeners is taken into account except PCBs 118. The RV for PCBs in the aquifer (groundwater) is 0.01 µg/l for the sum of congeners of polychlorinated biphenyls: PCBs 28, 52, 101, 118, 138, 153 and 180. When the average concentration of any polluting, dangerous and harmful substances in more than 25 m³ of soil volume, or in 100m³ of groundwater exceeds the RV, a Remediation and Reclamation Project is prepared and implemented.</p>
	<p>Rulebook on the Content of Remediation and Reclamation Projects (Official Gazette of RS, No. 35/19)</p>	<p>Defines the scope and content of Polluted Land Rehabilitation and Reclamation Projects.</p>
	<p>Rulebook on the list of activities that may cause soil pollution and degradation, procedure, data content, deadlines and other requirements for land monitoring (Official Gazette of RS, No. 68/19)</p>	<p>Waste management activities are recognized: 5.4. Landfills receiving more than 10 tonnes of waste per day or with a total capacity exceeding 25,000 tonnes, excluding landfills of inert waste; 5.5. Unsanitary landfills - landfills managed by local self-governments.</p>
	<p>Regulation on the Systematic Monitoring of the Condition and Quality of Land (Official Gazette of RS, No. 88/20)</p>	<p>Defines the content of the Soil Monitoring Program, methodology for systematic monitoring of soil quality and condition, criteria for determining the number and layout of measuring points, list of parameters for particular soil types, list of methods and standards for soil sampling, analysis of samples and data processing, scope and frequency of measurements, indicators for assessing the risk of land degradation, deadlines and manner of submitting data.</p>

Supplementary resources

Industrial pollution		
<p>Directive 2012/18 / EU on the control of major-accident hazards involving dangerous substances (Seveso III Directive), amending and subsequently repealing Council Directive 96/82 / EC. Explicitly excludes landfills, including underground waste storage facilities as the focus of this Directive (Article 2, paragraph 2, point (h))</p>		<p>In December 2021, a Draft Law on the Control of Major-Accident Hazards Involving Dangerous Substances was compiled, but has not yet been adopted. It does not apply to landfills, including underground waste storage, except for the transport of hazardous substances by pipelines, including pumping stations, outside the complex (Article 5).</p>
	<p>Law on Disaster Risk Reduction and Emergency Management (Official Gazette of RS, No. 87/18)</p>	<p>Art. 97 states that companies that use tailings and ash dumps are obliged to provide timely information and alert the population about the hazards that may arise or have occurred in reservoirs, tailings and ash dumps. Does not list accidents/emergencies at landfills.</p>
<p>Directive 2010/75 / EU on industrial emissions (IPPC)</p>	<p>Law on Integrated Prevention and Control of Environmental Pollution (Official Gazette of RS, No. 135/04, 25/15 and 109/21)</p>	<p>The law cites waste management in the basic principles of integrated prevention and control of pollution in the Precautionary Principles, in terms of preventing or reducing waste generation; and in the Principle of Waste Management Hierarchy, it defines the order of priorities in waste management practice, which consists of: the prevention of waste generation and its reduction, i.e. reduction of resource use and reduction of quantities and/or hazardous characteristics of generated waste; re-use, i.e. use of a product for the same or other purpose; recycling, i.e. treatment of waste in order to obtain raw materials for the production of the same or other product; utilization, i.e. use of waste (composting, energy recovery, etc.) (Article 3).</p>
	<p>Regulation on types of activities and plants for which integrated permits are issued (Official Gazette of RS, No. 84/05)</p>	<p>Activities and facilities listed in the Regulation are required to obtain an IPPC permit. Article 3 also lists waste management facilities (5.4. Landfills receiving more than 10 t of waste per day or with a total capacity exceeding 25,000 t, excluding inert waste landfills). Landfills that have obtained an IPPC permit are:</p> <ol style="list-style-type: none"> 1. "PWW Deponija" doo Jagodina, Gigoš (MEP, No. 353-01-01128 / 2016-16, dated 08.12.2016), with a validity of 10 years; 2. "FCC EKO" doo Lapovo, Vrbak (MEP, No. 353-01-00014 / 2014-08, dated 25.05.2017), with a validity of 10 years.

2.4.

Comparative table of limit values of basic pollutants in RS, EU and WHO regulations

Comparative table showing the limit values (LV) prescribed by the Regulation on monitoring conditions and air quality requirements (“Official Gazette of RS”, No. 11/10, 75/10 and 63/13), EU standards and recommended values (RV) from the World Health Organization (WHO) from September 2021. (Table 1)

Table 1. Comparative table of limit values of basic pollutants in RS, EU and WHO regulations

Averaging period	Basics	PM _{2.5}	PM ₁₀	SO ₂	NO ₂	O ₃
		µg/m ³				
1 hour	RS LV Regulation	-	-	350 [24] ¹	150 [18]	180 ²
	EU Standard LV	-	-	350 [24]	200 [18]	-
	WHO RV	-	-	-	-	-
24 hours	RS LV Regulation	-	50 [35]	125 [3]	85	120 ³
	EU Standard LV	-	50 [35]	125 [3]		120 ²
	WHO RV	15	45	40	25	100 ⁴
1 year	RS LV Regulation	25	40	50	40	-
	EU Standard LV	20	40	-	40	-
	WHO RV	5	15	-	10	-

¹ The maximum numbers of exceedances during one calendar year as provided in the Regulation are given in square brackets (e.g. the average hourly limit value of SO₂ concentrations of 350 µg/m³ can be exceeded a maximum of 24 times a year).

² Given as a concentration communicated to the public under the Regulation

³ Given as the maximum daily eight-hour mean value in 24 hours in order to protect health according to the Regulation

⁴ The recommendation is valid for a maximum 8-hour mean value in 24h

2.5.

CASE STUDY

ANALYSIS OF AIR QUALITY MONITORING DATA RELATED TO THE FIRE AT THE VINČA LANDFILL IN AUGUST 2021

The analysis of air quality monitoring data in relation to landfill fires within this study focused on the fire at the Belgrade unsanitary landfill in Vinča, which started on August 7, 2021, due to the fact that the data was available, but also because the incident caused great public distress, whereas no specifically timed data is available for other landfill fires.

According to the Annual Report on Air Quality Control at Measuring Points within the State Network in Belgrade for 2021 and Annual Report on the Results of Measuring Air Quality on the Territory of Belgrade in the Local Network of Measuring Stations/Locations for 2021, we may conclude that measurements of pollution parameters that may be relevant for monitoring the consequences of pollutant emissions during the fire at the Vinča landfill were performed at three locations from the state network and sixteen stations of the local network during 2021. Seeing as though these reports gave aggregated daily mean values, and that there were short-term episodes with high concentrations of pollutants during the fire at the landfill in Vinča, data on mean concentrations collected through cooperation with the National Environmental Association was used in the data analysis. This data was verified via comparison with the average daily data provided in the aforementioned official reports.

Mean hourly and mean daily data for four pollutants from both types of monitoring (state and “civil”) stations for the period 1.8.-10.9.2021 was analyzed. An overview of the stations and their locations with the pollutants considered in the analysis is given in Table 1.

Table 1. Overview of measuring stations and pollutants considered in the analysis for the period 1.8.-10.9.2021.

Automatic monitoring network	Measuring station	Pollutants
	Belgrade - Vracar	PM _{2.5} , PM ₁₀ , SO ₂ , NO ₂
	Belgrade – Zeleno brdo	
	Belgrade – Stari grad	
	Belgrade – Novi Beograd	
	Belgrade – Mostar	
State - City Institute for Public Health Belgrade	Belgrade - Despota Stefana	State - Environmental Protection Agency
	Belgrade – Omladinskih brigada	
	Belgrade - Ovča	
	Belgrade - Zemun TB	
	Belgrade - Vinca	
	Belgrade - Lazarevac	
	Belgrade - Obrenovac	
State - City of Pančevo	Pančevo - Starčevo	
	Pančevo – Vatrogasni dom	
	Pančevo - Vojlovica	

Supplementary resources

Citizens' network - Sensor Community	Bulevar Zorana Đinđića Belgrade	PM _{2.5} , PM ₁₀
	Gospodara Vučića Belgrade	
	Koče Kapetana Belgrade	
	Sazonova Belgrade	
	Milovana Marinkovića Belgrade	
	Obalskih radnika Belgrade	
	Gostivarska Belgrade	
	Borča-Greda Belgrade	
	Mileve Marić Ajnštajn Belgrade	
	Garsije Lorke Belgrade	
	Vojvode Hrvoja Belgrade	
	Vlajkovićeve Belgrade	
	Mažuranićeve Belgrade	
	Vitezova Karađorđeve Zvezde Belgrade	
	Stojana Novakovića South Banat Administrative District	
	Metropolita Petra Belgrade	
	Darinke Radović Belgrade	
	Bolečka mehana Boleč	
	Moše Pijade Vojvodina	
	Filipa Hristića City of Belgrade	
Timočke Divizije Belgrade		

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Figure 1. Mean daily concentrations of PM₁₀ at automatic stations from state monitoring (1.8-10.9.2021)

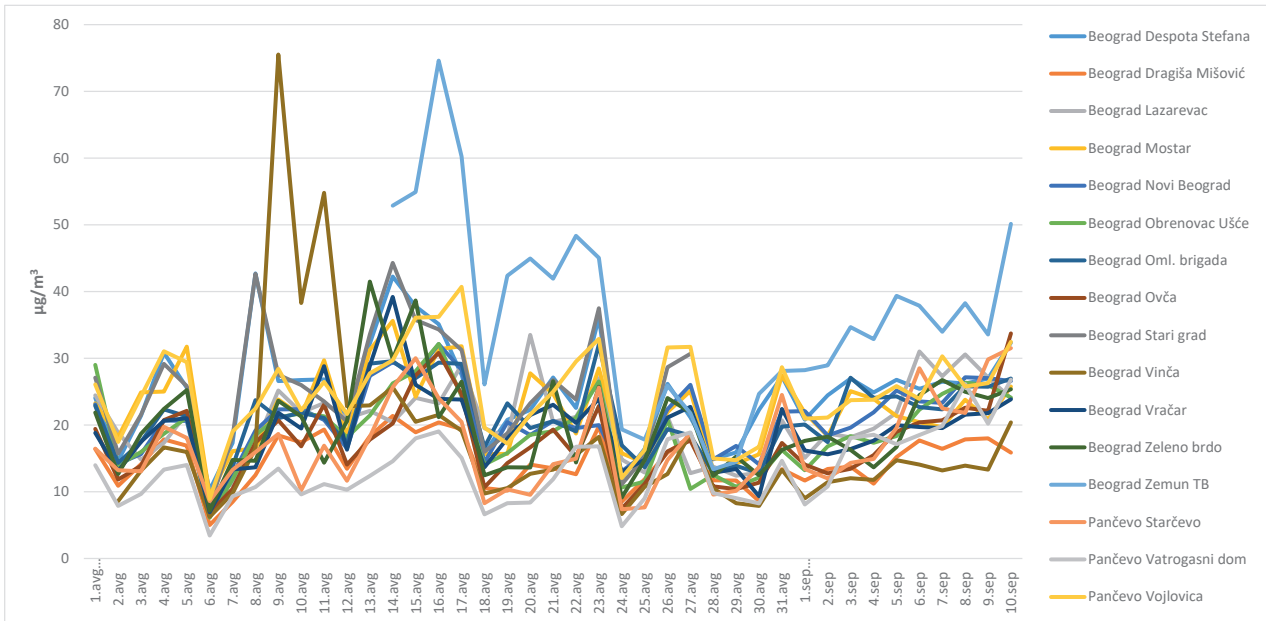


Figure 2. Mean daily concentrations of PM_{2.5} at automatic stations from state monitoring (1.8-10.9.2021)

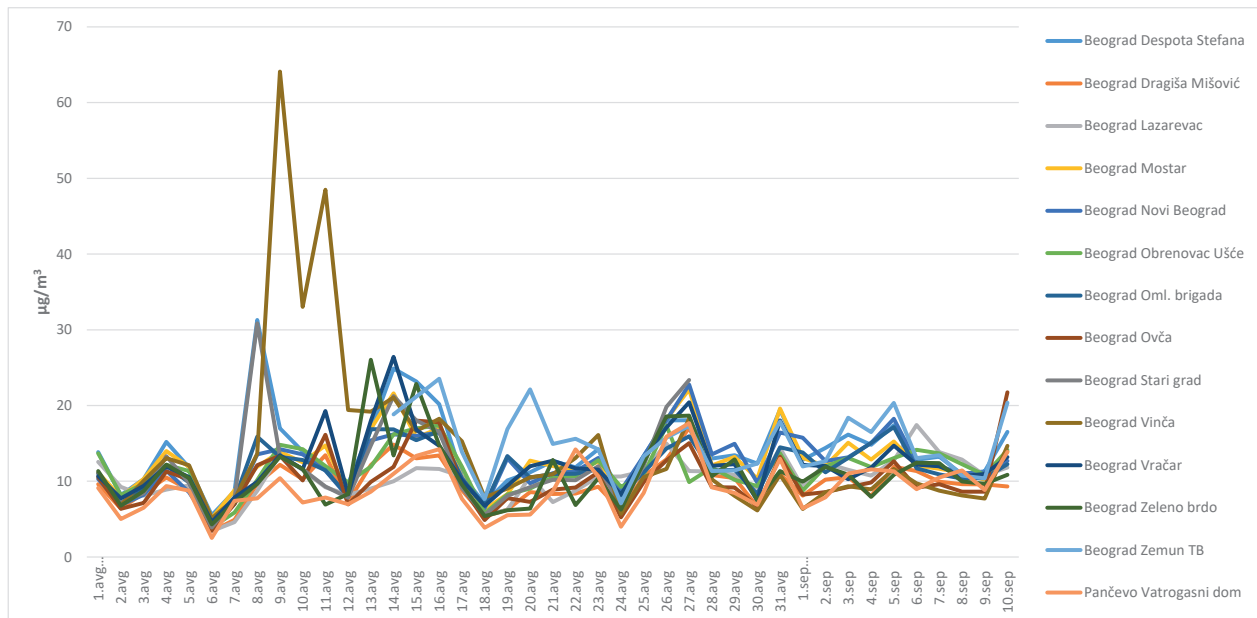


Figure 3. Mean daily concentrations of SO₂ at automatic stations from state monitoring (1.8-10.9.2021)

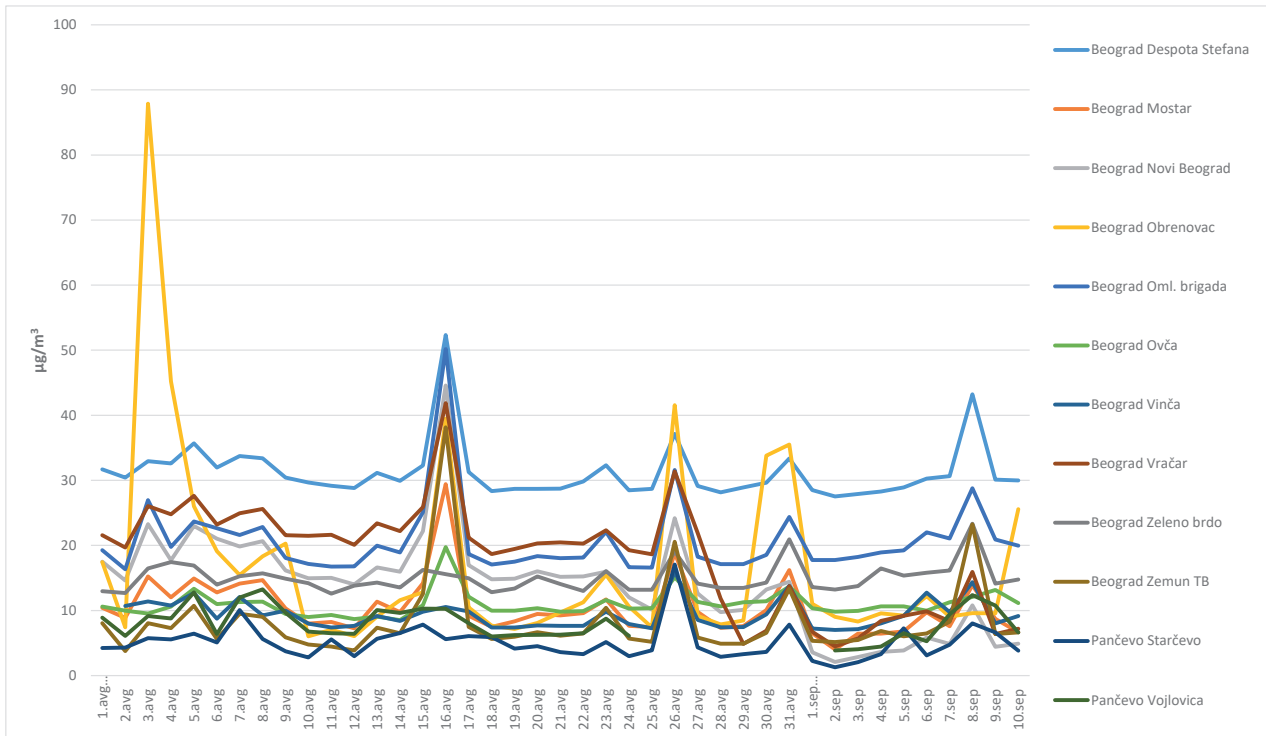
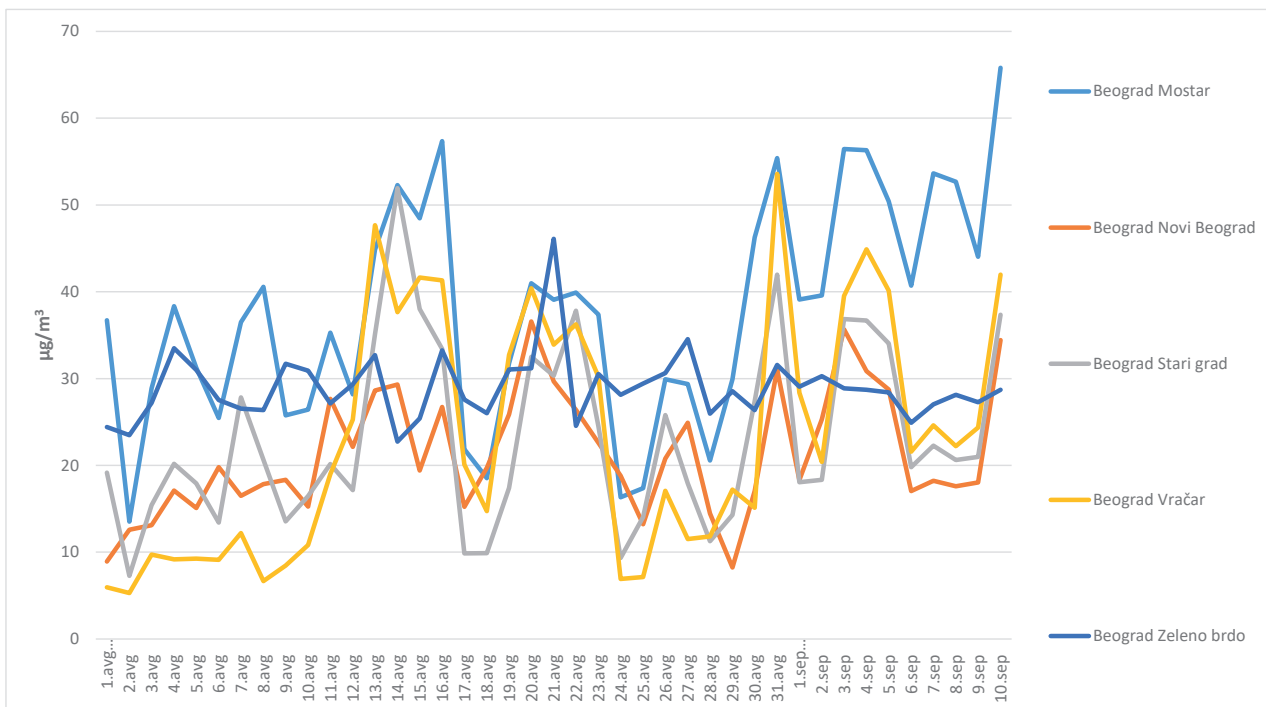


Figure 4. Mean daily concentrations of NO₂ at automatic stations from state monitoring (1.8-10.9.2021)



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Figure 5. Maximum daily concentrations of PM₁₀ at automatic stations from state monitoring (1.8-10.9.2021)

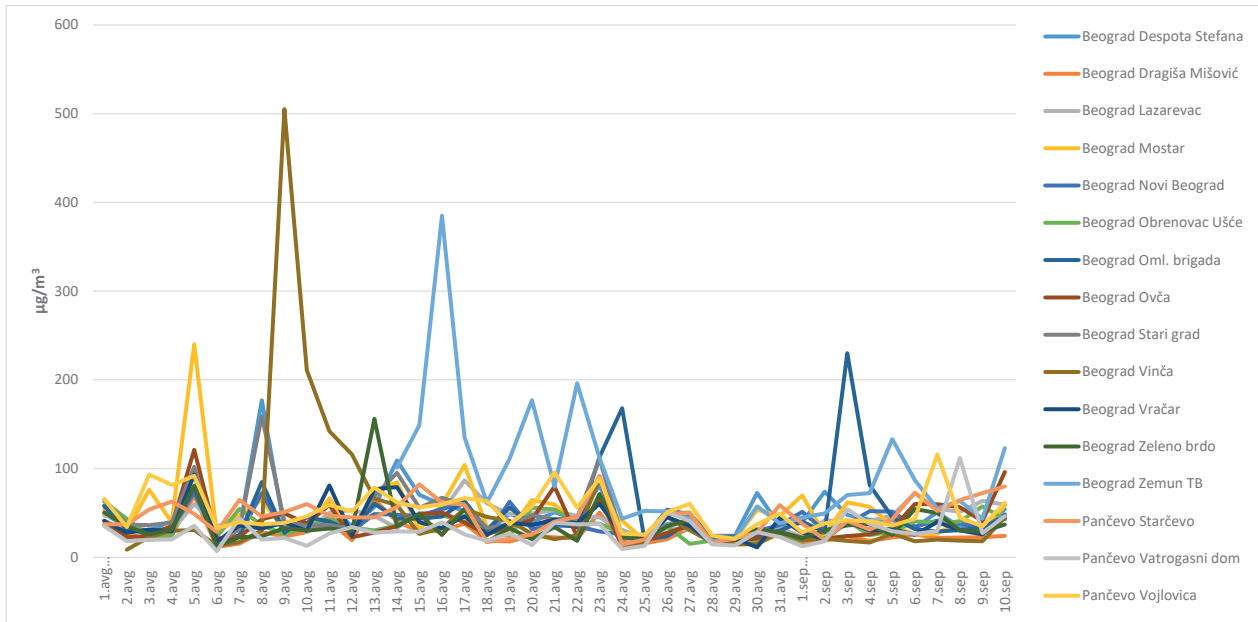


Figure 6. Maximum daily concentrations of PM_{2.5} at automatic stations from state monitoring (1.8-10.9.2021)

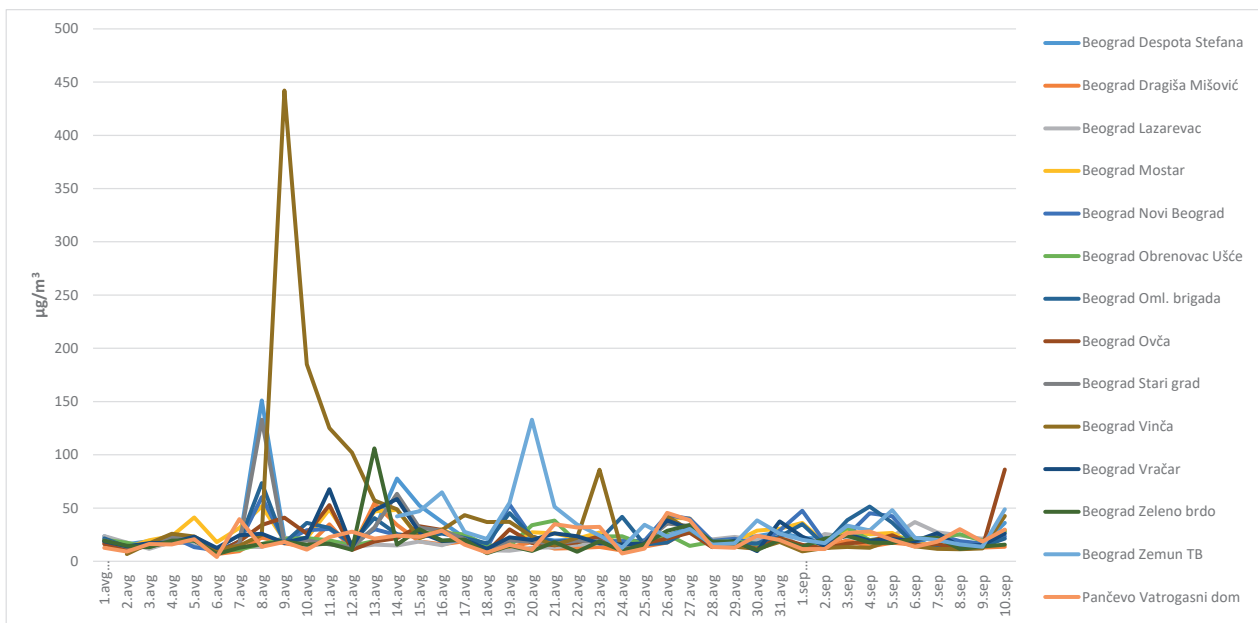


Figure 7. Maximum daily concentrations of SO₂ at automatic stations from state monitoring (1.8-10.9.2021)

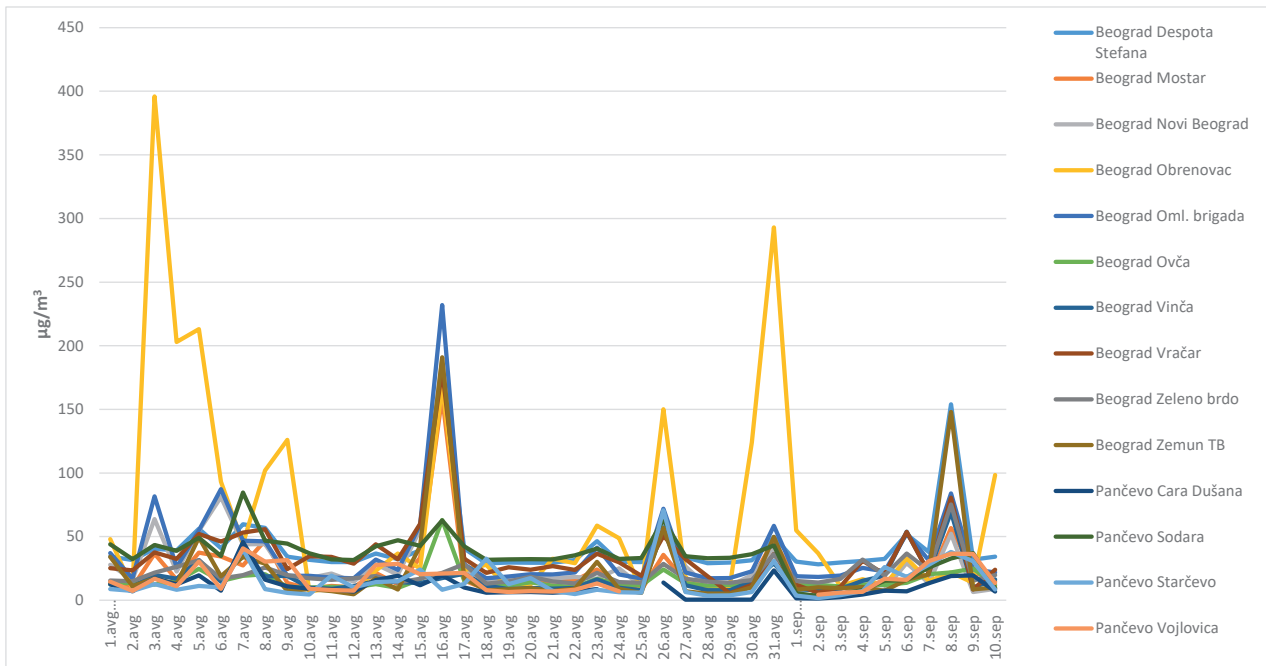
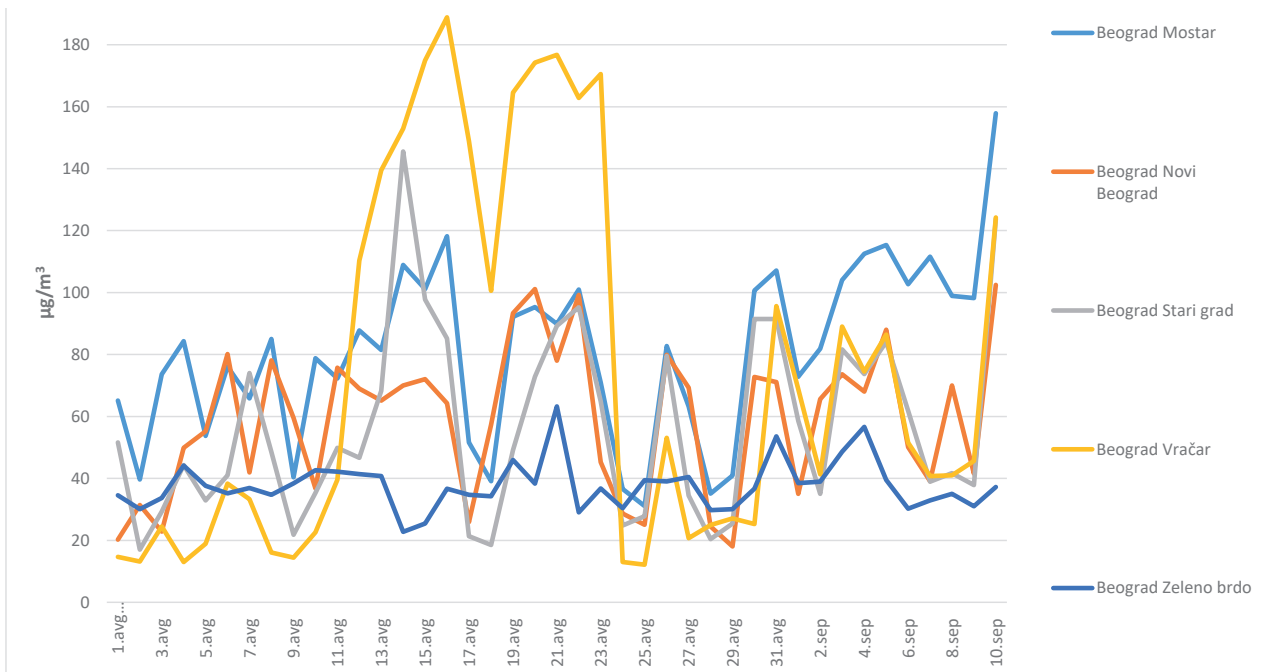


Figure 8. Maximum daily concentrations of NO₂ at automatic stations from state monitoring (1.8-10.9.2021)



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Figure 9. Measuring stations for “citizen” monitoring within a radius of 20 km from the Vinča landfill

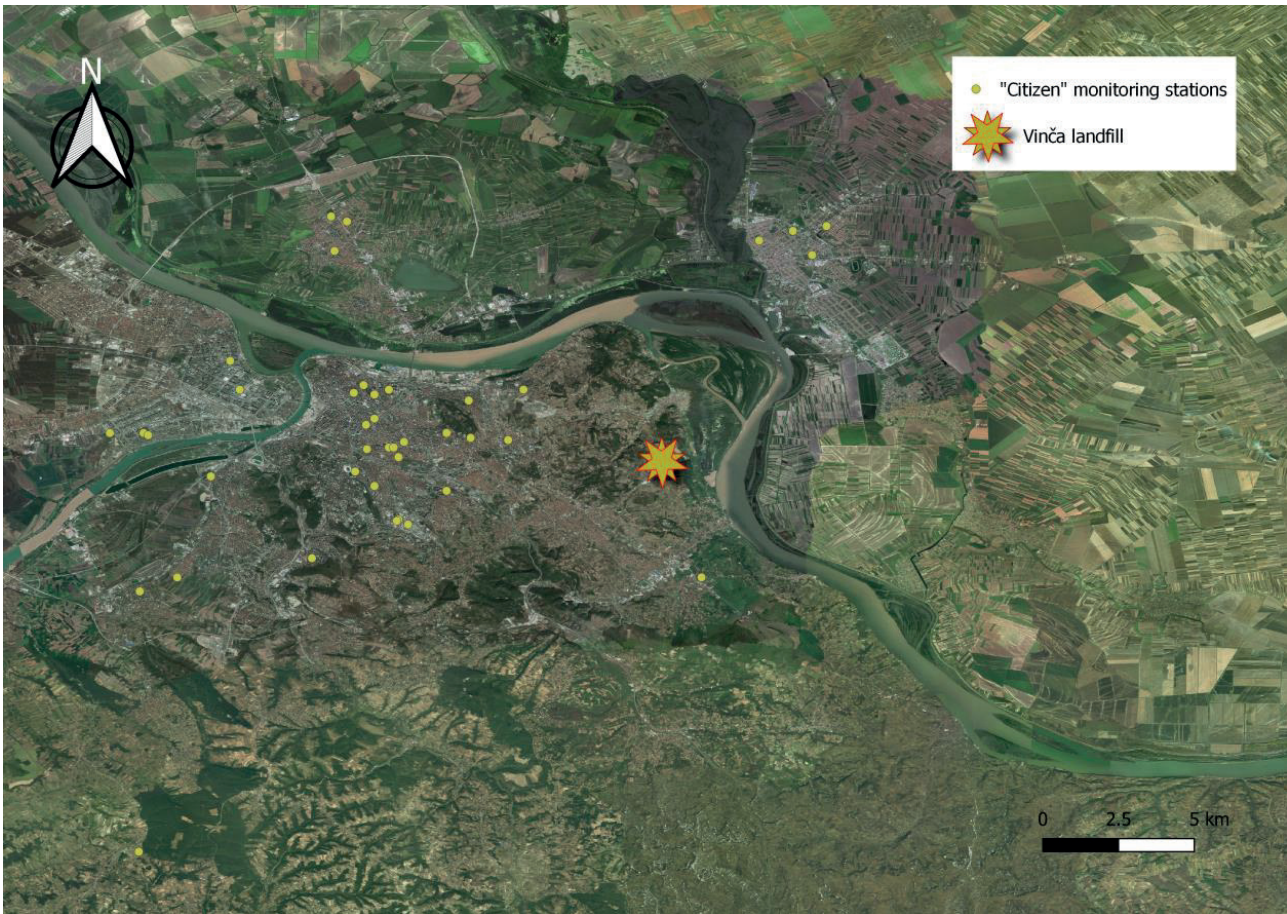
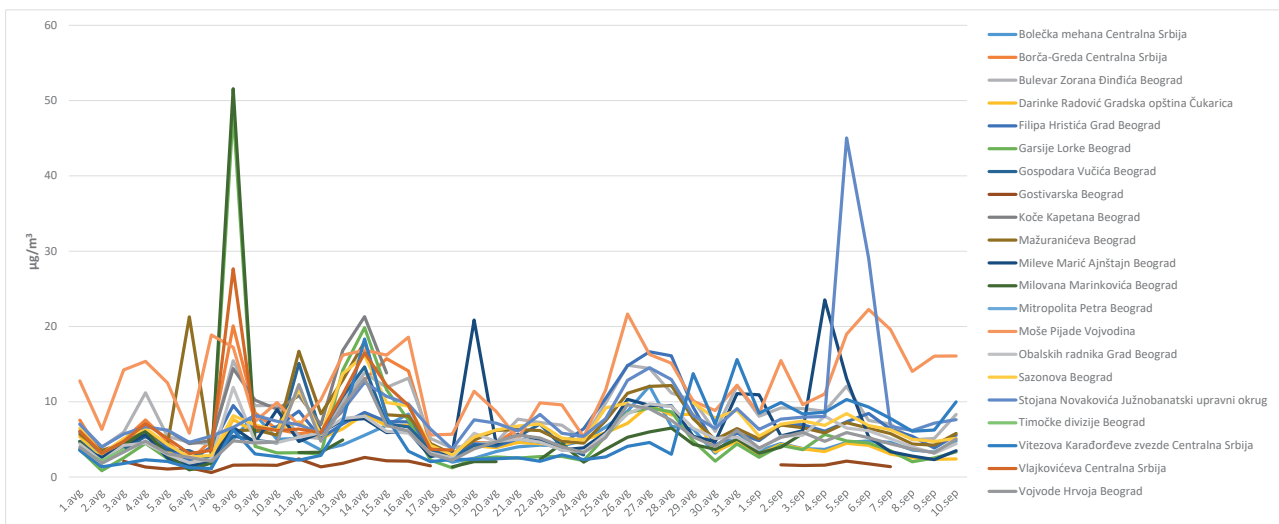


Figure 10. Mean daily concentrations of PM_{2.5} at automatic stations from “citizen” monitoring (1.8-10.9.2021)



Supplementary resources

Figure 11. Maximum daily concentrations of PM_{2.5} at automatic stations from “citizen” monitoring (1.8-10.9.2021)

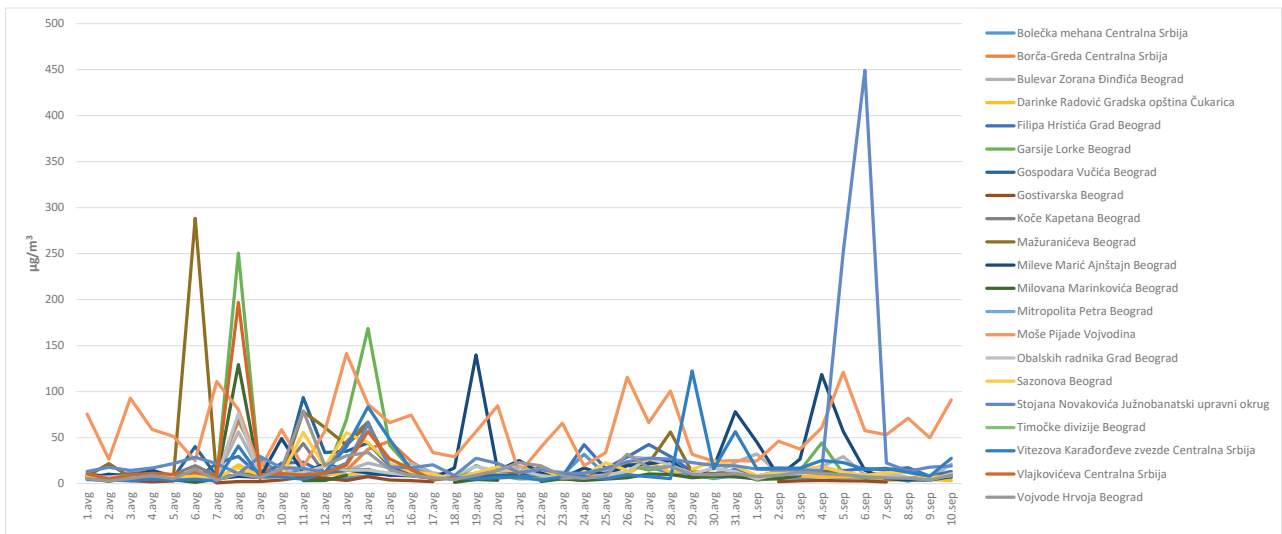


Figure 12. Mean daily concentrations of PM₁₀ at automatic stations from “citizen” monitoring (1.8-10.9.2021)

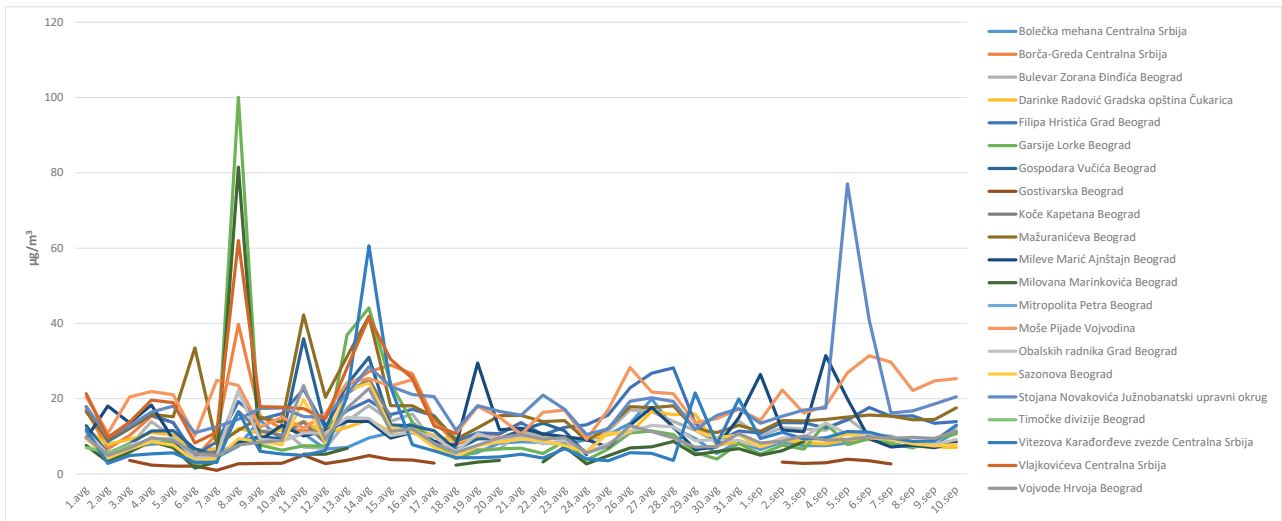


Figure 13. Maximum daily concentrations of PM₁₀ at automatic stations from “citizen” monitoring (1.8-10.9.2021)

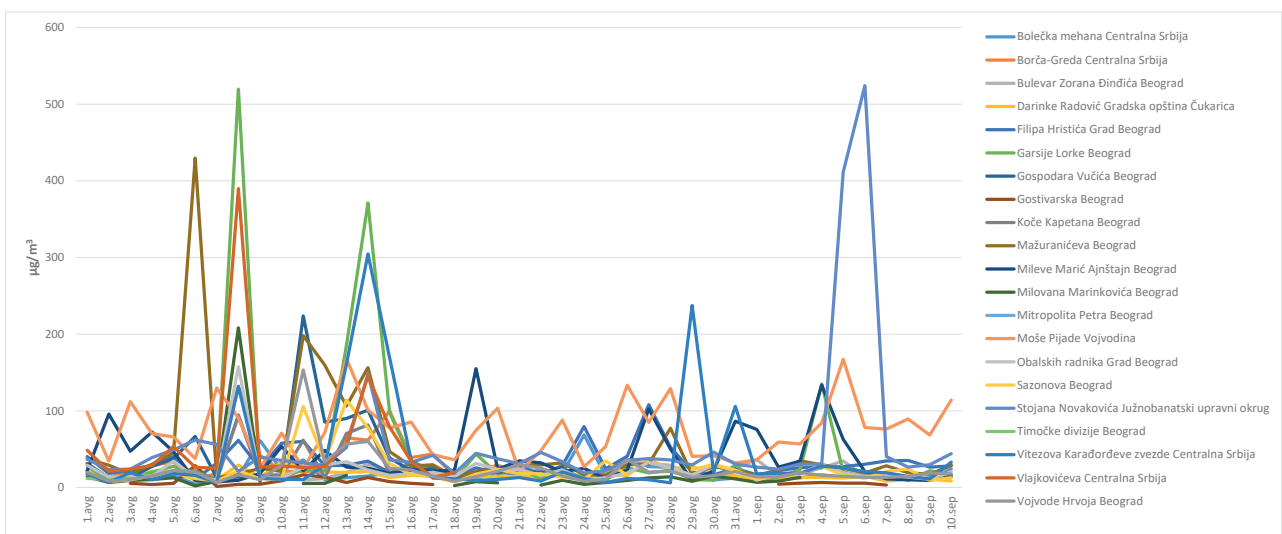


Figure 14. Mean hourly concentrations of PM_{2.5} and PM₁₀ at automatic stations from state monitoring in the period of observed high concentrations (1.8-10.9.2021)

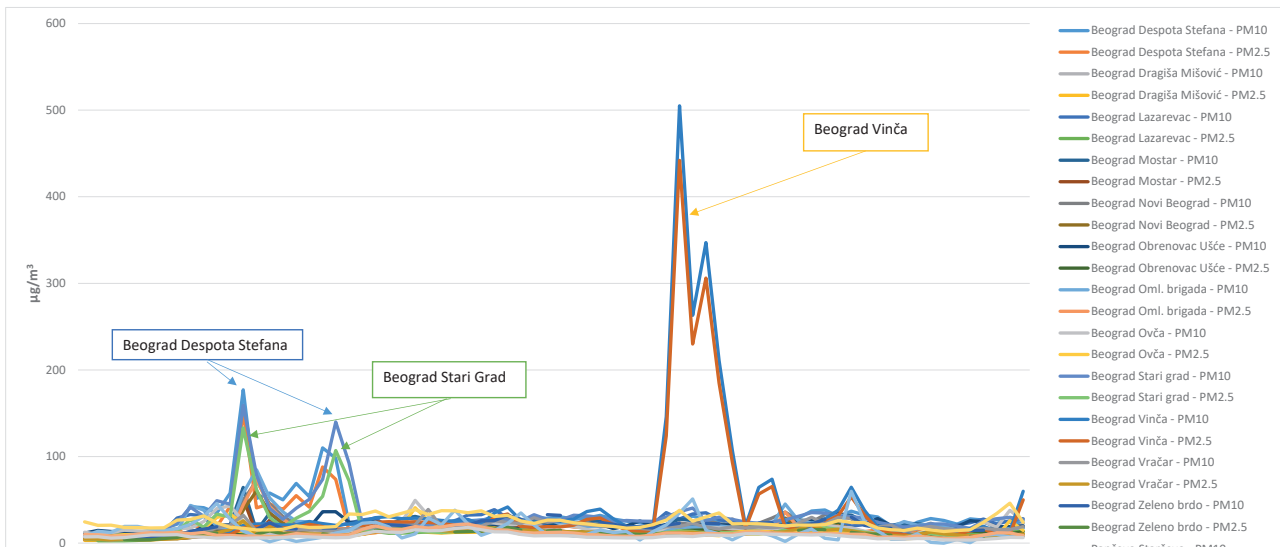


Figure 15. Mean hourly concentrations of PM_{2.5} and PM₁₀ at automatic stations from “citizen” monitoring in the period of observed high concentrations (1.8-10.9.2021)

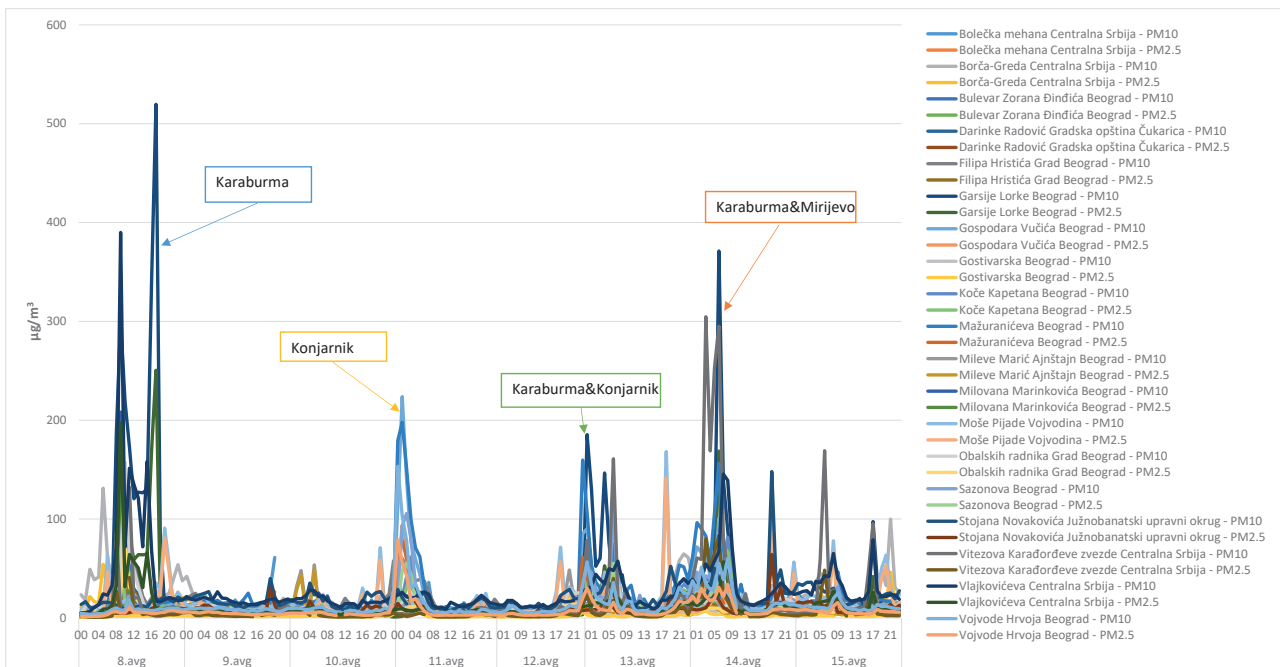


Figure 16. Locations of automatic stations from "citizen" monitoring where PM_{2.5} and PM₁₀ concentration peaks were recorded

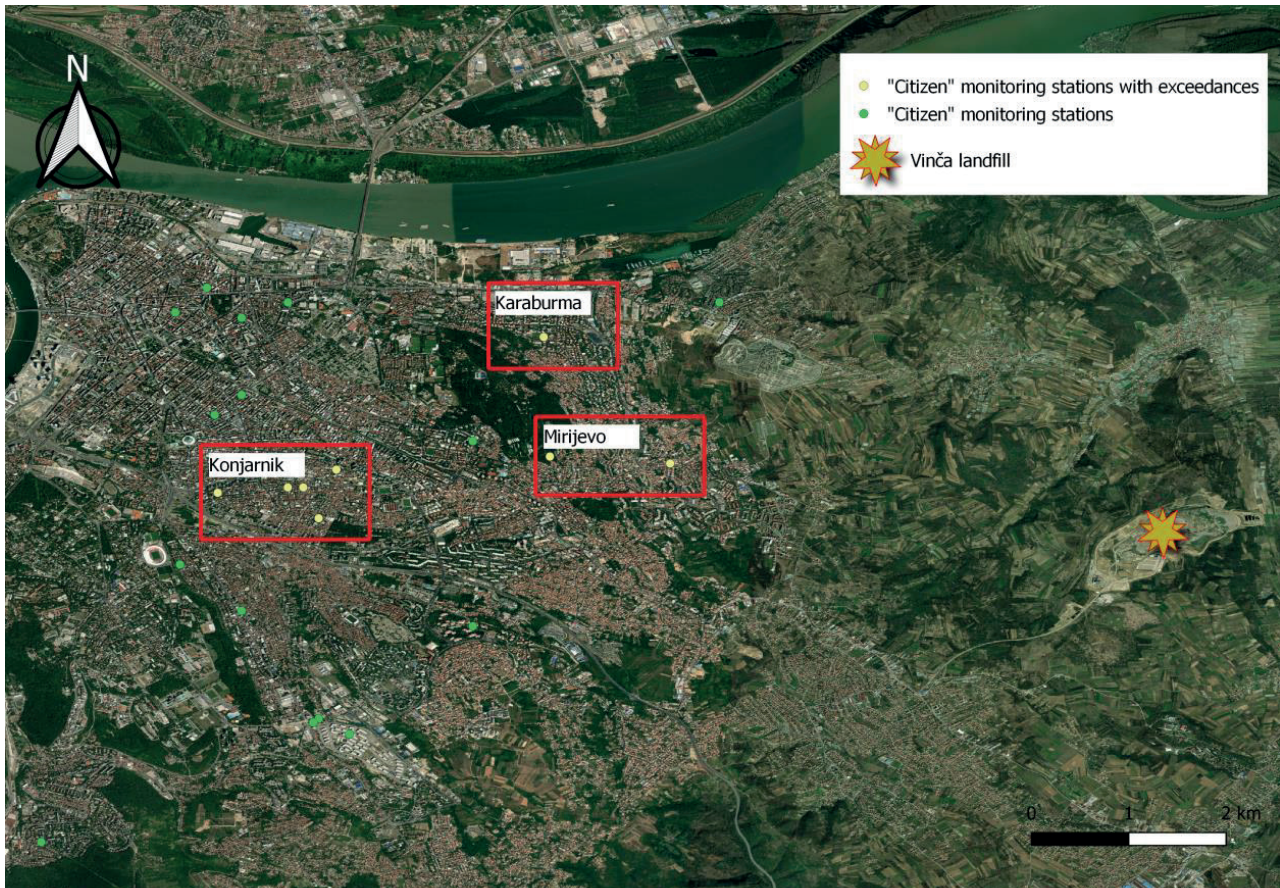


Figure 17. Wind rose in the period from 02:00, 8.8.2021. to 20:00, 8.8.2021. at Nikola Tesla Airport, Belgrade

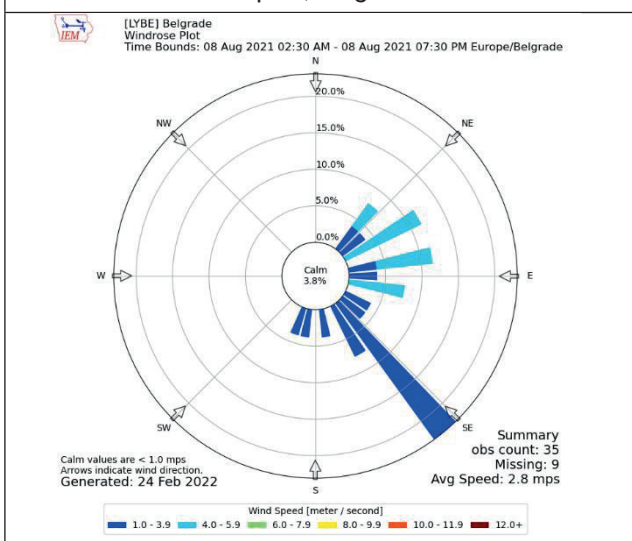
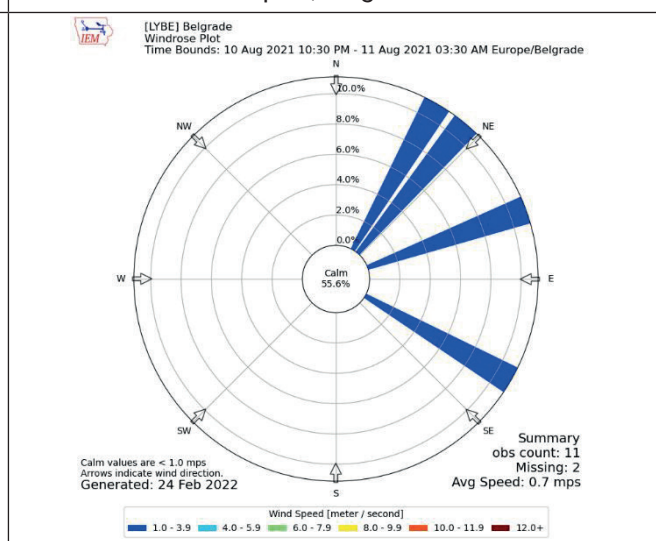


Figure 18. Wind rose in the period from 22:00 10.8.2021. to 04:00 11.8.2021. at Nikola Tesla Airport, Belgrade¹



¹ https://mesonet.agron.iastate.edu/sites/dyn_windrose.phtml?station=LYBE&network=RS_ASOS

According to the City Institute of Public Health Belgrade's report, specifically the section titled "Indicative Measurements of Pollutant Levels Conducted to Establish Fixed Measurements," using the available average daily data from three monitoring points where the potential impact of landfill emissions is monitored (AMS Vinča, BVK Reservoir Stojčino brdo in Mirijevo, and Milena Pavlović Barili Primary School in Višnjička Banja), the following conclusions can be drawn concerning the exceedance of limit values:

On August 9, 11, and 17, at the AMS Vinča monitoring station, concentrations of PM₁₀ suspended particles exceeded the average daily limit value for PM₁₀, which is set at 50 µg/m³ according to regulations. The highest mean daily value recorded was 113 µg/m³ on August 9, 2021. However, on August 10, 12, 13, 15, and 23, concentrations were slightly lower than the limit value but still above 45 µg/m³.

At the Reservoir BVK Stojčino brdo station in Mirijevo and the Milena Pavlović Barili Primary School station in Višnjička Banja, there were no instances of exceeding the daily limit values for the measured pollutants, which include soot, SO₂, and NO₂. Additional analyses of heavy metals (arsenic, cadmium, nickel, and lead) and benzo(a)pyrene were performed four times in August at the first station, while the second location had benzene concentrations analyzed four times as well. Since there are no hourly or daily limit values for these pollutants, any occasional increases would not be adequately represented by annual mean values.

For other pollutants not covered by legislation, except for average annual limit values, it is impossible to provide a qualitative assessment based on the average daily concentrations of heavy metals, benzene, and benzo(a)pyrene at AMS Vinča and BVK Reservoir Stojčino brdo or benzene alone at Milena Pavlović Barili Primary School.

In terms of monitoring suspended particles, both by state and "citizen" measurements, several instances of elevated concentrations of PM particles were recorded, including:

On August 8, in the morning (Palilula, Stari Grad), and then in the evening (Karaburma).

On August 9, in the evening at the Vinča state station.

On August 11, in the early morning hours (Konjarnik and Šumice).

On August 12-13, during the night and in the morning (Karaburma and Konjarnik).

On August 14, in the morning (Karaburma and Mirijevo).

At state stations, the maximum hourly concentrations of PM particles reached up to 177 µg/m³ for PM₁₀ and 151 µg/m³ for PM_{2.5} at the Despota Stefana station in the city center on August 8, 2021, at 12:00. The absolute maximum was recorded at the Vinča station, with PM₁₀ at 505 µg/m³ and PM_{2.5} at 442 µg/m³ on August 9, 2021, at 9 p.m. This episode at the Vinča station lasted for 3 hours with slightly lower concentrations.

According to the CAQI Air Quality Index applied by the City Institute of Public Health Belgrade on its website www.beoeko.com, air quality is considered "polluted" for average hourly concentrations above 55 µg/m³ (PM_{2.5}) and "heavily polluted" for concentrations above 110 µg/m³ (PM_{2.5}) and 90 µg/m³ (PM₁₀). Applying this criterion, there were multiple occasions when the air was classified as either "polluted" or "heavily polluted."

Supplementary resources

Period/Episode	Station	Polluted	Heavily polluted
8/8/2021 12:00 -19:00	Despota Stefana	PM ₁₀	PM _{2.5}
	Stari Grad	PM ₁₀	PM _{2.5}
	Novi Beograd	PM _{2.5}	
	Omladinskih brigada	PM _{2.5}	
8/9/2021 20:00-24:00	Vinča		PM _{2.5} , PM ₁₀
8/11/2021 00:00-08:00	Vinča	PM _{2.5} , PM ₁₀	
8/11/2021 20:00-23:00	Vinča	PM ₁₀	PM _{2.5}
8/15/2021 20:00-23:00	Zemun TB	PM ₁₀	
8/16/2021 09:00	Zemun TB		PM ₁₀
8/17/2021 11:00-16:00	Zemun TB	PM ₁₀	

Regarding the “citizen” monitoring stations, they hold significance due to their greater numbers and their comprehensive coverage of areas in the city that could potentially be affected by smoke originating from the landfill fire, including Karaburma, Mirijevo, Konjarnik, and others. These stations have reported numerous instances of high PM pollution levels, exceeding 180 µg/m³, which qualifies as “heavily polluted” according to the CAQI index, on the aforementioned dates.

In the context of the Regulation on Monitoring Conditions and Air Quality Requirements, as published in the Official Gazette of RS (No. 11/10, 75/10, and 63/13), particularly the sub-law that defines limit values of pollutants based on aggregation and duration (provided in the second chapter of this study), it can be concluded that there were only a few instances of exceeding the mean 24-hour limit values for PM₁₀ particles, which is set at 50 µg/m³. Notably, no mean hourly limit values are defined for PM₁₀, and for PM_{2.5}, neither daily nor hourly limit values are specified—only average annual values. Sulfur dioxide (SO₂) and nitrogen dioxide (NO₂) did not exceed their limit values at all, with the exception of one instance where the average hourly limit value of NO₂ was exceeded at the Vračar station. However, this isolated exceedance cannot be attributed to the Vinča landfill fire. However, this isolated exceedance cannot be attributed to the Vinča landfill fire. A similar number of exceedances could be inferred if the Regulation were applied to stations from citizen monitoring for average daily limit values of PM₁₀ particles, since the civic stations are the only ones relevant in terms of the pollutants monitored (PM_{2.5} and PM₁₀).

Nonetheless, wind data from Nikola Tesla Airport in Belgrade for the selected dates, August 8 and August 10-11, unmistakably demonstrates a direct connection between increased PM particle concentrations and the Vinča landfill fire.

Regarding other pollutants measured in the state system, a spike in the concentration of SO₂ and NO₂ was recorded by the state stations on August 15, but this phenomenon cannot be unambiguously connected with the fire at the landfill.

The fundamental question arises regarding additional pollutants that may have been part of the high-concentration, short-duration PM particles, affecting extensive areas in the densely populated eastern region of Belgrade. Regrettably, there is a lack of supplementary information in this regard.

In terms of data accessibility and public awareness, the City Institute for Public Health in Belgrade's webpage features information about the Vinča landfill fire. It mentions that the Mobile Ecotoxicological Unit of the City Institute conducted on-site measurements of pollutants during several visits to the area. It is also stated that, within the network of measuring points for continuous air quality monitoring conducted by the Institute, an analysis of concentrations and possible exceedances for the monitoring period of 24 hours was performed for: carbon monoxide, nitrogen dioxide, sulfur dioxide and suspended particles below 10 microns. It is also explicitly stated that field measurements did not show exceedances of specific parameters such as polycyclic aromatic hydrocarbons, while the results of these additional analyses are not presented even in descriptive form.

Additionally, the City Administration of Belgrade's webpage, particularly the section managed by the Secretariat for Environmental Protection (http://www.beograd.rs/lat/sekretarijat-za-zastitu-zivotne-sredine_3/), contains daily reports on air quality status. These reports include reviews of concentrations of fundamental pollutants such as PM₁₀, PM_{2.5}, SO₂, and NO₂ at six monitoring points overseen by the City Institute for Public Health Belgrade, namely: Ovča, Zemun, Bulevar Despota Stefana, Novi Beograd, Dragiša Mišović, and Vinča. However, measurement results for polycyclic aromatic hydrocarbons are conspicuously absent on this webpage. Furthermore, automatic stations managed by the Environmental Protection Agency (e.g., Zeleno Brdo, Vračar, Stari Grad, Mostar, Omladinskih Brigada, etc.), as well as those administered by the city of Pančevo (e.g., Vojlovica, Starčevo, etc.), are not included in the monitoring of this situation or in the development of these post-incident reports. Incorporating data from these stations would be highly relevant for comprehensively assessing the overall air quality status during a landfill fire event.



1st photo: 8.8.2021. 11:55 Karaburma and Zvezdara,
taken from Ada Huja, author: Dejan Lekić



Photo 2: 8.8.2021 19:36 Belgrade - Palilula (invisible),
taken from Višnjička Banja, author: Dejan Lekić



Photo 3: 8.8.2021 19:47 Višnjička Street towards the center,
taken from Višnjička Street, author: Dejan Lekić

2.6.

Regarding the monitoring of PCDD/PCDFs and dioxin-like PCBs in the Republic of Serbia (RS), no dedicated measurement is carried out in ambient air within state or local networks, but only in air/waste gas from stationary sources.

However, at the global level, several conventions and programs monitor POPs. Some of the most important, adopted at the level of the United Nations, are the Stockholm Convention on Persistent Organic Pollutants (POPs), and the Convention on Long-Range Transboundary Air Pollution (CLRTAP), which has provided the framework for the work of the EMEP program (the Co-Operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe) for several decades. It was established with the main goal of providing data and information to decision makers in accordance with the CLRTAP Convention by applying qualified scientific methods and in accordance with international protocols. Among other things, concentrations of POPs in the atmosphere are measured at a certain number of stations within the network, which can be directly accessed on the EBAS portal (<https://ebas.nilu.no/data-access/>). Within the RS, only data from the Kamenički vis station (near Niš), managed by the Environmental Protection Agency, is submitted to the EMEP program, featuring a standard set of data on the concentrations of pollutants (SO₂, PM₁₀, O₃) monitored by automatic analyzers, whereas the concentrations of polluting substances in precipitation also used to be monitored.

Within the framework of the Stockholm Convention, a number of Global Monitoring Plans for Persistent Organic Pollutants (POPs) were developed, with the last Third Regional Monitoring Report issued for the region of Central and Eastern Europe (<http://chm.pops.int/portals/0/download.aspx?d=UNEP-POPS-GMP-RMR-CEE-2021.English.pdf>) from March 2021 stating that the focus of the monitoring evaluation is precisely on the geographical region to which RS belongs. Thus, the historical analysis states that passive air sampling was carried out in Serbia in the period between 2003 and 2004, that soil is monitored, etc. Special emphasis is placed on the MONET program led by RECETOX - a research center at the Faculty of Science, Masaryk University, Czech Republic and a Regional Stockholm Convention center. Within this program, which is said to cover the largest POPs monitoring network in Europe in 27 countries, the Fruška Gora station in Serbia is also mentioned.

As part of the cooperation with the RECETOX center, RS institutions participated in two projects of setting up autosamplers to monitor soil and air. This air monitoring via passive air samplers (PAS) confirmed the results of previous studies on the presence of POPs in the air.

As a continuation of the cooperation with the RECETOX center, from 2009 to 2014, within the framework of the MONET project, the presence of POPs in the air was continuously monitored in Serbia, in addition to other countries in Europe and beyond, and Fruška Gora (Hotel Norcev) was chosen as a reference point for measuring POPs using passive samplers. The aforementioned activity in Serbia is continuously and actively monitored and research teams from the Faculty of Technical Sciences, University of Novi Sad, are actively involved in MONET. There are no references regarding the burning and emissions of POPs from landfills in terms of targeted monitoring.

At the national level, data on the emissions of unintentional POPs are also published in the Report on the State of the Environment prepared by the Environmental Protection Agency every year. Seeing as though measures and methods for reducing air pollution with these substances are prescribed as part of the CLRTAP Convention, such as a reduction in the total annual emissions of polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dioxins and furans (PCDD/PCDFs), as well as hexachlorocyclohexane (HCH), the Agency monitors trends in the emissions of these substances in its reports. According to the latest Report for 2020, all of the listed unintentional POPs have a slight downward trend, without reference to the possible contribution to emissions as a result of fires at landfills and dumps, because the methodology for calculating emissions does not include an assessment of emissions from these sources.

There are several other networks in European countries where monitoring is carried out nationally (e.g. the UK Monitoring Program TOMPs (<https://uk-air.defra.gov.uk/networks/network-info?view=tomps>); the Monitoring program in Spain (<https://pubmed.ncbi.nlm.nih.gov/29685685/>)), internationally (Nordic Environmental Research Programmes; Swedish Baltic Programme) and locally (the cities of Gdansk and Krakow) by individual research institutions and government bodies. The Czech Republic is a country with a long tradition of air monitoring activities, which participates in EMEP reporting on POPs through the regional observatory in Kosetič and has an established national monitoring system. These networks aim to identify sources of POPs in the atmosphere, to support inventories of POPs emissions, and assess the relationship between source emissions, levels in ambient air and human exposure based on measured concentrations of POPs in ambient air in urban and rural locations.

AMAP is the Arctic Environmental Monitoring and Assessment Program developed within the framework of the intergovernmental forum that promotes cooperation in the Arctic, which is tasked with, among other things, monitoring and assessing the status of the Arctic region in terms of pollution and climate change. Additionally, the program provides support in the implementation of international conventions including the UN Framework Convention on Climate Change (UNFCCC), the Stockholm Convention on Persistent Organic Pollutants, the Minamata Convention on Mercury and the CLRTAP Convention. In 2021, the program put out the publication “POPs and Chemicals of Emerging Arctic Concern: Influence of Climate Change”, which primarily deals with the multidisciplinary impact of climate change on the appearance of POPs in the atmosphere (<https://www.amap.no/documents/doc/amap-assessment-2020-pops-and-chemicals-of-emerging-arctic-concern-influence-of-climate-change-pre-print/3580>).

3.1

EXPOSURE TO PCDD AND PCDF AND ITS IMPACT ON HEALTH

Dioxin absorption

The key routes for PCDD/PCDFs entering the body are the digestive system (by ingestion), the respiratory system (by inhalation), and skin (percutaneously). Due to properties such as lipophilicity and liposolubility, these compounds easily penetrate through all membrane systems, which allows them to be deposited in target organs and tissues (Krauthacker Bel al. 1989).

Almost 90% of human exposure to PCDD/PCDFs comes from eating contaminated food. These toxins enter the food chain in different ways, being absorbed into the body through the digestive tract, by ingestion. Absorption of PCDD/PCDFs from the ambient air, by inhalation of respirable particles whose cores have these xenobiotics adsorbed, is negligible compared to food intake and amounts to some 8%, while percutaneous absorption is around 2%. It should be noted that there are also other pollutants in the air, like soot, which are also absorbed through the respiratory system, and at the same time affect the increase in the level of PCDD/PCDFs absorbed into the body (Grochowalski A, Chrzaszcz R 1995).

Clinical recognition of dioxin-related diseases can be quite difficult for the physician. Exposure to higher doses of 2,3,7,8-TCDD can lead to chloracne and increased porphyrin excretion and a condition known as porphyria cutanea tarda. Liver function disorders, peripheral neuropathy, hyperlipidemia, as well as manifest weakness and depression may occur after exposure; however, these findings are less specific because diseases and conditions such as diabetes and alcoholism can also lead to these symptoms (Webb KB et al. 1986).

Acute professional exposure to high doses of PCDD/PCDFs and dioxin-like compounds or during industrial accidents can cause persistent skin lesions, better known as chloracne, (WHO, 2002). Employees fighting such fires must be positioned upwind of the burning surface (regardless of its dimensions). In order to effectively reduce the absorption of harmful substances by inhalation or dermally, it is necessary to use comprehensive protective equipment (goggles, gloves, boots, protective suit, mask).

Environmental **exposure causes multiple toxic effects, including immunotoxicity, neurological function development disorders (neurotoxicity) in neonates, while in adults it manifests as polyneuropathy of the lower extremities (occupational exposure) (ATSDR 1998)**. Given that, due to their lipophilic properties, these compounds pass the transplacental barrier, and that contact with the neonate's body is enabled by lactation, it is generally accepted that the most sensitive phases in human development are the fetal and neonatal phases of development (IPCS, 2003; IPCS, 1993).

Experimental studies on animals indicate carcinogenicity in a number of species, at several possible tumor sites. Epidemiological studies dealing with occupational exposure also indicate carcinogenicity in humans, with multiple tumor localizations. The International Agency for Research on Cancer (IARC) classified TCDD in Group 1 (carcinogenic to humans) and some other PCDD/PCDFs in Group 3 (not classifiable as to human carcinogenesis) (IARC,1997; IARC, 2012). PCBs as a group are classified as Group 1 (carcinogenic to humans) (IARC, 2015). In addition, IARC classified 2,3,4,7,8-pentachlorodibenzofuran and 3,3',4,4',5- pentachlorobiphenyl in Group 1 (IARC, 2012).

With **chronic exposure to** dioxins, the appearance of a specific form of porphyria, known as *Porphyria Cutanea Tarda (PCT)*, is possible, which is characterized by hypopigmentation and sensitivity of the skin to physical stimuli (Daniell WE et al. 1997). In addition to the immunotoxic effect, long-term exposure to dioxins (PCDDs) also leads to ulcerative changes on the gastrointestinal mucosa in humans (IPCS, 1989).

Intake of dioxin by **inhalation** not only causes “suffocation” of the lungs, but also penetrates into the bloodstream, which is enabled by its lipophilic properties, passing unhindered through the lipoprotein membranes of the blood-lung barrier. The target organ of dioxin is the liver, so its chronic lesions can lead to carcinogenesis. Exposure to dioxin can lead to an increase in the concentration of cholesterol and triglycerides in the serum, which ultimately results in changes in lipid status and liver function indicators (Calkonsinski I et al. 2014). Long-term exposure to even low concentrations of dioxin alters reproductive functions including infertility, abortion, miscarriage, congenital anomalies, and developmental abnormalities in infants. Many scientists believe that dioxin exposure is responsible for the development of breast cancer in women and reduced sperm count in men. Organic compounds such as PCBs, PCDDs, PCDFs, OCPs belong to the group of compounds recognized as “endocrine modulators” (Garg V 2017).

In addition to the division into symptoms arising after short-term or long-term exposure to dioxin, there is also a division into groups of symptoms according to the dynamics of their appearance in relation to the moment of initial exposure, into early and late ones.

The **early symptoms**, which appear a few days after exposure to PCDD/PCDFs, include: the appearance of persistent chloracne (Neuberger, 1991); mental disorder (depression, apathy, long-term feeling of fatigue) (Hochstein MS et al. 2001); loss of body weight, anorexia (Lensu S et al. 2006); ascites (Hochstein MS et al. 2001); repeated and long-term inflammatory reactions of the airways (Calkonsinski I et al. 2013a); atypical inflammatory reactions (Xu G et al. 2013); hypochromic anemia – disorders of erythropoiesis (Calkonsinski I et al. 2012); susceptibility to infections - immunosuppressive effect (Oehme M et al. 1995); chronic bleeding in the digestive system - due to disorders in thrombopoiesis and fibrinogen synthesis (Calkonsinski I et al. 2013b); menstrual cycle disorder, miscarriage, high fetal mortality rate, reproductive health disorders at a younger age (Yang CY et al. 2011).

Late symptoms may appear several years after primary exposure to PCDD/PCDFs. These include: intrauterine effects: spontaneous abortion (embryotoxic effect) and teratogenic effect (cleft palate, acephaly) (Weber H et al. 1985); carcinogenic effect – various types of malignancy, especially connective tissue (La Merrill M et al. 2010); interaction with solid tissues – disorders of tooth structure and enamel (Dobrzynski M et al. 2009).

Table 1. Overview of studies on determining dioxin concentration in food samples and/or in the population and/or assessing population exposure in regions surrounding municipal waste incineration sites.

Study	Dioxin emission region/process	Type of sample	Analytics	Concentration	Applied method	Note
Moon CS et al. (2005)	Korea Burning process in an incinerator	Serum Workers The resident is a woman Residents - men Sum of male and female residents	17 PCDD/PCDFs	3.14, 8.04, 6,12 i 6.60 pg TEQ/g lipid	HR-GC/JMS	
Schaum J et al. (2010)	Gulf of Mexico Oil burning process	Air Composite sample	Modeled concentration PCDD/PCDFs within 10 m of the combustion site	0.17-0.54 pg TEQ/m ³ 0.2 pg TEQ/m ³	Exposure modeling	

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Burns JS et al. (2009)	Russia/ Chimprom chlorinated chemical production process	Serum of 482 boys in puberty from Chapaevsk, Russia	PCDDs/PCDFs C- PCBs	21.1 pg TEQ/g lipid (14.4-33.2)	HR-GC/SIM- MS	Factors of importance: mother's age, BMI, length of breastfeeding, mother's activity in the garden, distance from the factory if it is less than 2 km, intake of eggs, chicken, dairy products and fish
Kumagai S et al. (2000)	Japan	Settled dust and serum of 30 workers in the incinerator Incineration process	PCDD/PCDFs C-PCBs	4.8, 1.0, 6.4 ngTEQs/g dust; 22.9 pgTEQs/g lipid (part A), 28.8 pgTEQs/g lipid (part B), 23.6 pgTEQs/g lipid (part C incinerator)	HR-GC/JMS	Factors of importance: part of the factory, age, length of employment, Breckman index, BMI
Frery N et al. (2007)	France 1030 adults	Serum Incineration process	17 classic PCDD/PCDFs 4 indicator PCBs	1-2 pg TEQ/g lipid farmers up to 37 pg TEQ/g lipid smokers up to 4 pg TEQ/g lipid	GC-HR/MS	Factors of importance: Age, gender, BMI, change in body mass, farmers, smoking status, household wood burning, recreation, urbanization Food: pork, offal, eggs.
Myrin ES et al. (2014)	Sweden	Combustion of fuel obtained from food waste	PCDD/PCDFs	0.27-0.78 WHO- TEQ-2005	GC-HRMS	
Pilsner JR et al. (2018)	Russia	Russia Adult population 616 exposed as boys at 8-9 years, followed for 19-22 years	PCDD/PCDFs C- PCBs	11.1-56.4 pg TEQ/g lipid	HR-GC/SIM- MS	

Supplementary resources

Collins JJ et al. (2006)		Chlorophenol production process Population 20192 workers Serum	PCDDs C- PCBs	68.4 *(11.4–273.0) WHO-TEQ-2005	GC/MS	Factors of importance: Age, BMI, body mass loss, consumption of fish, game, smoking status, other possible occupational exposure, trade.
Humblet O et al. (2011)	Russia	Serum of mothers of sons in the Chapaevsk region	PCDD C- PCBs	Mothers 0.19 WHO-TEQ-2005 sons 0.36 WHO-TEQ-2005	HR-GC/SIM-MS	Factors of importance: mother's age, Dietary fat content, neonatal characteristics, household characteristics.
Mallon TM et al. (2016)	Iraq, Balag and Afghanistan, Begram	Incineration pits	PCDD/PCDFs + PAHs	Increased concentrations in the exposed population	Proposed GC/HRMS	*the entire paper is not available Factors of importance: demographic
Costopollou D et al. (2007)	Greece Evia, Helia, Arcadia Olive oil Olives	Fires	PCDD/PCDFs + PAHs	Max. 0.51 pg TEQ/g fat Max. 0.156 ppb (PAHs)	HRGC-HRMS (EI) HPLC/UV	Factors of importance: distance from fire and burning of PVC
Vassiliadou I et al. (2009)	Greece Thessaloniki	Fire Land food	PCDD/PCDFs dioxin-like PCBs	7.91 pg TEQ/g soil	HRGC-HRMS (EI)	
Weber R et al. (2015)	Germany	Land eggs	PCDD/PCDFs dioxin-like PCBs	Above the max allowed conc.	HRGC/HRMS And bioassay	Factors of importance: Soil contamination regardless of the incineration location

EXPOSURE TO PAHs AND IMPACT ON HEALTH

Polycyclic aromatic hydrocarbons (PAHs) form a large group of organic compounds that contain two or more joined aromatic (benzene) rings. PAHs have significant adverse effects on human health. Current scientific evidence suggests that PAHs in ambient air are associated with an increased incidence of cancer in exposed populations. A significant connection was established between exposure to PAHs in ambient air and breast cancer, lung cancer and the occurrence of cancer in childhood. Epidemiological studies have shown that PAHs are associated with reduced lung function, worsening asthma, and increased rates of obstructive lung disease and cardiovascular disease. Limited epidemiological evidence also suggests adverse effects on cognitive or behavioral functions in children (WHO, 2021).

Benzo(a)pyrene is considered the main representative of this group of compounds, with proven cytotoxic, genotoxic, carcinogenic, teratogenic and immunotoxic effects (IARC, 1989; Zasadowski A, Wysocki A 2002; Tang D et al. 2008).

Given the widespread distribution of PAHs in the environment, human exposure is widespread. These compounds enter the body by inhalation, through the respiratory tract. Most of them are adhered to the particulate fraction with a diameter below 2.5 μm ($\text{PM}_{2.5}$), which easily penetrates to the distal parts of the lungs (Han X, Naeher LP 2006; Gryniewicz-Bylina B et al. 2005; Šišović A et al. 2008). According to the IPCS (1989), the most toxic of this group of compounds are: benzo(a)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, fluoranthene, indeno(1,2,3-c,d)pyrene and benzo(g,h,i)perylene.

In the EU, B(a)P is on the list of 11 compounds identified as “primary hazardous substances”; according to the Water Framework Directive 2000/60/EC, B(a)P is widely distributed through by-products of incomplete combustion and pyrolysis of carbonaceous fossil fuels (organic matter). After emission into the environment, B(a)P can be detected in ambient air, drinking water, waste water and food treated by burning barbecue coal (charcoal). The degree of emission and the molecular structure are clearly related to the type of combustion source, where B(a)P is primarily emitted into the air, binding mainly to $\text{PM}_{2.5}$ particles (Jovičić SN et al. 2013; Gianelle V et al. 2013). EU Directive 2004/107/EC proposes B(a)P as a marker for carcinogenic risk from exposure to PAHs in ambient air, setting a target value of 1.0 ng/m^3 , as a mean annual value (EC, 2004).

Human exposure to PAHs is most common through food, after the entry of these compounds into the food chain, by deposition of particles from ambient air onto soil and crops, originating from sources of incomplete combustion of solid fossil fuels from households or some other sources, such as landfill fires (WHO, 2000a).

3.2

Examples of Human Biomonitoring Related to Inappropriate Waste Disposal as well as Open Waste Incineration*PCDD/PCDFs human biomonitoring*

Although PCDD/PCDFs have been detected in many human tissues, including kidney, liver, lung, pancreas, and adipose tissue (Domingo JL et al. 2017; Iida T et al. 2007), plasma/blood and breast milk are most commonly used in human biomonitoring (UNEP, 2013; Antignac JP et al. 2016; Brajenović N et al. 2018).

The most well-known area for open waste incineration is Campania in Italy, where there are about 2000 contaminated sites affecting the life of about 2.5 million inhabitants from 57 districts (municipalities, cities) located between Naples and Caserta and called "land of fire/arson". In 32 districts in the province of Naples, mortality exceeds the regional average by 10% for men and 13% for women, while in the 23 provinces of the region in the Cassera area, the average mortality is exceeded by 4% and 6%, respectively. According to the cancer registry of the province of Naples, an increase in the number of tumors of the central nervous system was recorded during the first year of life (+128%) and in the population up to 14 years of age (+42%). The mean value of dioxin toxicity measured in blood by the DR Calux method in 600 inhabitants was 44.9 pg 2,3,7,8-TCDD BEQ/g fat, and the 95th percentile was 73.8 BEQ/g fat. The population of the two exposed regions had significantly higher mean dioxin-like toxicity in the blood (60 BEQ/g fat) compared to the less exposed population group (41 BEQ/g fat) (IZSdM, 2021). Endogenous 17- β estradiol as well as total estrogenic activity were measured in the blood of women exposed to low, medium and high doses of dioxin. Total estrogenic activity was significantly increased in all exposed groups of women, while the level of 17- β estradiol was comparable to the unexposed population. Variation of total estrogenic activity in the range of 3 to 5 orders of magnitude compared to normal values of 17- β estradiol was also observed. The findings indicate the presence of endocrine disruptors in the blood of the tested female population.

In India, women living around landfills had more than 3 times higher TEQ in breast milk (38 pg TEQ/g fat) compared to women living away from landfills (12 pg/g fat) (Kunisue T et al. 2004).

Since 1987, the World Health Organization and UNEP have been testing breast milk for PCDD/PCDFs content on a global level in many countries, with the aim of evaluating trends worldwide, as well as evaluating the effectiveness of measures implemented within the framework of the Stockholm Convention (UNEP, WHO, 2013; Van Den Berg M et al. 2017). Within these measurements, there is no data on the concentration of PCDD/PCDFs in breast milk in Serbia.

Research on PCBs

In New York State, a study was conducted comparing the birth weight of babies born to mothers who lived near landfills and sites contaminated with PCBs versus mothers who lived further away from the contaminated site (Baibergenova A et al. 2003). The birth weight of babies of mothers who lived near the contaminated site was on average 21.6 g less than in more distant areas ($p < 0.001$). After taking into account the baby's sex, maternal age, race, weight, height, education, income, marital status, and smoking, there was still a statistically significant increased risk of 6% for having a low birth weight male child (Baibergenova A et al. 2003).

In a study of breast milk in a population living around a landfill in India, high concentrations of PCBs were detected, indicating that people were exposed to these compounds at a contaminated site (Kunisue T et al. 2004; Kunisue T et al. 2006).

The concentrations of PCBs in eggs in the vicinity of the German landfill exceeded the maximum allowed concentrations of the EU (Weber R et al. 2015) significant for the exposure of children to these compounds, above the tolerable daily intake (Weber R et al. 2018a).

Human biomonitoring and research on PBDEs

Populations living within 10 km of landfills in California had elevated blood levels of PBDEs compared to individuals living >10 km from any landfill (Liu R et al. 2016). Those living within 2 km had 45% higher levels of certain brominated diphenyl ethers such as BDE-47 (95% CI: 5–100%) and BDE-100 (95% CI: 0–109%), and those living between 2–10 km had 35% higher levels of BDE-47 (95% CI: 0–82%) and 29% higher levels of BDE-100 (95% CI: –9 to 82%). No associations were found for BDE-153 (Liu R et al. 2016).

Elevated levels of PBDEs in breast milk have also been observed in women living near a landfill in India (Kunisue T et al. 2006).

Furthermore, children (11 to 14 years old) who lived and collected waste in a landfill in Managua, Nicaragua, had elevated blood levels of PBDEs and OH-PBDEs (Athanasiadou M et al. 2008).

Elevated levels of PBDEs in soil, vegetables, milk and eggs have been documented around unsanitary dumps in Nigeria, leading to human exposure (Oloruntoba K et al. 2021). PBDE soil contamination in the vicinity of an unsanitary dump site due to open incineration was sufficient to result in relevant human exposure via accumulation in eggs (Oloruntoba K et al. 2021).

Monitoring of PFOS, PFOA and other PFAS

For PFOS and PFOA, extensive human exposure and contamination has been documented around contaminated sites including landfills (Oliaei F et al. 2013; US EPA, 2019). Contamination and exposure to PFOS and PFOA, however, is mainly associated with groundwater and exposure via drinking water (Oliaei F et al. 2013; US EPA, 2019). Most of the documented cases of high human exposure relate to sites where PFAS or fluoropolymers were produced and the respective waste was stockpiled (Oliaei F et al. 2013; Liu L et al. 2021). Additionally, the use of PFAS in the processing of animal hides and the production of PFAS-impregnated leather shoes and the associated disposal of industrial waste have resulted in human exposure via drinking water and fines for responsible companies totalling USD 110 million (US EPA, 2019; Malo S 2021).

Since PFAS are leached from all municipal landfills (Busch J et al. 2010; Gallen C et al. 2017; Lang JR et al. 2017; Kim JW et al. 2013), the population around the landfills is at risk from the presence of these compounds, especially if they use groundwater as drinking water or as irrigation water that can lead to food contamination (Brambilla G et al. 2015). Furthermore, if drinking water wells and water intakes used for the production of drinking water for a larger population are near storage facilities and landfills, they may be subject to long-term, low-intensity exposure to PFAS compounds from landfill leachates.

The conclusion of a recent study on PFAS contamination around a landfill in China is that the health risk of exposure to PFAS compounds estimated from daily intake (EDI) through vegetable consumption is alarming (Xu C et al. 2021). The US EPA is currently conducting a major project analyzing 150 landfills in the state of New York as a source of groundwater contamination with PFAS compounds, in order to protect people from exposure (US EPA, 2022). Given that PFAS are continuously leached in significant concentrations, even from landfills closed 30 to 60 years ago (Propp VR et al. 2021), and that PFAS can migrate long distances in groundwater over decades, it is necessary to check drinking wells and irrigation and livestock wells in the wider environment of dumps and landfills.

Biomonitoring is complementary to environmental monitoring because it takes into account the biokinetics or toxicokinetic factors of a given compound.

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