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Air Pollution Series

Wasted Air:

Impact of Landfill Fires on Air Pollution and People's Health in Serbia

- Working Paper -

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Glossary

Asphyxia - suffocation, hunger for oxygen, according to the medical definition, is a condition of impaired gas exchange before, during, immediately after birth, or later in life after injuries and other disorders (Mišić M, editor 2005).

Bioanalytical equivalent (BEQ) is a unit of measure in the field of biological tests. It is used, for example, in the CALUX biological test to test dioxins and dioxin-like compounds (Baston, 2011).

The body of the landfill consists of an organized space for waste disposal with a system to protect the bottom of the landfill from leakage, a system for separating and purifying leachate, a system for degassing the landfill and other technical facilities to ensure the operation of these systems and the stability of the landfill (GRS, 2010).

Dumpsite (wild landfill) is a place, a public area, where various types of waste are disposed of in an uncontrolled manner and which does not meet the conditions established by the regulation governing the disposal of waste at landfills (GRS, 2023).

An emergency situation is a state that is declared by the competent authority when the risks and threats or the resulting consequences for the population, the environment and material and cultural assets are of such scope and intensity that their occurrence or consequences cannot be prevented or eliminated by the regular action of the competent authorities and services, but require use of special measures, forces and means for their mitigation and elimination with an enhanced work regime (GRS, 2018).

Impact factor (IF) of a journal is a description of the influence the journal has in academic or university research circles. It is is a measure of how often the average research article in a journal has been cited or used in other research in any particular year. The IF is used to measure the importance or rank of a journal by calculating the times it's articles are cited. The higher the IF the more influential the journal. (The Oxford Review Encyclopedia of Terms)

Hazardous waste represents waste which by its origin, chemical composition or concentration of hazardous substance, may cause danger to the environment and human health and has at least one of hazardous characteristics determined by special regulations, including the packaging in which the waste was or is stored (GRS, 2023).

An illegal landfill is a place, a public area, where various types of waste are disposed of without control, and which does not meet the conditions determined by regulations governing the disposal of waste in landfills (GRS, 2023).

A landfill is a place for final sanitary disposal of waste on the surface or below the surface of the earth, including:

- internal disposal sites (a landfill where the producer disposes of its own waste at the place of origin),
- permanent sites (more than one year) used for temporary storage of waste, excluding warehouses where waste is unloaded in preparation for further transport to the place of treatment, i.e., reuse or disposal at other locations and storage of waste before treatment or reuse for up to three years, or storage of waste before disposal for up to one year (GRS, 2023).

Municipal waste is separately collected household waste, including paper and cardboard, glass, metal, plastic, biowaste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, bulky waste and mixed municipal waste and/or separately collected waste from other sources, if such waste is similar in nature and composition to household waste, but does not include waste from industry, agriculture, forestry, fisheries and aquaculture, waste vehicles and construction and demolition waste.(GRS, 2023).

The network of public health institutions includes all public health institutes established for the territory of any single administrative district, the Autonomous Province of Vojvodina, and the Republic of Serbia (GRS, 2016).

Non-hazardous waste represents waste which does not possess characteristics of hazardous waste (GRS, 2023).

Particulate matter (PM) refer to suspended particles; the following two are most common: PM10: respirable particles, generally 10 micrometers in diameter and smaller; and PM2.5 : inhalable fine particles, with a diameter generally 2.5 micrometers and smaller (GRS, 2010a).

Public health is a set of knowledge, skills and activities aimed at improving health, preventing, and combating diseases, prolonging, and improving the quality of life through organized measures by society (GRS, 2016).

Public health surveillance is a set of measures and activities carried out periodically and continuously in regular conditions, as well as during an emergency, by the Ministry of Health and the Network of Public Health Institutes, to prevent public health disorders, and encompasses sanitary inspections by the Ministry of Health, epidemiological surveillance in case of an epidemic, but also surveillance of dangers originating from the environment. These activities include collecting data on the health status of the population where a risk to public health has been determined. All activities that make up public health surveillance are defined by laws and bylaws, proposed by the Ministry of Health.

Risk assessment (as part of risk analysis) is a process that consists of hazard identification, hazard description, population exposure assessment and population health risk description. (GRS, 2016)

A sanitary landfill is a sanitary and technically organized space storing non-hazardous waste material generated in public areas, in households, in the process of production, i.e., work, in commerce or use, which has no hazardous properties and cannot be processed or rationally used as an industrial raw material or energy fuel (GRS, 2022).

Seveso plant - a plant where activities are performed with hazardous substances present in concentrations equal or higher than defined by the Seveso II Directive, i.e., a technical unit within a complex where hazardous substances are produced, used, stored, or handled (GRS, 2004).

Toxic Equivalency (TEQ) is the product of the concentration of an individual dioxin-like compound in a mixture and its corresponding TCDD TEF for that compound. (US EPA, 2010a)

An unsanitary landfill is a place where local self-governments dispose of waste in semi-controlled conditions, managed by a public utility company and operating a certain infrastructure (fence, gate, bulldozer), where the body of the landfill is not constructed in accordance with the regulation governing waste disposal in landfills (no waterproof layer, no drainage system for wastewater, etc.) (GRS, 2023).

Vulnerable social groups are groups of the population that are at higher risk of disease than the overall population. (GRS,2016)

Waste treatment includes reuse or disposal operations, including prior preparation for reuse or disposal (GRS, 2023).

Waste management is the implementation of prescribed measures for handling waste during the collection, transport, storage, treatment, or reuse and disposal of waste, including supervising these activities and maintaining waste management facilities after closure, as well as activities undertaken by traders and intermediaries (GRS , 2023).

List of abbreviations

AP Vojvodina - Autonomous Province of Vojvodina

B(a)P - Benzo(a)pyrene

BFR - Brominated flame retardants

BPA - Bisphenol A

BTEX - Benzene, toluene, ethylbenzene, xylene

CLRTAP - Convention on Long-range Transboundary Air Pollutants

CRM - Certified reference materials

EFSA - European Food Safety Authority

EU - European Union

GHG - Greenhouse gases

HBB - Hexabromobiphenyl

HBCD - Hexabromocyclododecane

HCB - Hexachlorobenzene

HRGC/HRMS - High resolution mass chromatography combined with high resolution mass spectrometry

IARC - International Agency for Research on Cancer

IPHB - Institute for Public Health Belgrade

IF - Impact factor

LV – Limit Value

MCCPs - Medium-chain chlorinated paraffins

MEU - Mobile ecotoxicological unit

MIA - Ministry of Internal Affairs of the Republic of Serbia

PAHs - Polycyclic aromatic hydrocarbons

PBDEs - Polybrominated diphenyl ethers

PCBs - Polychlorinated biphenyls

PCBs dioxin-like (dl-PCBs) - Polychlorinated biphenyls with dioxin-like toxicity

PCDD/PCDFs - Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (simplified name - dioxins and furans)

PCNs - Polychlorinated naphthalenes

PCP - Pentachlorophenol

PE - Public enterprise

PeCB - Pentachlorobenzene

PFAS - Per- and polyfluorinated alkyl substances

PFHxS - Perfluorohexanesulfonic acid

PFOA - Perfluorooctanoic acid, perfluorooctanoate

PFOS - Perfluorooctane sulfonic acid or perfluorooctane sulfonate

PM – Particulate matter;

POPs - Persistent Organic Pollutants

PT - Interlaboratory comparisons or proficiency testing programs

PUC - Public utility company

RS - Republic of Serbia

SCCPs - Short-chain chlorinated paraffins

SEPA- Serbian Environmental Protection Agency

SL - Sanitary landfill

TDI - Tolerable Daily Intake

TEF - Toxic Equivalency Factor

TEQ - Toxic Equivalency

UNECE - United Nations Economic Commission for Europe

UNEP - United Nations Environment Program

uPOPs - Unintentional POPs

US EPA - United States Environmental Protection Agency

VOC - Volatile organic compounds

GRS - Government of the Republic of Serbia

WHO - World Health Organization

Contents:

1. Introduction: Purpose, Scope and Structure of the Working Paper

Insufficient handling of municipal waste in the Republic of Serbia results in severe repercussions for both public health and overall well-being.

The consequences of waste accumulation in unsanitary landfills, which are the primary way waste is disposed of in Serbia, are becoming increasingly obvious. The fires that occur at these landfills are becoming more frequent and larger, in proportion to the increase in the amount of waste dumped there. Unfortunately, opening a small number of sanitary landfills and increasing the amount of waste disposed there has not solved the problem of continuous improper disposal of municipal waste and decades of neglect when it comes to this issue.

This study aims to identify the key challenges in municipal waste management and air quality facing Serbia. The results obtained represent a foundation for raising awareness among key decision makers about the importance of this issue and its impact on the quality of life in Serbia.

At the initiative of the United Nations Environment Program (UNEP), the Working Paper was prepared by the Environment Engineering Group in cooperation with Safer Chemicals Alternative (ALHem), and with the support of international and national experts, by reviewing available data and analyzing the current situation, based on which recommendations for improvement are given. Implementing said recommendations would improve the waste management system and air quality monitoring, while continuing the current is expected to lead to a greater number of fires and increasing impact of these fires on deteriorating air quality and human health. The Paper is written in a style which is intended for a very broad audience which includes experts as well as a broader community of decision makers and public policy developers. It often goes into detail to explain both the technical side of the issue, the chemical processes which result in fires and consequent environmental and health hazards, as well as the normative side of the issue, the policy framework, the management and practice which could and should prevent these dangerous events from happening. In this way the authors hope that a broad spectrum of stakeholders could grasp this very complex issue and engage in remedying the situation.

The Paper is composed of the following three units, i.e. Chapters: (2) Impact of waste management on the occurrence of landfill fires (3) Air quality monitoring in this context and (4) Impact of air pollution from landfill fires on human health. It concludes with a (5) Summary of conclusions which point to the gaps in the waste management governing framework and its implementation and a detailed list of recommendations for prevention and reduction of the negative impact of landfill fires on air pollution and human health.

This Working Paper explains that the key to preventing the negative consequences of pollutants released during fires at municipal waste landfills is to prevent fires, i.e., taking measures to prevent the occurrence of fires, providing an adequate response when one occurs, as well as improving the monitoring system to assess the environmental impact, which is the foundation on which public health surveillance is established.

The Paper further finds that if Serbia does not systematically reform its waste management system, but instead continues the current practice of waste management accompanied by a low level of commitment by key actors to dealing with the problem, it will certainly worsen the existing problem and increase the frequency of landfill fires. Climate change, accompanied by an increasing number of "tropical" days and dry periods, in synergy with the large amount of organic waste in landfills will additionally increase the frequency and intensity of fires. The COVID-19 pandemic has further increased the use of disposable packaging and disinfectants, and thus the amount of packaging waste from disinfectants and hygiene products. These types of materials can further complicate the response to fires and their consequences on the environment. The hazardous nature of the pollutants released during landfill fires and their serious impact on health are the key reasons to work on solving this problem. The lack of adequate monitoring for specific pollutants as well as a system for informing the population about preventive health protection measures enables pollutants to reach our bodies via inhalation or indirectly through food and cause diseases that can have a fatal outcome. This situation requires that certain activities be undertaken immediately, to clearly define the locations most at risk and provide necessary preventive measures, to establish an adequate pollution monitoring system and an early warning and notification system.

The impacts of pollution on human health are costly. Due to biological and social factors, pollution impacts women, men and children in different ways leading to developmental deficiencies and illnesses depending upon the levels of exposure and this is sometimes linked to gender roles and/or socioeconomic status. Taking an integrated approach to waste management is thus an effective way of ensuring policies and strategies are not only more effective by catering to the needs of everyone is society, but also by making progress towards the SDGs in an efficient way and within the narrow timeframe we have left.

In conclusion, this Paper shows that integrated approach requires all relevant stakeholders and the society at large must take responsibility and start managing waste in accordance with the principles of circular economy and sustainable development. This is the only way to keep the waste around us from ending up inside us.

2. Impact of Municipal Waste Management on the Occurrence of Landfill Fires

2.1. Waste Management in Serbia

The system of municipal waste management in Serbia is underdeveloped, with waste most often disposed at unsanitary landfills used by communal services or dump sites without any kind of prior selection or treatment. This type of waste management poses a significant risk to the environment and human health because unsanitary landfills/dump sites and illegal landfills have no systems to prevent the spread of pollution from waste into the environment and are often fire hazards. According to National Waste Management Program for period 2022. – 2031. (GRS, 2022) only 20% of the collected waste ends up in sanitary landfills.

Modest progress in the waste management system is particularly noticeable in managing municipal waste, which is mostly generated in households, with local self-governments being responsible for its collection, transportation, treatment, and disposal. As a result of a shortage of sanitary landfills, local communal services resort to depositing gathered municipal waste on unsanitary landfills, often with inadequate or minimal measures in place to regulate and safeguard the environment. That is the main reason behind the fact that the largest number of fires occurs on these places. Due to the ineffective oversight of businesses, industrial and hazardous waste can very often be found at these landfills, creating an additional danger to the environment and human health. As a rule, municipal waste also contains hazardous household waste, which is mixed with it and disposed of together, so when a fire breaks out, this waste becomes a source of the most dangerous compounds with a direct harmful effect on human health. Hazardous household waste consists of all materials that directly endanger the health of people and animals and reduce the quality of the environment, such as waste batteries, packaging waste from households chemicals, pesticides, paints, oils, cleaning agents, glue, fluorescent tubes and mercury lamps of all types, accumulators, pressure vessels, sprays, motor oils, packaging and filters for motor oils, residues of medicines and cosmetics, items containing mercury and various other items containing dangerous elements and compounds.

Due to the complexity of the problem this paper will focus primarily on municipal waste and the consequences of fires at unsanitary landfills/dump sites.

2.1.1. Illegal landfills (dumpsites)

Illegal landfills or dumpsites exist primarily due to the lack of adequate system which would ensure coverage of 100% of the population with municipal waste collection and transportation services, so illegal landfills are most often created in rural and semi-rural areas, where the system for collecting and transporting municipal waste is not established or is insufficiently organized (GRS, 2022).

According to data from the Environmental Protection Agency, the average coverage of municipal waste collection in 2020 is 86.4%, which is an increase of 0.2% compared to 2019, but is still lower than in 2018, when it was 87.2% (SEPA, 2021a).

The total number of recorded illegal landfills according to data from the Environmental Protection Agency is 3,319 (SEPA, 2021a), while according to data from the Government of the Republic of Serbia, this number is over 3,500 (GRS, 2022).

Illegal landfills are "beyond the control of municipal utility companies", with widely different sizes and risk factors, and it is estimated that about 20% of municipal waste ends up at these landfills (GRS, 2022), but due to the lack of any kind of control, there is a high probability that other types of waste end up mixed in with municipal waste in illegal landfills.

Illegal landfill clean-up efforts requiring significant resources have yielded very few results. Namely, out of 905 illegal landfill sites that were reported to have been cleaned during 2020, waste was again dumped at 855 locations (SEPA, 2021a). This further indicates that without a systematic approach, full coverage by municipal waste collection services and effective inspection, the re-accumulation of waste at the same or at other locations and creation of illegal landfills cannot be prevented.

The scope of municipal waste collection throughout Serbia is on trajectory to reach up to the necessary 100% in 2031 (GRS,2022), which clearly indicates that, in the coming period, we can expect that the practice of waste accumulation in illegal landfills will be continued. Larger amounts of waste in illegal landfills, along with other factors, realistically lead to increased risk of fires on those sites, thus increasing the negative impacts on health and the environment.

To prevent this, a system of municipal waste collection must be established as soon as possible, covering 100% of the population and preventing the creation of additional illegal landfills. The locations, quantities and types of waste disposed of in existing illegal landfills must also be considered, and their level of risk to health and the environment assessed, with remediation and reclamation being prioritized based on the results of the risk assessment. The system of inspection supervision must be further improved to ensure that waste is disposed of in designated places, instead of at illegal landfills.

Most local self-governments have their own unsanitary landfills/dump sites, which were planned to be rehabilitated and closed, according to the Waste Management Program for the Period 2022-2031 (GRS, 2022). These landfills fail to meet even the minimum technical standards, there is no controlled discharge of landfill gas, leachate is not collected and treated, there is no systematic monitoring of emissions, 70% of these sites are not included in spatial planning documents and do not have a study on environmental impact assessment, nor the necessary permits. (Vasović D et al. 2023)

Data on the sizes and volumes of the landfill bodies are not reliable due to the lack of technical documentation. These landfills are typically situated on property owned by the Republic of Serbia, with their ages ranging from 4 to 60 years. (SEPA, 2021a) According to reports submitted to the Environmental Protection Agency by 144 local governments, PUCs dispose of waste in 138 landfills located in 114 local governments, of which 22 landfills are inactive and 116 are still in use. Out of 116 landfills currently in use, 107 are unsanitary.

Out of the total number of unsanitary landfills, waste disposal takes place without any control at 40, it is sorted at 56, and disposed of layer by layer at 33. At 123 landfills, it was reported that the disposed waste was partially or completely covered with inert material. 23 landfills are in whole or in part in floodplains. No waste collection records are kept at 59 unsanitary landfills. Rehabilitation, closure, and remediation projects have been prepared for 92 landfills, 41 of which are being carried out in full or in part, while a new or updated remediation project is required for 53 landfills (SEPA, 2021a).

Table 1. Estimated period of unsanitary landfills exploitation (SEPA, 2021a)

Estimated period of exploitation	Number of unsanitary landfills
Up to 3 years	22
3-5 years	20
Over 5 years	47
Emergency closure and remediation	49
In total	138

In the year 2020, Serbia produced a total of 2.95 million tons of municipal waste. Out of this, 2.34 million tons were successfully collected and properly disposed of. Approximately 19% of the total generated municipal waste, equivalent to 558,568 tons, was directed to sanitary landfills for disposal. (SEPA, 2021a)

A significant portion of the waste is being informally collected and recycled by informal waste collectors. Different analyses from international organizations and development agencies such as the World Bank, GIZ, and UN agencies recognize the issue of the informal waste pickers (secondary raw material collectors) as an important piece of the puzzle in transforming waste management sectors in developing countries. Serbia, however, is not a developing country but this is an important factor (GIZ,2018). There is a significant community of waste collectors mostly Roma men, women, and children. "Around 8,000 families in Serbia are engaged in the collection of secondary raw materials, with a quarter of workers aged under 18. A collector's life expectancy, ca. 46, is much shorter than of other members of the Roma population" (Ćurčić D et al. 2016). The status of Roma in Serbia is a well-covered topic. Roma face harsh poverty, social exclusion. Waste picking is often their only chance of informal employment.

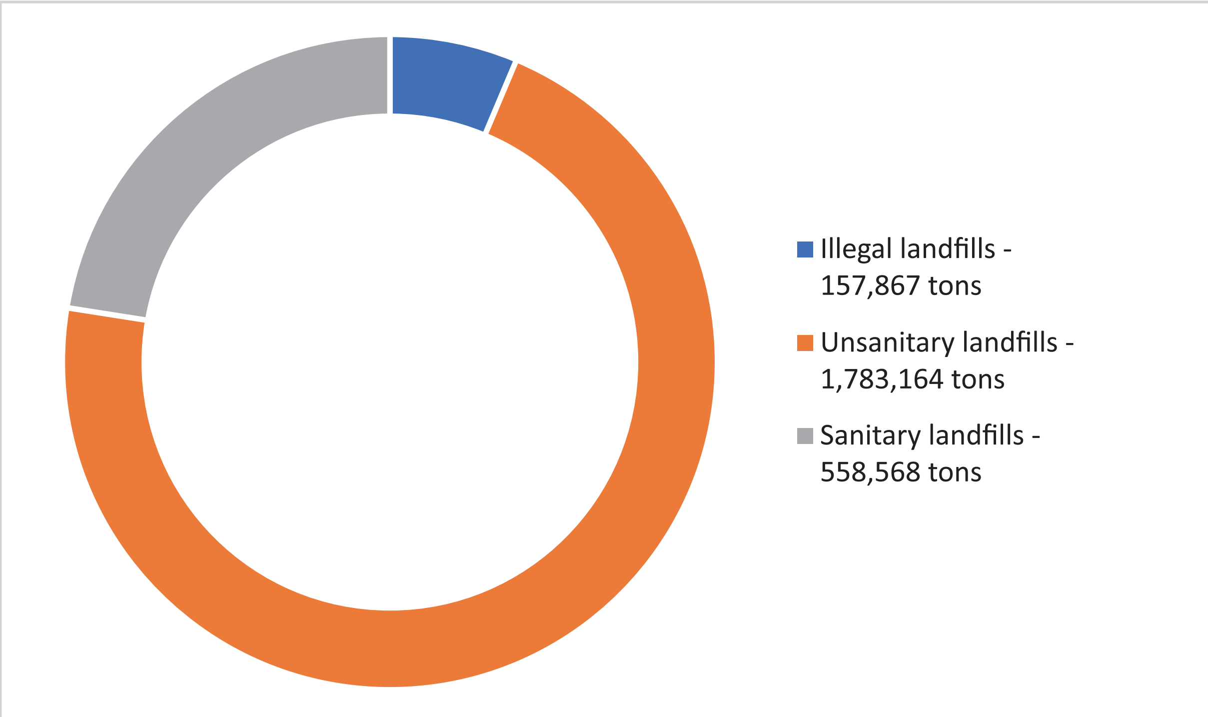

Figure 1. Disposed municipal waste, in tons (SEPA, 2021a)

Out of total 2,947,496 tone of generated waste in 2020. in Serbia, only 558,568 tone was disposed on sanitary landfills, 1,783,164 tones were disposed on unsanitary landfills and 157,867 tones on illegal landfills.

Despite an observable trend showing an increase in waste disposal at sanitary landfills, a significant portion of the collected municipal waste continues to be deposited in unsanitary landfills, often categorized as illegal landfills.

Unsanitary landfills/dump sites are estimated to hold over 80 million cubic meters of waste (FTS, 2009; SEPA, 2021a).

Unsanitary landfills/dump sites are planned for closure until 2034 (GRS,2022), which means that until that time, we should expect that a part of the generated municipal waste will end up at these sites.

All the above leads us to conclude that unsanitary landfills are the priority when it comes to preventing pollution from landfills, because they contain the largest amounts of waste, are often located near large settlements and watercourses, and fail to ensure even the minimum technical conditions to prevent the free penetration of the resulting pollution into the environment, and thus its impact on human health.

To best reduce their negative impact, a detailed assessment of their risk to human health and a fire risk assessment must be made, based on which preventive measures could be implemented, reducing the risk of fires, adopting clear procedures in case of fire, and protecting public health. Additional efforts are needed to motivate local governments to establish regional waste management systems and comply with regulations in this area, with adequate inspections by competent institutions.

As a result of underdeveloped waste management system, limited to collection and disposal without any prior separation, all environmental media and organisms living therein are being contaminated. The ambient air pollution from the ignition at the unsanitary landfills and dumpsites, uncontrolled waste burning and odors from organic waste decomposition, travels further with the wind reaching wider populated urban areas (Petrovic M et al. 2018). Moreover, the presence of persistent organic pollutants (POPs) resistant to various degradation processes, which are often found in the municipal mix, pose an additional risk to the environment and health of the population living in the vicinity of unsanitary landfills and dumpsites (Đogo M 2017, Petrovic M et al. 2018), especially during the fire accidents.

2.1.2. Sanitary landfills

The recent construction of sanitary landfills has notably enhanced the waste disposal situation, ensuring a more environmentally safe disposal process. A total of 12 sanitary landfills have been established in the Republic of Serbia, contributing to improved waste management practices. (SEPA, 2021a)

Although currently only "19% of the generated municipal waste is disposed of in sanitary landfills" (SEPA, 2021a), establishing a system of selection and treatment of waste to prevent disposal of waste that still has use value, i.e., that can be used for recycling, composting or incineration, is crucial to ensure their functionality within the operational period they were built for.

Because, during 2020, only 455,457 t (15.45%) of municipal waste was recycled, and over 2,340,000 t of municipal waste was disposed of by PUCs in all types of landfills (GRS, 2022), it is evident that unless the waste management hierarchy is respected, and an efficient system of selection and treatment of waste before disposal is introduced, the lifespan of sanitary landfills will be much shorter. It should also be pointed out that due to economic development and growth in purchasing power, increase in waste production per capita is expected, as well as a transfer of waste disposal flows from illegal and unsanitary landfills to sanitary landfills.

In order to make the best use of sanitary landfills, it is necessary to ensure that only waste that cannot be further used or is left over after the waste treatment process is completed, is deposited at these sites. This requires the introduction of a waste selection system that will allow most of the waste to be recycled or reused before disposal. Special attention should be paid to preventing the mixing of hazardous waste with municipal waste.

2.1.3. Morphological composition of waste

In 2020, the morphological composition of waste was dominated by biodegradable waste, with a share of 48.4% (SEPA, 2021a). This situation, in conjunction with the method of disposal in illegal and unsanitary landfills/dump sites, leads to an uncontrolled production of landfill gas, as well as risks arising from the unknown amount of flammable matter present, and failure to implement adequate landfill management measures.

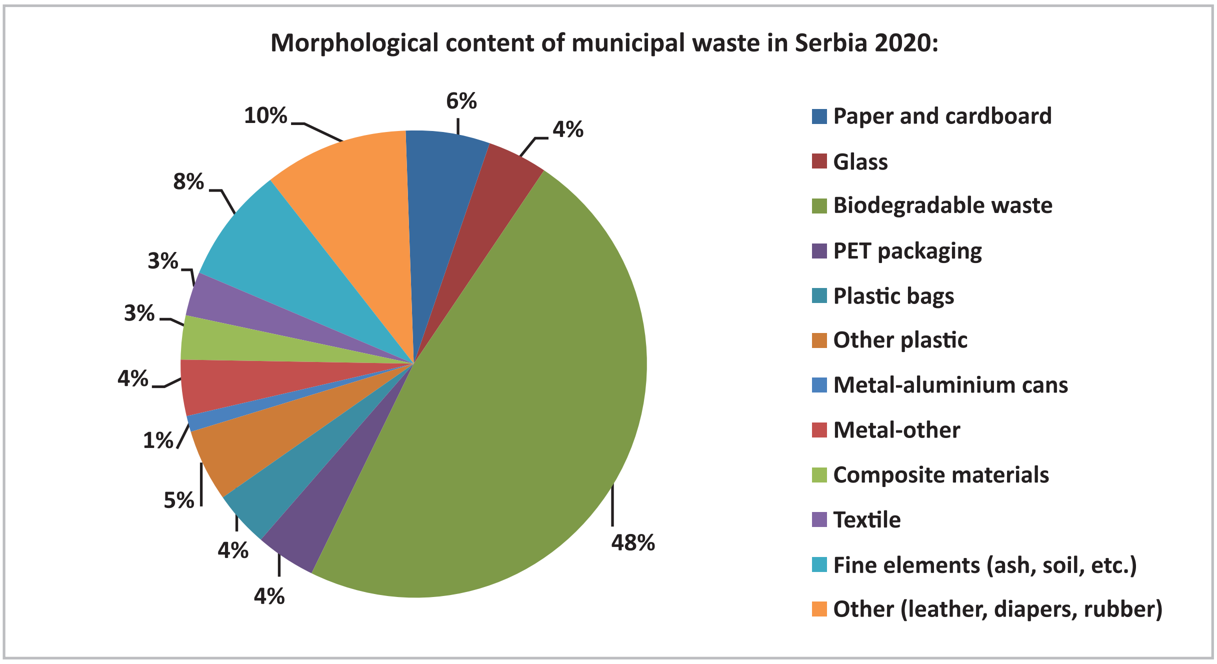

Figure 2. Morphological composition of municipal waste in 2020 (SEPA, 2021a)

Although the National Waste Management Program state that the “data on quantities, types and composition of waste is the starting point in the waste management planning process”, and that the “planning process must be based on a reliable database of existing waste quantities, sources and types, as well as the existing management method” (GRS, 2022) the lack and inaccuracy of these data are noticeable in practice and reflect on inadequate implementation of the requirements of the Law on Waste Management and its bylaws.

Special attention should be paid to the fact that, for decades, the waste management system in Serbia was based on collection and disposal without proper control of waste streams, and that industrial waste management was not systematically organized, resulting in the mixing of hazardous and non-hazardous industrial waste with municipal waste, which ended up in illegal landfills and unsanitary landfills/dump sites. Although the situation with medical waste has improved somewhat, part of it, in addition to pharmaceutical household waste, ends up in municipal waste.

It can therefore be concluded that there are large amounts of municipal waste in unrehabilitated landfills/dump sites, which have been accumulating for decades and will continue to accumulate. In addition to municipal waste, the landfilled waste also contains hazardous household waste, and there are locations where it is probably mixed with hazardous and non-hazardous industrial waste.

A large percentage of organic waste that is disposed of generates landfill gas such as methane, which creates a serious risk of fires and explosions in landfills, as well as the risk of pollutants spreading through the air and all other environmental media.

To establish an adequate waste management system, it is primarily necessary to provide reliable data on the quantities and types of waste that are collected, treated and disposed of. Based on reliable data, a system to reduce waste generation, its proper treatment and recycling must be built. Special attention should be paid to reducing the disposal of biodegradable waste, since it is the main cause of landfill gas as well as plastics which is a major fuel for landfill fire.

2.2. Impact of Municipal Waste Disposal on Air Pollution in Regular and Crisis Conditions

According to Petrovic M et al (2018), "inadequate waste disposal leads to the contamination of all environmental media (water, air, soil and biota)". Water that percolates through the body mass of the deposited waste dissolves various substances, which go on to reach the groundwater through horizontal and vertical migration. Contamination of ambient air and soil in the vicinity of landfills is an additional problem, due to the spread of waste by "wind, uncontrolled burning of waste, and evaporation of components of organic origin".

Numerous toxic and dangerous organic and inorganic substances, as well as mixtures of unknown composition that have the possibility of further complex interactions, are generated by complex physical processes, chemical and biochemical reactions in the body of the landfill. External conditions, such as temperature, humidity, pressure, wind speed and wind direction, affect the flow and speed of chemical and biochemical reactions and, consequently, the generation of various toxic substances. Depending on the type of waste that is disposed of hazardous substances from the group of organic pollutants can be registered and identified with great certainty in environmental media in the immediate vicinity of landfills. The persistent release of POPs into the environment is frequently linked to industrial waste. However, it is now widely recognized that substantial quantities of chlorinated, brominated, and fluorinated POPs, present in commonly used items such as electronics, textiles, furniture, upholstery, insulation foam, synthetic carpets, and impregnated paper, have been disposed of without proper control in municipal waste landfills for an extended period. (Chrysikou L et al. 2008; Weber R et al. 2011; Lou Z et al. 2016).

2.2.1. Landfill gas

The basic precondition for fires and explosions at landfills is the generation of landfill gas. Landfill gas is generated in all landfills where biodegradable waste is disposed of and is a by-product of aerobic and anaerobic biodegradation of the biodegradable part of municipal waste.

Methane (CH_4) and carbon dioxide (CO_2) are the two main key components of landfill gas. However, it may also contain many other impurities in minor amounts, including sulfides, disulfides, nitrogen, ammonia, carbon monoxide, oxygen, hydrogen, water vapor, as well as mercaptans, volatile organic compounds (VOCs), and many other organic gases. Previous studies of environmental media on landfill sites, primarily landfill leachates, showed the presence of toxic heavy metals, cadmium, lead, mercury, copper, iron and other metals and semimetals, as well as anions NO_2^- , NO_3^- , PO_4^{2-} , SO_4^{2-} and others (Christensen TH et al. 1994; Chu LM et al. 1994; Kjeldsen P, Christophersen M 2001; Kjeldesn P et al. 2010; Stanisavljević N et al. 2012; Vujić G et al. 2010). A health risk may occur when landfill waters migrate through groundwater to surface waters. (Przydatek G 2019; Khalil C et al. 2018; Mishra H et al. 2018; Naveen BP et al. 2017). There are documented cases of spontaneous landfill gas explosions and fires that have caused loss of life and injury to people, as well as property damage.

Also, the presence of increased concentration of carbon monoxide (CO) in the landfill gas indicates that fires occur under layers of disposed waste.

Many compounds found in landfill gas impurities are known as smog factors or as reactants in the smog formation process. Therefore, landfill gas contributes to local air pollution.

In addition to methane, carbon dioxide is the most abundant constituent of landfill gas. Both gases are well known greenhouse gases (GHG). However, due to its higher infrared absorption capacity, methane has a much higher potential as a GHG compared to CO_2 , 25 to 28 times higher over the 100 years' timeframe (IPCC, 2014), or more (on the basis of mass). Due to the contribution of CH4, landfill gas that is not collected or burned (escaped gas) is considered a potential and significant factor contributing to global climate change and global warming.

2.2.2. Air pollution caused by landfill fires

Air quality at landfills is primarily threatened by the fires therein. This is due to the fact that most of the unsanitary landfills used by communal services across Serbia do not have a landfill gas removal system, which can result in ignition, and even explosions at landfills. According to the data of the Ministry of Internal Affairs of the Republic of Serbia - Sector for Emergency Situations (MIA, 2022), the number of registered fires at landfills is constantly increasing.

Table 2. Number of landfill fires in Serbia

Year	2016	2017	2018	2019	2020	2021
Number of fires	584	1,296	950	1244	1205	1715

During 2021, an area of 42,220,376 acres was affected by 1,715 landfill fires (MIA, 2022).

Illegal and unsanitary landfills pose a heightened risk of surface and subsurface fires, primarily attributed to the accumulation of landfill gas and the inherent properties of the deposited waste. A significant part of landfilled waste becomes fuel with medium or high energy value (e.g., plastics) during a fire, which implies the positive correlation between the amount of landfilled waste and landfill gas contained in it, increasing the risk of fire.

Fire breakouts are especially engendered by the warmer weather and high temperatures that occur during the summer months, during which the intensity of solar radiation is higher, and the amount of precipitation is lower. Due to climate change, an increase in dry periods, the number of “tropical” days and an increase in temperature can be expected, which will further affect the occurrence of fires landfills in Serbia.

The absence of a landfill gas management system, along with inadequate cover layers, combined with the impacts of climate change and slow improvement of the waste management system in Serbia, raises concerns about a significant anticipated rise in both the frequency and scale of landfill fires.

However, fires where methane from landfill gas plays an important role are caused indirectly. In conditions of high ambient air temperature, the body of the landfill is harder to cool, i.e., it releases excess heat generated inside waste layers in the process of biological and chemical decomposition of organic matter. However, this increase in temperature is usually not significant enough for spontaneous ignition of landfill gas. The dominant reasons for the initial spark of flames at landfills include the disposal of combustible (unburned) materials such as plastics and embers or pieces of unburned wood, access to open flames, the intentional burning of waste, or the presence of flammable types of waste in landfilled waste.

Another increasing source for ignition of fires in landfills and other waste management facilities are lithium batteries which will also further increase (US EPA,2021a).

Depending on the prevailing conditions for the degradation of organic matter (depth of waste, organic matter content, oxygen penetration, humidity, etc.), the amount and composition of landfill gas changes. The theoretical conditions for the breakout of fires at landfills can be created at any time of year, but they are much more likely to coincide in the summer, when, due to high air temperatures, more hours of intense sunlight, and no precipitation, the moisture content decreases, especially in the upper layers of waste. These are precisely the conditions that favor the spark of an initial flame, which can then ignite the landfill gas and thus spread throughout the landfill.

As unsanitary landfills do not have landfill gas management systems, which entails the control of quantities, composition, movement, discharge from the landfill body and potential utilization of the gas, once a flame is generated, the conditions for the spread of uncontrolled fire are created as well.

The body of the landfill can be seen as a reservoir of different quantities and compositions of landfill gas, which is pressurized due to the continuous generation of new quantities of gas. In uncontrolled conditions, the gas can flow out through the surface of the landfill body at any place with different intensities. It is for this reason that fighting and extinguishing landfill fires is a complex and time-consuming process. Extinguishing fires at landfills often takes several weeks.

According to the Purser DA et al. (2016), Wakefield JC (2010) and Griffiths SD et al (2018), “depending upon the source of the fire, **the fire emission plume** will comprise a complex mixture of gaseous airborne toxicants and PM, including:

- **asphyxiants**, such as carbon monoxide (CO), hydrogen cyanide (HCN), and carbon dioxide (CO2)
- **irritants**, including sulfur dioxide (SO2), nitrogen oxides (NOx), phosphorus pentoxide (P2O5), hydrogen chloride (HCl), hydrogen fluoride (HF), hydrogen bromide (HBr), acrolein and formaldehyde
- a range of **complex organic contaminants** including polycyclic aromatic hydrocarbons (PAHs), PCDD/PCDFs and other unintentionally produced POPs
- **PM** is also produced, and these may contain **adsorbed metals** and organic contaminants."

Special emphasis is placed on POPs, due to their properties, i.e. the long-term impact they have on human health and the environment, as well as through accumulation in the food chain. In Supplementary resources (EEG, 2023), a more detailed overview of these substances is given on the basis of peer-reviewed international scientific publications.

According to the Stockholm Convention on Persistent Organic Pollutants (POPs), "Parties are required to reduce total releases from anthropogenic sources of unintentional POPs with the goal of continually minimizing and, where feasible, ultimately eliminating releases of these unintentionally produced chemicals". One of the sources of unintentional POPs emission is open burning of waste. Republic of Serbia is a party to the Stockholm Convention and as a party, it has an obligation to prepare a National Implementation Plan (NIP) for the implementation as well as set of actions to further identify and address the release of unintentional POPs. As prescribed by the Convention, Action plans, amongst other things, "include evaluations of current and projected releases that are derived through the development and maintenance of source inventories and release estimates" (UNEP, 2013), whilst simultaneously addressing the human dimension through the adoption of gender-responsive policies on hazardous chemicals and waste. Serbia adopted the initial NIP and specific action plan for uPOPs in 2010, however, updates are not adopted by the Serbian government even though financial support for updates was provided.

Based on the available data on the affected surface area during landfills/dumpsites fires in 2021 estimates are that the emission of unintentionally produced POPs is in a range of 63 to 190 grams TEQ PCDD/PCDFs (Figure 3.). As the information on the volume of the waste affected by the fires is not available, the volume was calculated based on the date of average depth affected by the surface fires on landfills/dumpsites. The surface fires on landfills affect from 0.3m to 1.2 m.[1]

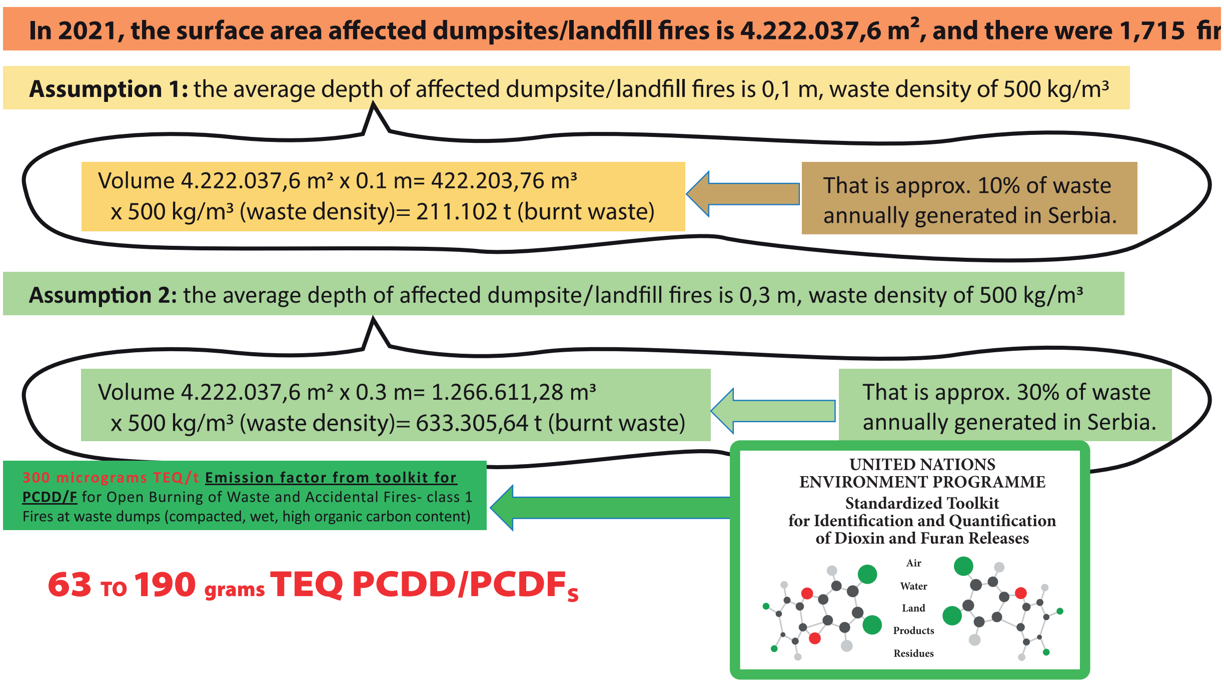

Figure 3. Estimation of the emission of unintentionally produced POPs for 2021, a summary of the calculation model

[1] More information available at: www.wasteadvantagemag.com/landfill-fires

The estimation assumes that the depth of affected dumpsite/landfill fires is 0.1- 0.3 m and the average waste density is 500 kg/m3. Lower depth of 0.1 m was used as obtained data from the calculation of volume of burned waste and the amount of waste generated in one year in Serbia was compared. If the average depth is 0.1 m translates that 211.102 t of waste was burned in 2021, what is 10% of waste annually generated in Serbia. If the average depth of burned waste is 0.3 m then 630.000 t waste was burned and representing 30% of waste annually generated in Serbia. The 1.2m as the average depth affected by the surface fires on landfills/ dumpsites was not used in calculation because than calculation shows that 2.5 million t of waste is burned, and it is the amount of annually generated waste in Serbia. The emission factor from the Toolkit for Open Burning of Waste and Accidental Fires- class 1 Fires at waste dumps (compacted, wet, high organic carbon content) was used and it is 300 micrograms TEQ/t.

In order to obtain the more precise data on the mass of incinerated waste, in addition to the area covered by fires, it would be necessary to have data on the affected depth and density of waste.

To some extent, The Sector for Emergency Situations of the Ministry of Internal Affairs records the location, number of rescue firefighters, number of vehicles and other important data related to a specific emergency event for each individual fire at landfills (MIA, 2022), but the data are in narrative format and cannot be summarized automatically.

Extinguishing fires at landfills requires calling in fire and rescue units, fire trucks and other resources for a prolonged period, incurring significant costs. In addition, during landfill fires, the mobility of fire and rescue units and their readiness to react to other emergencies decreases (fires in residential buildings, rescuing citizens in traffic accidents, chemical accidents, etc.) (MIA, 2022). In addition to occupying fire and rescue units, larger fires cannot be extinguished without the additional engagement of the local community, which must provide additional mechanization and inert material, which are key resources for fighting and extinguishing landfill fires. If these resources are not provided, there is the danger of the fire spreading further and being extinguished later, thus producing a larger number of pollutants.

2.3. Prevention of Air Pollution during Waste Disposal

Establishing a proper waste management system and adequate waste sorting, treatment and disposal plays the key role in the prevention of air pollution during waste disposal. The most significant and most dangerous air pollution from landfilled waste is caused by fire, which, in addition to pollution that directly endangers employees and the local population, most often causes significant damage to infrastructure and, as mentioned above, high costs for extinguishing.

The risk of fire increases with the growth of the amount of landfilled waste and with inadequate application of landfill management measures, which can be divided into preventive and emergency measures.

Unsanitary landfills can be large stocks of flammable material, with a very high energy value. These materials can cause surface and deep fires. In order to understand the reasons behind occurrences of landfill fires means one would have to consider the entire fire triangle: what is the fuel, how much oxygen is available, and where the ignition source is located.

Considering the state of waste management in Serbia and the increase in the number of fires that break out at landfills, we can expect that this trend will continue. Therefore, it is crucial to implement measures to prevent fires and clearly define measures to respond to fires, all with the aim of reducing risks to human safety and health and reducing environmental pollution.

For the successful prevention of fires, it is extremely important to ensure that all municipal waste is collected by authorized operators and disposed of at designated sites, which would prevent the formation of illegal landfills. Existing illegal landfills must be rehabilitated to prevent the occurrence of fires. However, by closing illegal landfills, the amount of municipal waste that is deposited in non-sanitary landfills/dump sites and sanitary landfills will increase. For a waste management system to be adequate, it must be known exactly who is responsible for which part of the system. In the case of waste at illegal landfills and the illegal landfills themselves, they are a "gray" zone where ownership is not determined as a consequence of decades of neglect and inadequate development. Such a system should integrate safeguards to ensure social inclusion objectives to ensure that both male and female informal waste collectors are also integrated into formal roles; and that children are removed from such roles.

Sanitary landfills, in accordance with their permits and methods of work, should be equipped with identified measures for preventing pollution and fires, but they also need constant improvement in terms of knowledge and measures to prevent adverse events, because in practice, it has been shown that the process of proper management is quite often more difficult than the process of establishing and building a sanitary landfill.

Unsanitary landfills will have to receive large amounts of waste until they are completely closed but directing waste from illegal landfills to them will create a final and limited number of landfills that need to be considered.

Regardless of whether the landfill in question is sanitary or unsanitary, the most effective preventive measure for air pollution and fire prevention is to reduce the amount of municipal waste deposited, with special emphasis on reducing the amount of biodegradable waste and plastic waste as well as lithium batteries. Furthermore, waste containing substances which are or become carcinogenic, teratogenic, and mutagenic as they degrade or release POPs if they are caught in a fire should be reduced.

At unsanitary landfills/dump sites, it is necessary to:

1. establish the practice of regularly and properly covering the landfill body with a layer of inert material and create conditions for landfill stability;
2. limit the size of the active working zone;
3. restrict access to the landfill body and prevent access by unauthorized persons;
4. establish an efficient system of monitoring, extraction, treatment and utilization of landfill gas;
5. monitor the landfill body temperature and visually control for smoke;
6. perform continuous training of employees and informal collectors, contracted persons on occupational health and safety measures and fire protection measures.

2.4. Response Measures in Case of Landfill Fire

The key role in extinguishing fires at these landfills is played by the Sector for Emergency Situations of the Ministry of Internal Affairs and local self-government units where the landfill is located. Two types of fires occur at landfills: a) fire on the body of the landfill or in the immediate vicinity and b) fire at other facilities at the site which does not include landfilled waste (ISWA, 2019).

At illegal and unsanitary landfills, type a) fires break out, i.e., fires on the body of the landfill or the immediate vicinity.

Keeping in mind that part of the deposited waste consists of flammable substances, as well as the presence of potentially large amounts of flammable landfill gas, it is especially important to react quickly and take appropriate measures to reduce and eliminate fires on the body of the landfill. It is very important that the fire is noticed quickly and accurately located. From the very beginning, locating the fire should be related to the mobilization of fire-fighting resources and informing the fire and rescue unit.

During a fire, the following steps must be taken:

a) the landfill gas collection and management system must be turned off (if such a system exists at the landfill);

b) a water supply must be provided, as well as a sufficient amount of inert material;

c) an electricity supply must be ensured and

d) good communication and support for fire and rescue units must be provided.

Depending on the type of fire, different extinguishing approaches should be taken. The choice of approach depends mostly on the intensity and direction of the wind, the location where flammable materials have been disposed and the ability to mobilize fire service personnel and equipment. One should also bear in mind the vicinity of local communities and potential impact of a landfill fire to their health and wellbeing.

It should be noted that engaging a wide variety of local stakeholders, building capacities and providing education to the local women and men as well as informal waste collectors, can help improve communication with public service providers and institutions responding in emergency situations. Continuous engagement would foster monitoring and prevention of landfill fires, especially for those living and working in the vicinity.

3. Air Quality Monitoring in the Context of the Impact of Waste Disposal and Landfill Fires

3.1. The State of Air Quality in Serbia in 2020

The official assessment of the Annual Report on the State of Air Quality in the Republic of Serbia in 2020, by the Environmental Protection Agency, which was adopted based on measurements from the state network[2], is that the air is excessively polluted (i.e., third category - with limit values for one or more pollutants exceeded) in the following agglomerations and cities:

- in Belgrade, Niš, Smederevo, Pančevo, Užice, Kosjerić, Valjevo, Kraljevo and Novi Pazar with an exceedance of the limit values of suspended particles PM_{10} and $PM_{2.5}$
- in Kragujevac, Zaječar, Popovac and Zrenjanin with an exceedance of the limit value of suspended particles PM_{10} ;
- in Subotica with an exceedance of the limit value of suspended particles $PM_{2.5}$;
- in the Bor agglomeration with an exceedance of the limit value of $SO_{2;}$.

This means that about three million citizens were officially breathing in excessively polluted air during 2020, although the monitoring of particulate pollution with $PM_{2.5}$ and PM_{10} covers about half of the population of Serbia. This means that the air is assessed as “clean” even in the cities in which the existing automatic air quality monitoring does not contain a PM analyzer, even though high concentrations of $PM_{2.5}$ and PM_{10} are the main reason for exceedances in almost every city in Serbia.

Benzo(a)pyrene content (B(a)P) in suspended PM_{10}, as the most important representative of polycyclic aromatic hydrocarbons (PAHs), was determined in 2020 within the state network as well as within local air quality monitoring networks. The results of measuring benzo(a)pyrene during 2020, with a number of samples per location ranging from 104 to 365 showed that the target value (average yearly target value 1 ng/m^3) was exceeded in Valjevo (4 ng/m^3), Užice (3 ng/m^3), Sombor and Novi Sad-Kać (2 ng/m^3) (SEPA, 2021b).

New data on air quality from the European Environment Agency in 2021 states that by far the highest concentration of PM particles and B(a)P carcinogens is observed in the Western Balkans, i.e. in the Republic of Serbia, Bosnia and Herzegovina and North Macedonia (EEA, 2021). However, there is insufficient data disaggregated by sex and age to specifically indicate how human health is impacted by this pollution. Integrated approaches such as ‘One Health’ may be channels to promote better consolidation of such data in future.

Regarding the content of heavy metals in suspended PM_{10} particles, in 2020 the content of arsenic (As) and cadmium (Cd) in suspended PM_{10} particles in Bor significantly exceeded the annual target values. In Bor, the average annual value of arsenic at the measuring points Bor-Gradski park, Bor Jugopetrol and Bor-Krivelj was 77 ng/m3, 277 ng/m3, and 8 ng/m3, respectively, and cadmium 12 ng/m3, 37 ng/m3, and 5 ng/m3. These results are compared to a target annual value of 6 ng/m3 for

[2] According to NEA (2021) "only 12 of the 29 cities with more than 50,000 inhabitants have state-operated automatic monitoring stations that measure PM concentrations. About 1.35 million citizens living in the remaining 17 cities do not have information on real- time PM concentrations”. For some of these cities, pollutant concentrations are published in the annual air quality report, which is usually put out in the second part of the year for the previous calendar year.

arsenic and 5 ng/m3 for cadmium, which was exceeded at all measuring points except for cadmium at the Bor-Krivelj station. The limit value of lead was 500 ng/m3 and the target value of nickel 20 ng/m3 was not exceeded at any station (SEPA, 2021b).

The annual analysis of automatic measurements of benzene concentrations was performed on the basis of data submitted from stations in Belgrade, Novi Sad and Pančevo by state and local air quality monitoring networks. The results of benzene measurements during 2020 show that there was no exceedance of the annual limit value of 5 $\mu g/m^3$.

The key message from the Report on the state of the environment in the Republic of Serbia for 2020 is that more than four-fifths of the total number of exceedances of the limit values of pollutants refer to the concentrations of suspended PM_{10} particles, showing that air quality in Serbia is predominantly determined by the concentrations of suspended PM_{10} particles, as in previous years.

It is also worth to mention the problem that arises due to the application of different Air Quality Indexes, which, unlike the criteria for assessing air quality, is not covered by existing legislation. Serbian Environmental Protection Agency, as well as the City Public Health Institute of Belgrade's service Beoeko[3], use an adjusted version of the Common Air Quality Index with only hourly averages of 6 pollution substances for categorizing air quality into five categories (Excellent, Good, Acceptable, Polluted and Heavily polluted). There is no link between the range limits of these categories and legally defined limit values for particular substances.

In Supplementary resources (EEG, 2023), a brief overview and comparison between the air quality index of the European Environment Agency (https://airindex.eea.europa.eu/Map/AQI/Viewer/) and of the Environmental Protection Agency of the Republic of Serbia (http://www.amskv.sepa.gov.rs/) and others being given.

3.2. Waste Disposal - a Source of Air Pollutant Emissions

As highlighted in the previous chapter, one of the important factors affecting air quality is the way municipal waste is managed.

Pursuant to Annex VI, Article 26, paragraph 4 of the Regulation on Waste Disposal in Landfills (GRS, 2010), within the monitoring of gas emissions from gas wells, the emissions of the following gases must be measured: CH_4, CO_2 and O_2 once per month during the operation of the landfill, and for the first ten years after the decommissioning of the landfill, every 6 months, and then every two years until the landfill becomes inert. Measurements of other landfill gases (H_2S, H_2 and others) are performed as needed depending on the composition of the disposed waste, and in accordance with the permit. Based on the information obtained from the Serbian Environmental Protection Agency (SEPA), it is clear that the data on monitoring gas emissions at landfills is only submitted to the Environmental Protection Agency for some of the sanitary landfills, which is obligatory under Art. 27 of the Regulation. Data on gas emission monitoring was avialble for 7 out of 11 sanitary landfills, specifically for sanitary landfills in Lapovo, Jagodina, Leskovac, Vranje, Kikinda, Sremska Mitrovica, while for the sanitary landfill in Gornji Milanovac only data on monitoring leachate and surface waters, for 2007 and 2008, respectively was available.

[3] http://www.beoeko.com/

Gas emission monitoring data was not provided to us for any unsanitary landfill. Additionally, by going through the results of emission measurements from the submitted reports, we concluded that the concentration of carbon monoxide, together with other gases, was monitored within all implemented measurements. This is very important for recognizing fires, since carbon monoxide is considered to be the most sensitive indicator, and a concentration higher than 0.1% vol. is considered a reliable indicator of underground fires (Milošević L 2016).

At locations where waste has been disposed of for decades, at landfills where there are no modern landfill gas removal systems, landfill gases may self-ignite, i.e., pollutants may be emitted into various environmental media, as analyzed in detail in the previous chapter. Ignition can also occur due to inadequate treatment of waste by unauthorized persons with the aim of collecting secondary raw materials, such as burning cables to remove insulation and release copper wires. Fires can occur not only in landfills, but also during waste transportation, as well as at waste management sites, such as transfer stations and recycling centers, especially when recycling tires, plastics, and electrical and electronic waste (Griffiths SD et al. 2018) with a crucial and increasing impact of lithium batteries (US EPA, 2021a).

The impact of waste disposal on air quality is either not recognized at all in the national strategic and planning documents (e.g., Waste Management Program in the Republic of Serbia for the period 2022-2031), or they recognize it insufficiently. (Jezdimirović I. 2022) Similar case is with local level policies, with the exception of the Air Quality Plan in the Belgrade Agglomeration 2021 (City of Belgrade, 2021) which clearly recognizes the problem of pollutant emissions, both in terms of constant emissions of landfill gases (predominantly methane), as well as in terms of possible accidents, i.e., fire (an example of a large fire at the Vinča landfill during 2017 is given). In this regard, a clear goal has been set, measures and a set of activities that are expected to result in a reduction of emissions in the field of municipal waste disposal have been proposed. However, it remains uncertain whether this example will have any effect on goals and future procedures for other landfills managed by local governments.

3.3. Regulatory Aspects

According to the latest European Commission Progress Report on Serbia for 2020 for Chapter 27 - Environment and Climate Change (EC, 2021) it is clear that Serbia has only partially fulfilled its obligations in the field of environment and climate change. In the field of air quality, the Report states that the country has achieved a "good level of alignment with the EU acquis". However, it is clearly emphasized that it must speed up the implementation of laws in this area, as well as the development and implementation of air quality plans. It is stated that the network for air quality monitoring has been improved, the number of measuring stations has been increased, data are available in real-time, but with a significant need for improvements in air quality monitoring. In particular automatic stations in some cities have to be equipped with PM analyzers that are currently missing (Šabac, Vranje, Kruševac, etc.) while some other large cities with a population above 50 thousand have to be included in the automatic air quality monitoring network by actually establishing new automatic stations (Subotica, Leskovac, Jagodina, etc.).

In order to assess the degree of compliance with, together with a comparison to EU regulations it was necessary to analyze the regulations in Serbia related to the monitoring of pollutants in environmental media, primarily in the air, within the present study. The list of relevant regulations in Serbia and EU, as well as baseline GAP analysis can be found in Supplementary resources (EEG, 2023).

The GAP analysis concludes that all pollutants prescribed for monitoring in the framework of regular monitoring of ambient air by EU regulations have been transposed into domestic regulations.

On the other hand, the legal regulations of the European Union do not recognize accidents at landfills and dumps in their regulations. Moreover, Directive 2012/18/EU of the European Parliament and of the Council on the control of major-accident hazards involving dangerous substances, which amends and subsequently repeals Council Directive 96/82/EC, Article 2 (2)(h), explicitly excludes landfills, including underground waste storage facilities as facilities this Directive focuses on.

Other EU regulations dealing directly or indirectly with air quality, such as Directive 2008/50/EU of the European Parliament and of the Council on ambient air quality and cleaner air for Europe, Directive 2004/107/EU of the European Parliament and of the Council relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air, and Commission Directive (EU) 2015/1480 amending several annexes to Directives 2004/107/EC and 2008/50/EC of the European Parliament and of the Council laying down rules relating to reference methods, data validation and location of sampling points for ambient air quality assessment, do not in any way mention or regulate the area of emergency monitoring in waste-related accident situations, not even fires. Additionally, the European Parliament calls for gender mainstreaming in all its environmental and climate change related work. European Parliament resolution 11 of September 2012 calls for the compilation of age- and gender-disaggregated data in strategies, programmes, projects and budgeting for environment and climate sectors; as well as the establishment of gender mainstreaming mechanisms in environmental policies at national, regional and international levels. In its resolution of 9 June 2015, the European Parliament also called for the collection of gender-specific data in conducting impact assessments for women on environmental, climate and energy policies.

It should be noted that the European Commission has already announced a revision of the EU Ambient Air Quality Directive following the publication of new WHO guidelines (from September 2021). The new WHO guidelines recommend lower values primarily for $PM_{2.5}$ particles, which incur the highest healthcare costs, for which a new annual concentration of 5 $\mu g/m^3$ is now recommended, and for NO_2 the WHO recommends a new annual concentration of 10 $\mu g/m^3$.

The EU is currently revising its air quality standards through the European Green Deal and the EU Zero Pollution Action Plan, which include a commitment to bring current EU air quality standards more closely in line with WHO guidelines (EC, 2022).

Supplementary resources (EEG, 2023) contains a comparative table presenting the limit values (LV) prescribed by the Regulation on Monitoring Conditions and Air Quality Requirements (GRS, 2010a), and EU standards and recommendations of the World Health Organization (WHO) from September 2021.

It should be noted that, in the EU as well as in Serbian regulations, there are no prescribed maximum 1-hour or short-term concentration limits for PM_{10} and $PM_{2.5}$ (for $PM_{2.5}$ there are no prescribed 24-hour or even 24-hour limits), even in accident situations, such as fires.

In addition to regulations managing air quality, which prescribes limit values for certain pollutants dangerous to human health that are reported to the public, it should be kept in mind that the Law on Environmental Protection and the Aarhus Convention prescribes an obligation to inform the public. Law on Environmental Protection, Article 78, paragraph 1, reads: "State bodies, bodies of the Autonomous Province, bodies of local self-governments and authorized and other organizations are obliged to regularly, immediately, completely and objectively inform the public about the state of the environment, that is, on phenomena tracked as part of monitoring levels of pollutants and their emissions, as well as warning measures or the development of pollution that may pose a danger to human life and health, in accordance with this Law and other regulations" (GRS, 2004).

Additionally, Article 5, paragraph 1, item c. of The Law on Ratification of the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, better known as the Aarhus Convention, reads: "In the event of any imminent threat to human health or the environment, whether caused by human activities or due to natural causes, all information which could enable the public to take measures to prevent or mitigate harm arising from the threat and is held by a public authority is disseminated immediately and without delay to members of the public who may be affected" (GRS, 2009).

3.4. Overview of Measurements taken by Air Monitoring Networks close to Landfills in EU Countries and the Republic of Serbia and Existing Infrastructure

According to available data, there is no dedicated ambient air quality monitoring within national or local ambient air networks close to landfills and/or dump sites in EU countries. Quality monitoring is mainly based on scientific research in the context of the release of pollutants from the landfill body in daily operational work, or in accident situations when emergency monitoring is performed, and the data available from "stationary" monitoring is analyzed[4].

In the context of the selection of sites for automatic or "manual" fixed air quality monitoring, the domestic Regulation on Monitoring Conditions and Air Quality Requirements (RGS, 2010a) recognizes four station types: Urban, Suburban, Rural and Basic rural. The aim of this division is to evenly monitor air quality in the context of the protection of human health, i.e. vegetation and natural ecosystems. The issue of landfills and dumps, as well as the impact of emissions of pollutants into the air from such sites, are not mentioned in this Regulation.

In Serbia, there is no dedicated ambient air quality monitoring within national or local ambient air networks close to landfills, except in Belgrade. According to the "Annual Report on the results of measuring air quality in Belgrade in the local network of measuring stations/sites for 2021", compiled in the context of a program entitled "Indicative measurements of pollutant levels for the purpose of establishing fixed measurements", it can be noted that three measuring points have been defined (one of which features automatic measurements) in order to monitor possible emissions of pollutants from the unsanitary landfill in Vinča.

The Serbian Environmental Protection Agency operates the second closest automatic station at the Zeleno brdo site within the Agency's headquarters at an aerial distance of some 5.2 kilometers from the unsanitary landfill in Vinča.

[4] To illustrate, in 2010 the Environmental Agency of England and Wales published a report entitled "Landfill air quality monitoring: a supplementary survey" (EA of England and Wales, 2010) which is the result of a research project to additionally monitor and analyze pollutants that are generated in the body of the landfill during its operation (without fire).

Bearing in mind that all other cities in Serbia usually have only one automatic station, except in the case of the largest or "industrial" cities, the coverage of a large number of unsanitary landfills/dump sites by "state" air quality monitoring can be taken into account as negligible.

A case study analyzing data on air quality monitoring based on measurements from measuring stations and civil monitoring in relation to the fire at the unsanitary landfill in Vinča in August 2021 is provided in Supplementary resources (EEG, 2023). This particular case study was chosen both due to the availability of data and due to the great public disturbance it caused, as well as the lack of clearly timed data on fires at other landfills.

The first research on emissions of organic pollutants using modern methods of sampling and analysis of samples from different environmental media at unsanitary landfills in Serbia was conducted in a Ph.D. dissertation entitled "Concentration Levels and Management of Persistent Organic Pollutants in a Heterogeneous System of Municipal Waste Landfills" (Đogo M 2017). Samples of leachate, ambient air and soil at ten unsanitary landfills of municipal waste in AP Vojvodina in the period from 2012 to 2013 were examined.

Đogo found that the examined municipal waste landfills did not feature the planned measures for protection from and prevention of environmental pollution, except landfills in Novi Sad and Temerin. Occasional burning of waste and fires occurred at all examined municipal waste landfills. All sites examined in this study are characterized by an unsystematic and unregulated "management system of specific waste streams, which include spent batteries and accumulators, waste oils, waste tires, electrical and electronic waste, waste fluorescent tubes containing metallic mercury, waste containing PCBs, waste contaminated with persistent organic substances, waste containing asbestos, waste vehicles, waste from titanium dioxide production, and packaging waste". Data on the quantities of special waste streams disposed of at the examined sites is unavailable. Sampling locations were selected based on the technical feasibility of installing passive ambient air samplers over a longer period of time and taking into account the proximity of the landfill to the local population.

PAHs, PCBs, organochlorine pesticides, polybrominated diphenyl ethers, dioxins and furans were determined in the collected ambient air samples. In the collected samples of ambient air, the highest content of PAHs was detected in Ruma, Temerin and Novi Sad. The highest content of selected substances from the group of organochlorine pesticides was detected in the ambient air in Novi Sad, Vrbas, Temerin and Bečej. In the samples of ambient air, the highest content of total PBDE was detected in Zrenjanin. In ambient air samples, the highest PCDD/PCDFs concentration levels were detected in Temerin, Bečej, Subotica, Novi Sad and Vrbas. The results of the research with statistical data processing in order to identify potential sources of test substance emissions are being prepared for publication in an international journal with an impact factor.

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

At the global level, in order to monitor the effectiveness of the implementation of international conventions and programs (Stockholm Convention, CLRTAP/EMEP program), airborne POPs are monitored within international networks, as well as special programs at the EU level by individual research institutions and government agencies. More detailed information on international, EU and national networks for measuring POPs can be found in Supplementary resources (EEG, 2023).

3.5. Mobile ecotoxicological units - review of the current situation in Serbia

Until 2014, Serbia formally had mobile ecotoxicological units available to provide professional assistance as part of the emergency management system in cases of major chemical accidents, primarily at SEVESO plants, but also during landfill fires. They would receive calls from centers for informing local self-governments or the republic inspector for environmental protection. They would go out into the field immediately after receiving a report, and perform appropriate measurements and sampling, which were later analyzed in the laboratory.

However, since the Ministry of Environmental Protection cut funding after 2014, these units are officially no longer operational. Only two active units which can provide professional assistance remain; one at the Institute for Public Health Belgrade (IPHB), and the other at the Public Health Institute “Pomoravlje” from Ćuprija. On the webpage of IPHB, the Center for Ecotoxicology is described as an organizational unit, which, among other things, performs the following tasks: “Determining and implementing measures during natural and other major disasters and emergencies; Preventing and responding to chemical accidents, with constant (24-hour) readiness of the mobile ecotoxicological unit”.

This unit now goes out into the field only within the area of the City of Belgrade. In the meantime, a unit was formed from within the ranks of the Fire Brigade of the City of Belgrade, which received funds from the Ministry of Internal Affairs - Sector for Emergency Situations, but without the official involvement of the mobile ecotoxicological unit, which still goes into the field at the invitation of the Sector for Emergency Situations.

The mobile ecotoxicological unit (MEU) at the IPHB Beograd numbers 6 staff members, 2 medical doctors, 2 B.Sc. technology engineers or graduate chemists and 2 technical associates. There are two MEU teams at the IPHB. The first team of 3 members (medical doctor, technologist and technician) goes out into the field, while the second team is in reserve.

Within the section covering information on the organizational structure, the website of the Public Health Institute “Pomoravlje” Ćuprija shows the Institute has a mobile laboratory for emission, immission and accident measurements, which is, among other things, authorized to measure and take samples in the fields of air pollution, soil, waste and sediment, issue test reports, interpret test results and give opinions, as well as to undertake professional and methodological activities in the fields of air pollution, soil, waste and sediment. The mobile ecotoxicological unit at this institute currently has 5 staff members (1 chemist and 4 technicians), with 2 more trained technicians from another service available for assistance, enabling formation of 3 teams, if necessary. However, the number of available teams depends on the specific accident situation and the type of measurement, as well as the necessary equipment for each specific situation.

When landfill fires occur, the MEU at the IPHB conducts immediate measurements of pollutants (carbon monoxide, carbon dioxide, explosive mixture level, methane, sulfur dioxide, nitrogen monoxide, nitrogen dioxide), and samplers are installed to measure other pollutants.

When setting up the sampler, meteorological data for the accident site (wind speed, wind direction, atmospheric pressure, air temperature and humidity) are taken into account, the sampling point is chosen to be set in the wind direction, in the nearest populated place at different distances from accident sites.

Samplers for measuring PM_{10} and a sampler for measuring polychlorinated biphenyls (PCBs) in air on polyurethane foam (PUF) are installed, as well as samplers for measuring BTEX on activated charcoal tubes.

The PM_{10} sample is then analyzed at a stationary lab for polycyclic aromatic hydrocarbon (PAHs) content, heavy metals, anions and cations, as well as organic carbon. PCBs presence is determined from the PUF sample, and airborne BTEX content is analyzed from the activated charcoal tubes.

If necessary, a vehicle equipped with automatic monitors for measuring pollutants, where pollutant content is measured online (CO, SO_2, NO, NO_2 NH_3, CH_4, PM_{10}, $PM_{2.5}$, BTEX), is available to be driven into the field, though a power source is required for this type of measurement.

According to the previous experience of the members of the mobile ecotoxicological unit, over 90% of accidents were related to endangering air quality. That is why it would be very useful for the mobile team in Belgrade to have a mobile FTIR gas analyzer, (e.g. Gasmet DX4040 Portable FTIR Gas Analyzer) that measures the content of toxic gases in the air at the accident site in real-time with high reliability. They also need a vehicle onto which they could install a chromatograph with a mass detector, which they already have, to enable online measurement of volatile compounds in the air at the accident site.

The mobile ecotoxicological unit of the Public Health Institute "Pomoravlje" from Ćuprija should acquire an HV sampler, an automatic analyzer for SO_2, NO_2 and CO in ambient air for small fires and/ or a portable gas chromatograph for analyzing gases.

There is no additional information on protocols for engaging ecotoxicological units on the websites of the IPHB Beograd or the Public Health Institute Ćuprija, nor is there any information on their work, i.e. the results of any measurements taken during accidents. In the context of the fire at the landfill in Vinča in August 2021, there is a separate page on the IPHB Beograd website, which contains reports on air quality given as a list of daily reports in the period from August 14 to 25, 2021, a week after the fire broke out (it broke out on August 7, 2021) in the form of interpretations of the air quality readings from fixed automatic stations using the air quality index, without providing the results of the ecotoxicological laboratory analysis.

3.6. Assessment of Laboratory Capacities for Measuring PCDD/PCDFs

3.6.1. Detecting PCDD/PCDFs and dioxin-like PCBs

As previously mentioned, open waste burning, including landfill fires, is a major source of PCDD/ PCDFs, as well as other unintentionally produced POPs (PCBs, PCNs, HCBs, PeCB) in developing countries and countries in transition (UNEP, 2017d).

The WHO Air Quality Guidelines for Europe (WHO, 2000a) provide clear conclusions regarding human exposure to PCDD/PCDFs, stating that "food is the main source of human intake, and intake through drinking water is negligible".

Human exposure to PCDD/PCDFs by inhalation is generally low, less than 5% of daily intake, while more than 95% of intake is up the food chain. Assuming that the TEQ PCDD/PCDFs in ambient air is “0.1 pg/m3 and the inhaled air volume is 20 m3/day for adults, the inhalation intake would be about 0.03 pg/kg body weight per day” (Wevers M et al. 1993; Duarte-Davidson R. et al. 1994). Nevertheless, areas close to major dioxin sources, such as certain industrial and urban areas, can have up to 20 times higher concentrations in the air.

In the case of large landfill fires, PCDD/PCDFs concentrations in the air during fires can be up to 4000 times higher than concentrations in the post-fire period, as was the case in Croatia during a fire at an unsanitary landfill in a nature park in close proximity to the Vrana Lake in 2007; 25.7 fg TEQ/m^3 during the fire, compared to 0.004 fg TEQ/m^3 after the fire (Fajković H et al. 2017). In the case of a large fire at a landfill in the town of Iqaluit in northern Canada in 2014, for example, the mean daily concentrations of PCDD/PCDFs in the air were 66 times higher during the fire (0.2 pg TEQ/m^3) compared to the period after the fire was extinguished 0.003 pg TEQ/m^3) (Weichenthal S et al. 2015).

The ambient air sampling methodology for PCDD/PCDFs analysis is very demanding. At landfill sites where preconditions exist, the use of an active air sampler should be considered in order to determine the dioxin concentration in the gas and particulate phases. Active air sampling is financially demanding, and requires a power source, but provides information on the amount of sampled air and allows for calculating the concentration of tested pollutants in units of mass/volume of air. The sampling module’s exposure time is shorter than the exposure time of passive samplers (24 - 48 h).

According to Melymuk et al.l (2016), “there are numerous active air sampling configurations in use such as low/high/very high volume active samplers, and various passive samplers”. They also report that “the use of different active sampler deployment configurations (e.g., sorbents, sampling times, sample volumes, sampler types, and different inlets) may lead to a range of sampling artifacts (e.g. breakthrough, filter blow- on/blow-off, degradation, etc.)”. The main advantage of active air samplers is the possibility to collect gas and particle phase at the same time in order to obtain more realistic data. The analytical procedures for preparation of filters, exposing period and analysis are developed by RECETOX Centre, Masaryk university Brno and are not available, but they are partially explained in many scientific papers.

Passive air sampling with polyurethane foam (PUF) filters is mainly used for scientific research and provides information on the mean values of pollutant concentrations within a certain time interval (sampling is carried out for 28 to 86 days), is financially more favorable, and does not require a source of electricity. Its shortcoming is that the results are obtained only for the gaseous phase of air, and that information on airflow can only be estimated from the available meteorological data (Đogo M 2017). Passive air sampling has been mentioned as a cheaper technique that is suitable for long-term monitoring programs. The analytical procedures of preparation of filters, exposing period and analysis are developed by RECETOX Centre, Masaryk university Brno and are not available, but they are explained in many scientific papers.

3.6.2. Determination of the mass concentration of PCDD/PCDFs and dioxin-like PCBs in ambient air

According to data from the Accreditation Authority of Serbia[5] at the moment, there is no laboratory in the Republic of Serbia that is accredited to determine the mass concentration of PCDD/PCDFs and dioxin-like PCBs in ambient air which is of high importance for assessing the influence of fire episodes on landfill sites and their vicinity.

The analysis is performed using a high-resolution gas chromatograph in combination with a resolution high-resolution mass spectrometer (HRGC-HRMS). This sophisticated device is very expensive to procure, costing about $700,000 (UNEP, 2019a) in addition to the need to buy standards, the operating costs of the device are also high. To illustrate, the cost of one set of standards - labeled HRMS PCDD/PCDFs standard mix (EPA 1613, calibration, clean-up, syringe) is around $2,820 (UNEP, 2019a). According to our information, in Serbia, units of this device are owned by the Institute for Meat Hygiene, the Institute for Nuclear Science "Vinča" and the Serbian Agency for Environmental Protection. For analyzing POPs, in addition to modern, state-of-the-art equipment, it is necessary to develop, validate and implement testing methods that would enable the quantification of very low concentrations of organic substances. Quality control of laboratory analysis includes the use of Certified Reference Materials (CRM) and participation in interlaboratory comparison programs or proficiency testing (PT) programs.

US EPA has developed methods for the detection and quantification of PCDD/PCDFs in various environmental matrices, such as:

- EPA 1613B - Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution HRGC/HRMS (US EPA, 2010b)
- EPA 8280B - is used for the detection and quantitative measurement of polychlorinated Dibenzo-p-Dioxins (PCDDs) And Polychlorinated Dibenzofurans (PCDFs) By High-Resolution Gas Chromatography/LowResolution Mass Spectrometry (HRGC/LRMS) (US EPA, 2007a)
- EPA method 8290A - is used for the detection and quantitative measurement of polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by High-Resolution Gas Chromatography/High Resolution Mass Spectrometry (HRGC/HRMS) (US EPA, 2007b)

The operational costs of quantification are high, analysts must be specially trained to work on this apparatus and ready to solve problems, which is why participation in interlaboratory comparison programs or proficiency testing (PT) programs is of great importance.

3.6.3. Determination of the mass concentration of PCDD/PCDFs and -like PCBs in the air from stationary sources

The Regulation on Measuring Emissions of Pollutants into the Air from Stationary Pollution Sources (GRS, 2016a) prescribes standard reference methods for periodic and continuous measurement of emissions of PCDD/PCDFs and dioxin-like PCBs into the air from stationary sources.

[5] Registry of the Accreditation Authority of Serbia is available at: http://www.registar.ats.rs/

Table 3. Standard reference methods for periodic and continuous measurements emissions of PCDD/PCDFs and dioxin-like PCBs into the air from stationary sources (based on the Regulation on Measuring Emissions of Pollutants into the Air from Stationary Pollution Sources)

Stationary source emissions – Determination of the mass concentration of PCDD/PCDFs and dioxin-like PCBs- Part 1: Sampling PCDD/PCDF	SRPS EN 1948-1
Stationary source emissions – Determination of the mass concentration of PCDD/PCDFs and dioxin-like PCBs- Part 2: Extraction and clean-up PCDD/PCDFs	SRPS EN 1948-2
Stationary source emissions – Determination of the mass concentration of PCDD/PCDFs and dioxin-like PCBs- Part 3: Identification and quantification of PCDD/PCDFs	SRPS EN 1948-3
Stationary source emissions – Determination of the mass concentration of PCDD/PCDFs and dioxin-like PCBs- Part 3: Identification and quantification of dioxin-like PCBs	SRPS EN 1948-4

According to data from the Accreditation Authority of Serbia at the moment six laboratories are accredited to conduct sampling from stationary sources to determine the mass concentration of PCDD/PCDFs and dioxin-like PCBs - Part 1: PCDD/PCDFs sampling according to SRPS EN 1948-1: 2009. At the moment, there are no laboratories in the country which can carry out an accredited method for determining the presence and concentration of these compounds from stationary sources. The only option is to sample the air from a stationary source and then test it at one of the accredited laboratories abroad.

Based on information obtained from laboratories that carry out a sampling from stationary sources, samples are most often sent to the German laboratory Eurofins Analytik GmbH[6] or the RECETOX Center in Brno, Czech Republic[7] for further analysis, i.e. determination of dioxin content. Sampling is complex and lasts at least 6-10 hours, and if lower concentrations are expected, it is necessary to sample for 24 hours. Based on interviews with accredited sampling laboratories from Serbia that send their samples to the EU for analysis, it was reported that the total cost of sampling, sending, and analyzing one sample is between RSD 120,000 and RSD 260,000. The sampling capacity is one to two samples per day. The time required for sampling, sending the sample, and obtaining results is around seven days on average.

[6] More information available at: https://www.eurofins. com/contact-us/worldwide-interactive-map/germany/eurofins-analytik/

[7] More information available at: https://www.recetox.muni.cz/en/services/recetox-central-laboratories

4. Impact of Air Pollution from Landfill Fires on Human Health in Serbia

4.1. The Public Health Aspect of Exposure of Populations Living Near Waste Disposal Sites (even without fires)

4.1.1 Population exposed to pollution due to improper waste management

According to WHO (2016), "living near a landfill can pose a risk to the health of residents, as they are exposed to pollutants in several ways: by inhalation from ambient air, by consuming contaminated water or food grown on contaminated land”.

A relevant factor in terms of the health consequences of inadequate waste management is how many people and which populations are exposed to the risks. Various studies conducted in Europe, such as SESPIR and INTARESE (Ranzi A et al. 2014; Forastiere F et al. 2011), estimate that 2-6% of the general population in urban areas is directly threatened due to emissions from such sites. It is to be expected that populations living in the immediate vicinity of landfills are more exposed to the harmful effects of emissions, which includes social inequality as an element when it comes to the impact of the environment on health. These studies were, however, made for individual EU countries and the impact of sanitary landfills and incinerators was considered.

In addition to the exposure of the general population, the occupational health risks must also be emphasized, especially among informal waste collectors, given that their regular contact with landfill sites causes direct and continuous exposure to this risk. Toxic substances and heavy metals are most often absorbed dermally when protective equipment is not used. Namely, with dirty, oily skin, liposoluble substances penetrate more easily from the surface layers of the skin into the tangle of subcutaneous capillaries. Gelberg KH (1997) found that landfill workers have an increased prevalence of respiratory and dermatological symptoms compared to workers in other locations.

According to Ner York State, Departmern fo Health[8] "short-term exposure (usually up to about two weeks) to elevated levels of ammonia and hydrogen sulfide from the ambient air can cause coughing, eye, nose and throat irritation, headache, nausea, and breathing disorders. These effects usually disappear when exposure is stopped. Studies conducted near landfills have shown a correlation between health effects and exposure to landfill gases. The studies were conducted over a period of several months, during which, health problems were reported coinciding with periods of elevated levels of hydrogen sulfide and odors in landfills. Reported health problems include: eye, throat and lung irritation, nausea, headache, nasal congestion, sleeping disorders, weight loss, chest pain, and worsening asthma. Although other chemicals may have been present in the air, it is known that many of these effects may be due to exposure to hydrogen sulfide."

If impurities (primarily hydrogen sulfide – H_2S) are present in concentrations that pose a danger to human health, certain health risks are implied. Although the content of hydrogen sulfide in landfill gas is several ppm, its presence in concentrations higher than 3,000 ppm has been recorded at some landfills (Kung K et al. 2015). While measuring the composition of landfill gases at the Vinča landfill in Belgrade for the Faculty of Technical Sciences, University of Novi Sad (results not yet published), concentrations of over 1000 ppm H_2S were measured. Hydrogen sulfide has been found to be lethal to humans in concentrations as low as 100 ppm.

[8] More information available at: https://www.health. ny.gov/environmental/outdoors/air /landfill_gas.htm

According to the Health Protection Agency – UK (2011), "the presence of detectable odors may cause annoyance among the local population, possibly leading to stress and anxiety. Some people may experience a symptom such as nausea or dizziness as a reaction to the odors even when the concentration of these chemicals is insufficient to be directly harmful to health".

Chronic toxicity due to prolonged exposure to landfill gases as a danger. Many of the trace components of landfill gas are known or suspected to cause cancer in humans. Special attention should be paid to compounds that have been found to be present in concentrations higher than the recommended threshold for long-term toxic doses of exposure, with a focus on industrial waste disposal sites.

Heller L, Catapreta CA (2003) observed an increased prevalence of respiratory symptoms in children living near landfills. Deloraine A et al. (1995) also observed a positive correlation between living near landfills and respiratory symptoms. In Finland, Pukkala E, Ponka A (2001) found more cases of asthma and cancer among residents of houses built on sites near landfills. Research in the United Kingdom, also dealing with the impact of an industrial waste landfill, has observed an increase in hospitalization due to respiratory diseases (Fielder HMP et al. 2001). In another retrospective U.S. cohort study, the results indicated an increased hospitalization rate for asthma and respiratory disease (Ma J et al. 2007).

For general congenital anomalies, based on the results of research into 11 conducted studies, six confirmed a statistically significant correlation with landfill gas exposure, while five studies did not (Mattiello A et al. 2013). Dolk H et al. (1998) reported about a study of "incidents of congenital anomalies near hazardous waste landfills in Europe" (EUROHZCON study) which "investigated the outcome of pregnancy in women living within 7 km of 21 hazardous waste landfills in five countries". Overall, "a higher incidence of non-chromosomal congenital anomalies – especially neural tube defects and arterial and vein anomalies -" was found in infants whose mothers lived near landfills compared to infants whose mothers lived farther away.

Some studies have assessed the risk of cancer in populations living close to landfills (Mattiello A et al. 2013). Other studies have found a correlation between cancer cases and distance from landfills, such as laryngeal cancer in an Italian study (Michelozzi P et al. 1998). No correlation was found in most studies (Mattiello A et al. 2013).

Ingestion of hazardous pollutants also takes place by inhaling PM particles and other pollutants emitted from continuously smoldering landfills, which contain hazardous organic compounds and heavy metals (Yang H et al. 2018).

When assessing health risks, it is necessary to consider and integrate various sources of pollutants, not only air, but also contaminated soil or groundwater located near a given site. According to WHO (2016), "some studies have provided evidence of an association between living near controlled landfills and various health risks, but, overall, such evidence is incomplete. The disadvantage of these studies is related to the quality of the exposure assessment. In most available studies, the distance from the landfill is used as a substitute for exposure". However, the distance from landfills can at best provide only a preliminary approximation in relation to the actual exposure to pollutants emitted from such a site.

Additionally, many persistent organic pollutants – POPs can be released from sanitary landfills, unsanitary and illegal dumpsites by various mechanisms. Disposal and storage of persistent organic pollutants and other persistent hazardous chemicals can lead to contamination of the environment and even the food chain (Petrlik J et al. 2022, Weber R et al. 2018b), which poses a risk to human health.

Biological and social factors further influence how POPs and other pollutants impact the health of women, men and children. Research linking gender roles, sex, age, socioeconomic status and other vulnerabilities is required to aid the formulation of more effective policies. Despite being the least contributors to pollution, the poorest in society face the highest consequences as they are the ones likely to live in more polluted environments or undertaking waste collection roles, both paid and unpaid. Bearing in mind the majority of the poorest in society are women, utilizing a gender lens remains the recommended approach (WHO, 2015; WHO–WHA, 2015). Taking an integrated approach to waste management is thus an efficient way of ensuring policies and strategies are not only more effective but also contribute towards the achievement of the SDGs.

4.1.2. Impact of air pollution on the health of the population due to landfill fires

Health related consequences of landfill fires fires can be direct and indirect.

Deterioration of ambient air quality is among the most significant indirect consequences of landfill fires, which occurs due to the emission of various pollutants released during combustion at relatively low temperatures.

PCDD/PCDFs released into the air during a fire are deposited on vegetation and soil, entering the food chain. Due to the severity of the long-term consequences that may develop after exposure to these compounds and much later, rapid implementation of prevention measures to reduce exposure is a priority. Additionally, it has already been indicated that consumer products containing POPs are disposed of in landfills (sanitary and unsanitary). Open combustion can affect discharge and facilitate release. Additionally, fires at landfills containing PVC plastic, i.e. chlorine-containing plastic, should be analyzed with due care, because during the combustion and pyrolysis of such materials, many substances with negative effects on health are emitted, such as PCDD/PCDFs and PCBs. (Wu D et al. 2021).

> More information on exposure to PCDD/PCDFs and PAHs and their health effects is given in Supplementary resources (EEG, 2023).

During waste incineration, as already mentioned, PM particles are also emitted. In the case of PM, the particle concentration is commensurate with the impact of emissions on the environment and health, since it has been shown that, no matter how much the PM concentration increases, it has an adverse effect on the surrounding flora (He K et al. 2012) and human health (WHO Regional Office for Europe, 2013b).

In the event of a landfill fire, the following must be taken into account regarding potential detrimental health impacts:

- Smoke exposure can have both acute and chronic consequences;
- Danger of burns/explosions, primarily as an occupational risk for landfill employees, firefighters, but also informal waste collectors;

- Neurological symptoms such as headache, nausea, fatigue and vomiting may occur with exposure to slightly elevated concentrations of carbon monoxide;
- Anxiety/stress – occurrence of anxiety and stress reactions in populations living near a burning landfill; (Have enough staff trained to inhibit these reactions in accident situations; Deliver calming and rational addresses to the public, without stoking further panic);
- Fine particles, less than 2.5 micrometers in diameter ($PM_{2.5}$) can exacerbate existing chronic respiratory diseases, such as "asthma and bronchitis, and are associated with cardiac arrhythmia, myocardial infarction, and acute heart failure". People with already diagnosed respiratory and heart diseases, the elderly and children are at the highest risk of exposure to $PM_{2.5}$ particles;
- Exposure to PCDD/PCDFs "has been linked to suppression of the immune system, liver damage, skin rashes, reproductive and developmental disorders, as well as certain types of cancer". Due to the severity of the long-term consequences that may develop after exposure to these compounds and much later, rapid implementation of prevention measures to reduce exposure is a priority;
- Harmful effects on health caused by pollutants due to possible contamination of water supply sources.

4.2. Implementation of landfill fire measures – Health risk assessment, risk management and communication – Initial approach to the problem

4.2.1. Environmental and public health surveillance

When landfill fires occur, appropriate environmental, as well as public health surveillance must be established in line with precisely defined parameters within the procedure for reacting in such cases.

Environmental surveillance should focus on the following:

- Air quality: monitoring specific parameters typical for landfill fires: presence of particles (PM), carbon monoxide (CO), PAHs, BTEX, heavy metals, PCDD/PCDFs and others. A list of pollutants measured during fires must be compiled within a clearly defined procedure for monitoring air during landfill fires;
- Meteorological data (direction, wind speed, etc.): continuous monitoring of air quality and an accurate weather forecast are necessary for effective monitoring;
- Water quality: this is important if a surface water intake supplying a large population that is not directly endangered by a landfill fire can be contaminated;
- Data on food contamination with certain contaminants along with data on eating habits.

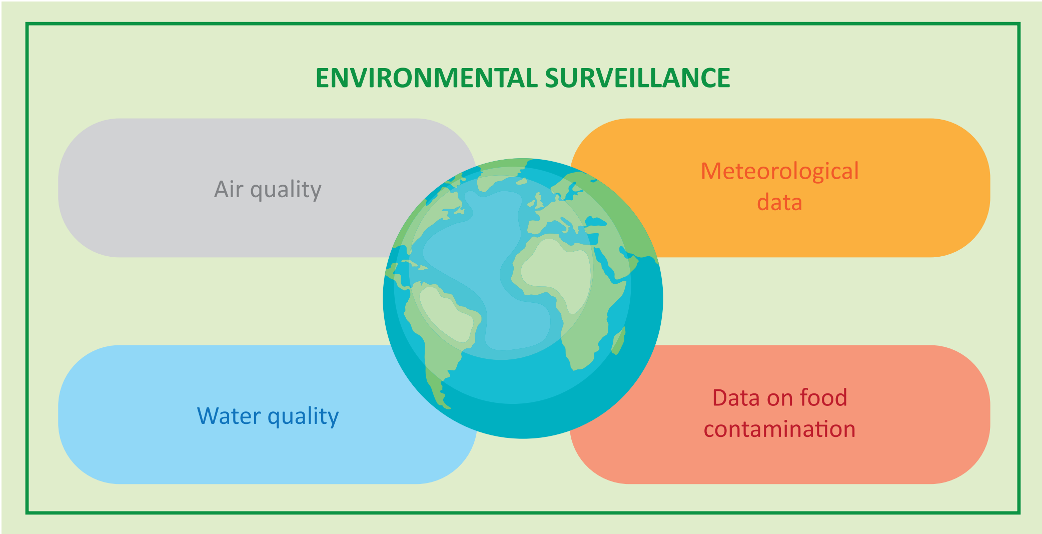

Figure 4. Environmental surveillance during landfill fires

Within public health supervision, it is necessary to record the following: calls to emergency medical services, visits to emergency care institutions (Emergency Center of the Clinical Centre of Serbia, Clinical Centre of Vojvodina, National VMA Poison Control Center, emergency services at general hospitals, etc.), rates of hospitalization possibly related to landfill smoke exposure, such as worsening "asthma, bronchitis, chronic obstructive pulmonary disease, heart attack, and neurological problems potentially associated with chronic carbon monoxide exposure".

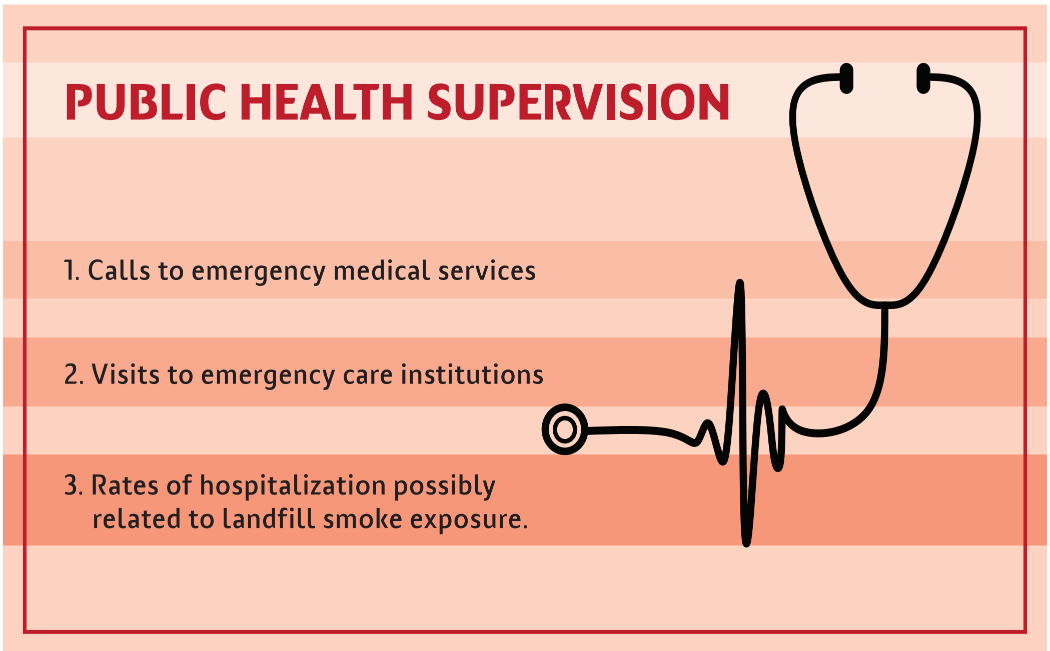

Figure 5. Public health surveillance during landfill fires

This type of monitoring should be carried out some point of time after the fire has been physically extinguished, given the possible prolonged action of some pollutants, such as POPs.

4.2.2. Preparatory measure for public health response

To start resolving the situation, the following information must be obtained:

- Gather as much information as possible on the fire – its location, characteristics of the waste at the landfill;
- Determine whether air pollutants are monitored; if so, provide an emission estimate for pollutants of public health importance;
- Find out whether reports were made after exposure to smoke from a landfill fire by inspecting hospital admission records;

Then, the following tasks need to be undertaken:

- Consider short-term measures to mitigate the health risks of the exposed population, (e.g. acute risk due to exposure to PM and aggressive gases; risk of chronic consequences due to exposure to PCDD/PCDFs, etc.);
- Create key messages in communication with the public on the topic of reducing exposure, both of the general population and particularly vulnerable categories of the population;
- Organize the distribution of important health messages to health workers in primary and secondary health care institutions (health centers and general hospitals) in terms of expected types of acute deterioration of health, after obtaining information on the type of incinerated waste and the category of the exposed population.

4.2.3. The role of the health profession in risk communication – focus on vulnerable groups and messages related to exposure

Landfill/dumpsite fire risk communication by the health profession should focus on the following facts:

- Women who are pregnant or plan becoming pregnant should limit their exposure to smoke when a landfill fire starts and while it lasts; Specific safeguards should be put in place for the most vulnerable women (especially pregnant and lactating mothers);
- Men and children who may reside in close proximity to landfills and who work in the landfills should be targeted as well bearing in mind that often they would not have contingencies to fall back on.
- Children also suffer significant impacts and their exposure to smoke should be limited.
- The most effective way to reduce exposure to smoke from the landfill is to stay indoors (if the space is not already filled with smoke), with the possibility of mechanical air purification, especially in non-residential areas occupied by many people at the same time (educational, sports and business activities);

- Although average daily concentrations of PM particles may be below the limit value, sudden increases in values may occur due to a change in wind direction, carrying pollutants from the landfill to the urban area, with landfill smoke having a detrimental effect on the health of "vulnerable populations, including the elderly, children, pregnant women and people with chronic cardiovascular, respiratory and cerebrovascular diseases" (FEMA, 2002; US EPA, 2014, 2015; Nunavut Department of Health, 2014).

4.2.4. Food contamination as a consequence of landfill fires

Due to contamination in areas around landfills and illegal dumps, where waste is often burned openly, the land is most likely not suitable for keeping livestock for food production (Weber R et al. 2018b, Petrlick J et al. 2022). If livestock and poultry are reared freely in areas affected by major (historical) open waste burning, then the food produced (eggs, meat and milk) should be tested for PCDD/PCDFs and PCBs content.

To illustrate this, three case studies are considered here, all of them of of fires which resulted in the contamination of land, livestock and food, with the competent authorities implementing very rigorous measures to protect the population, based on measurements.

In the first case study conducted following a fire at the Tagarades sanitary landfill (Thessaloniki, Greece) in 2006, there were indications of food contamination with dioxin originating from the landfill fire. The landfill was used to store household waste (organic, plastic, paper materials, etc.) from the wider Thessaloniki area from 1980, with the waste amounting to 16% of the total household waste generated in Greece (around 12.500 tonnes per year). The goal of the study was to determine the PCDD/PCDFs and dioxin-like PCBs dioxin levels in around 60 food samples (meat, eggs, dairy products, vegetables and olives) taken 7 km from the fire site, immediately after the fire, and again 6 months later. The goal of the study was also to compare the findings to the usual concentrations of these compounds detected in Greek food. The study gathered and analyzed 12 soil samples from various locations 10 days after the fire was extinguished, 5 km from the fire site. When the PCDD/PCDFs concentration results were obtained, the use of food products from the contaminated area was banned, until concentrations were found to have reduced to permitted levels. More than 80.000 kg of milk and 1.000 sheep and cows were destroyed. An increase in the percentage of genetic defects was detected in a herd kept 500 m from the fire site where high dioxin levels were recorded, resulting in 10 out of 400 (2.5%) kids born in the spring season having noticeable congenital defects (Vassiliadou I et al. 2009).

The soil inside the landfill had elevated dioxin concentrations (7.9 pg WHO PCDD/PCDFs - TEQ/g). Most soil samples taken in a range from 0.5 to 5 km from the landfill did not record elevated dioxin concentrations, which is in line with previous studies showing that soil sample contamination is not recorded more than 200 m from the source.

The second case study was conducted with regard to a fire in Sicily, and it shows that EU countries pay close attention to PCDD/PCDFs emissions during fires, as well as to the bioaccumulation of dioxins in livestock kept at farms in the immediate vicinity of fires. In fact, an area with a circumference of 20 km from the site was established immediately after the fire, with products from the farms inside that area, including milk and eggs, as well as other products with the potential to accumulate dioxins, banned for sale and consumption (Mazzucco W et al. 2020).

The third case study is IPEN global egg monitoring. According to Petrlik et al (2022), "within the monitoring of 20 chicken flocks around dump sites and waste burning sites in 12 developing countries revealed that most sites were contaminated: Mean and median TEQ of the 20 pooled egg samples were 17.7 and 14.3 pg TEQ/g fat three times above EU regulatory limits highlighting relevant contamination and human exposure. 16 (80%) of the 20 pooled eggs were above the EU regulatory limit for PCDD/PCDFs or sum of PCDD/PCDFs and dl-PCBs".

In Serbia, the Law on Food Safety (GRS, 2009a) and the Rulebook on Establishing the Program for Monitoring the Safety of Plant and Mixed Origin Food for 2021 (GRS, 2021); the Rulebook on Establishing the Program of Monitoring Food of Animal Origin (GRS, 2021a) and the Rulebook on the establishment of the Food Safety Monitoring Program (GRS, 2022a) prescribe the measures to be taken in the event of a chemical hazard, including information from the Rapid Alert System for Food and Feed (RASFF) and the International Food Safety Authorities Network (INFOSAN).

According to the Rulebook on maximum concentrations of certain contaminants in food (GRS, 2019) determining dioxin concentrations in food samples and the maximum permitted concentrations of dioxins in food is prescribed for meat, meat products, fish and fish products, milk and milk products, eggs and egg products, animal and vegetable fats. The Rulebook stipulates that the HR GC-MS method is used to measure the concentration of PCDD/PCDFs and PCBs in food samples. Additionally, rulebooks adopted annually in connection with the program of monitoring food of animal origin stipulate that PCDD/PCDFs on PCBs must be monitored in pasteurized cow's milk and fish.

In 2018, the Institute of Meat Hygiene and Technology has declared the national reference laboratory for dioxins and dioxin-like compounds in food, and intensive cooperation is underway with the EU reference laboratory for halogenated persistent organic pollutants (Freiburg Institute for Chemical and Veterinary Analysis, Germany). However, according to the Accreditation Body of the Republic of Serbia, there are currently no accredited laboratories for measuring dioxins and dioxin-like PCBs in food via the HRGC/MS method or any other analytical method (http://inmes.rs/otvorena-prva-laboratorija-za-dioksine-u -region /? script = lat). The concentrations of dioxins and dioxin-like PCBs in food are measured at laboratories abroad (e.g. Hamilton, Poland).

Regulations in Serbia provide a basis for managing the risks of PCDD/PCDFs intake through food. The lack of validated and accredited methods and laboratories for measuring PCDD/PCDFs in food samples or in human material must be rectified in order to assess the general population's exposure to PCDD/PCDFs.

The estimated dietary intake of dioxins in the EU ranges from 0.93 pg I-TEQ/kg/day in the Netherlands to 3.0 pg I-TEQ/kg/day in Spain, calculated for a body weight of 70 kg which is within the tolerable daily intake (TDI) recommended by the WHO of 1-4 pg I-TEQ/kg/day (EC, 2012; WHO, 1998). Exposure variations can be considered by gender and age as well as the length of exposure and specific subpopulations or "risk groups", while those who consume the most foods containing dioxins (95th or 97th percentile of the population) are exposed to dioxins at 3.1 pg I-TEQ/kg/day (EC,1999).

Exposure of the adult population of the Serbia through food was estimated in the study by Petrović V et al. (2008) at 3.14 pg I-TEQ/kg/day, which is within the TDI recommended by the WHO (1-4 pg I-TEQ/kg/day), but is ten times higher than the EFSA recommendation (2018) of 2 pg I-TEQ/kg per week (EFSA,2018; WHO,1998). The calculated value is slightly above the value given by the Joint

FAO/WHO Expert Committee on Food Additives JECFA of 70 pg TEQ/kg for PCDDs, PCDFs and PCBs expressed as a toxicity equivalent factor based on reproductive toxicity findings (WHO 2016). The value calculated in the scenario given by Petrović V et al. (2008) is higher than the TDI value given by the Scientific Committee on Food (SCF) of 14 pg WHO-TEQ/kg per week (COT, 2001).

4.3. Establishing a Human Biomonitoring System - Biomarkers of Exposure and Effect

According to Calafat AM et al. (2006) and Jones K (2020), "human biomonitoring is a form of public health surveillance. It is an important and useful tool for researching human exposure to chemicals from the environment or occupational exposure, providing a reliable measurement of the internal dose of pollutants, through various routes of exposure”. Human biomonitoring can be used to monitor chemicals by “providing decision-makers with a more comprehensive view of the actual exposure of the population to pollutants, and can provide better evidence or appropriate conclusions" (Ganzleben C et al. 2017).

Indulski JA, Lutz W (1995) state that “biomarkers of exposure, but also of early health effects and individual sensitivity, can serve as useful tools in health impact assessment studies in a population living near waste disposal sites” Their advantage is that they consider differences among individuals in “absorption, metabolism, bioavailability, excretion, and distribution” (Bond J et al. 1992). Additionally, adjusting these markers for different covariates such as age, sex or socioeconomic status can provide researchers with opportunities to make a more differentiated analysis of exposure. (WHO,2000b)

Table 4. Examples of human biomonitoring related to inadequate waste disposal as well as open waste incineration (WHO,2000b)

Substance	Exposure biomarker
Lead, Pb	Pb in the blood
Cadmium, Cd	Cd in urine
Chrome, Cr	DNA-protein cross-links
Mercury, Hg	Hg in urine
Polychlorinated biphenyls, PCBs	Serum levels of PCBs
VOCs	VOC in the blood
Polycyclic aromatic hydrocarbons, PAHs	DNA adducts

In developed industrial countries, a number of studies have been conducted on human exposure around landfills and thus the health impact (e.g. UK Environment Agency, 2010; Mattiello A et al. 2013; US EPA, 2022). A study by the UKEnvironment Agency (2010) considers a number of routes of exposure to a number of pollutants from landfills, but did not take into account open landfill fires, but incineration of landfill gas from closed landfills, as well as sanitary landfills.

Data on environmental and food chain contamination are available for a range of POPs and other low volatile, persistent chemicals released from landfills, but the number of studies on human biomonitoring for POPs compounds in populations living around sanitary/unsanitary landfills is limited.

The most relevant studies are given in Supplementary resources (EEG, 2023) for the main groups of POPs compounds - PCDD/PCDFs, PCBs, PBDEs and PFAS.

In Serbia, there are no epidemiological studies of the impact of pollutants from landfills on the health of the population living in the immediate vicinity. Additionally, there is no human biomonitoring in Serbia for pollutants that can be emitted from landfills, especially PCDD/PCDFs and PCBs that are emitted during open waste burning or from stationary sources, listed in the Stockholm Convention.

The global biomonitoring of the presence of PCDD/PCDFs in breast milk conducted by the WHO and UNEP in order to review the effectiveness of the Stockholm Convention measures, does not include samples of breast milk from Serbia.

4.4 Public Health Risk Assessment Methodology for Populations in Fire Impact Zones based on Pollutant Emissions and Transport Modeling, as well as PM Concentration Measurements

In the last ten years, there have been several academic papers analyzing pollutant emissions after landfill fires using simulation models to assess the exposure of the population to pollutants. Although the emission of different pollutants has been identified as a problem, there are still few studies that quantify these emissions.

According to some authors, one of the measurable effects of fire at an unsanitary landfill on air quality which could be taken into account is the PM concentration. In the case of PM, the emitted mass, and the correlated particle concentration, characterize the effect of emissions on the environment and health, since it has been shown that, no matter how much the PM concentration increases, it has an adverse effect on the surrounding flora and differentiated impacts on human health.

PM_{10} is emitted during the combustion of any type of material, which is why all factors critical to the assessment of landfill fires are taken into account in the context of PM_{10} concentration. An example of an analysis of pollutant emissions modeled through emissions and transport of PM_{10} suspended particles are given in the paper “Contribution of landfill fires to air pollution – An assessment methodology” and in the paper “The critical factors of landfill fire impact on air quality” published in 2021, which analyzes landfill fires in Poland in 2018. The authors state that “air quality in Poland is among the poorest in the EU, which makes the impact of landfill fires on PM_{10} concentration even more significant in the context of differences between air quality within the EU”. The paper first calculates PM_{10} emissions using emission factors. Then, using the HYSPLIT simulation model, the spatial impact of PM_{10} particles emitted during each fire is estimated, and the number of inhabitants exposed to increased PM_{10} concentrations due to a landfill fire is estimated.

Since the increase in PM_{10} concentration was chosen as an indicator of changes in air quality caused by landfill fires, the factor is the estimated number of people directly exposed to the increased values of PM_{10} emitted during the fire. Taking the data from the census for a given settlement, the exact number of people living in the territory affected by the fire is determined; this area is defined as a “*landfill fire spatial impact zone*”. This number can indicate whether the fire at the landfill will be considered a priority public health risk, on the level of a community, province, or state. Thus:

- PM_{10} concentrations in ambient air are estimated every hour, considering microclimatic parameters.
- In parallel with these estimates, polygons with significantly increased PM_{10} concentrations are zoned, by taking hourly mean values

Thus, the essential factors associated with increased PM_{10} values are: impacted territory in km^2, PM_{10} concentrations and number of exposed residents (Bihałowicz JS et al. 2021b)

A good example of organizing an emergency response service for appropriate public health protection, based on PM measuring and potential use of 1-h thresholds PM concentrations, is the United Kingdom, as published in the “Study of particulate emissions during 23 major industrial fires: Implications for human health” (Griffiths SD et al. 2018). The study "describes how the UK developed its *Air Quality in Major Incidents – AQinMI* service to provide fire emission plume concentration data for use by decision makers at the time of the incident and to allow an informed public health response".

"Incident-averaged concentrations ranged from 38 to 1450 μg/m^3 for PM_{10} and from 7 to 258 μg/m^3 for $PM_{2.5}$". Worryingly, the author state that “for several incidents, 15-minute average concentrations reached> 6500 μg/m^3 for PM_{10} and 650 μg/m^3 for $PM_{2.5}$, although such episodes tended to be relatively short in duration. In the absence of accepted very short-term (15-min to 1 hour) guideline values for PM_{10} and $PM_{2.5}$, the relationship between hourly and 24-hour limit values was analyzed, as well as whether 1-hour value could be used as an indicator to predict long-term exposure”. "Based on this analysis, for PM_{10}, “tentative 1-h threshold value for use in deciding whether to close public buildings or evacuate areas is 510 μg/m^3. For $PM_{2.5}$, 1-h concentrations exceeding 350 μg/m^3 might indicate longer-term exposure problems". Authors concluded that "whilst services such as AQinMI are a positive development, there is a need to consider further the accuracy of the data provided and for the development of very short-term guideline values (i.e. minutes to hours) that responders can use to determine the appropriate public health response". The Report also offers an "overview of the health effects, advice and recommended actions derived from various public health sources for 24-h exposure to $PM_{2.5}$ and PM_{10} at different levels".

In addition to this publication, in connection with the work of the Air Quality in Major Incidents (AQinMI) service, a new publication “Characterizing the ground level concentrations of harmful organic and inorganic substances released during major industrial fires, and implications for human health” (Griffiths SD et al. 2022) is published. According to the authors, "the objective of this paper is to improve our understanding of the nature, composition and potential health impacts of emissions from major incident fires and so support the risk assessment process”.It also directs to finding sustainable solutions which cater to everyone in society irrespective of their gender age or socio-economic status.

For planning emergency service in a time of fires, and consequently to give advice for the protection of public health as quickly as possible, 1-h threshold PM concentrations is relevant. In the study “A novel approach to the development of 1-hour threshold concentrations for exposure to particulate matter during episodic air pollution events” (Deary ME, Griffiths SD 2021) a novel approach is developed, “based on Receiver Operating Characteristic (ROC) statistical analysis, that derives 1-h threshold concentrations that have a probabilistic relationship with 24-h GVs”.

5. Conclusions and Recommendations

Conclusions listed in this chapter are summarizing the major findings form the literature review and the review of waste management related strategi documents, legislation and practices in Serbia. They point to gaps which need to be filled in both the normative framework and in its implementation.

In line with these conclusions, the recommendations aim to indicate the key activities that need to be carried out in order to reduce the negative impact that landfill fires have on air pollution. They are divided into several parts to make them easier to follow and understand.

5.1. Summary of Conclusions

The emergence of illegal landfills in Serbia is a burning issue both literally and figuratively. To start with, it can and must be prevented by providing 100% coverage of the population and businesses with the system of municipal waste collection which for the time being does not exist. In order to manage waste properly Serbia has to conduct a detailed risk assessment of unsanitary landfills/dump sites for human health and fire risk assessment. This assessment should include assesement of health consequences on local populations differentiated by sex, age and socioeconomic status or other vulnerabilities. Current availability and accuracy of data on waste quantity and composition is insufficient.

Fires are the primary source of landfill air pollution in Serbia and landfill gas contributes to landfill fires. Due to climate change and the increase in the amount of inadequately disposed waste, the trend of increasing the number of landfill fires can be expected to continue in the coming period. The increase in use of lithium batteries is also a cause for increasing fire risk. Extinguishing fires, in addition to pollution, also creates significant material costs.

Strategic framework for dealing with unintentional POPs is still not in place. Republic of Serbia is a party to the Stockholm Convention and as a party, has obligation to prepare a National Implementation Plan (NIP) for the implementation as well as an action plan to characterize and address the release of unintentional POPs. Serbia adopted the initial NIP and specific action plan for uPOPs in 2010, however, any updates are not adopted by the Serbian government even though financial support for updates was provided.

The implementation of preventive measures at landfills plays a key role in preventing the occurrence of air pollution from landfills. Reducing the amount of waste disposed will lead to a reduction of potential for fire and their size. Waste must be sorted and treated before disposal, in order to prevent the backfilling of sanitary landfills with waste. If they do occur, landfill fires must be contained and extinguished as soon as possible in order to prevent air pollution and citizens must be informed in a timely manner of the measures to be taken in the event of an increase in air pollution due to a fire at a landfill; Local self-governments must be ready to provide support to fire and rescue services in extinguishing fires at landfills. Building the capacity of local women and men, informal waste collectors and other local stakeholders, can also be leveraged into productive value chains in terms of monitoring and preventing fires whilst supporting the SDGs in terms of providing meaningful green jobs to those often left furthest behind.

The legal framework for this is already in place. The Law on Environmental Protection, as well as the Law on Ratification of the Aarhus Convention, prescribe clear obligations to the competent authorities on providing the public with timely information on the levels of pollutants and emissions, as well as warning measures or the development of pollution that may endanger human life and health.

When it comes to EU legal framework, all pollutants prescribed by EU regulations for monitoring in the framework of regular ambient air monitoring have been transposed into domestic regulations. The limit values provided by the domestic Regulation on Monitoring Conditions and Air Quality Requirements are fully compliant with EU legislation and prescribed standards except in the case of annual concentrations of $PM_{2.5}$ for which the limit value is 20 µg/m^3 as of 01.01.2020. in the EU, and which, according to the domestic Regulation, will start to be applied in Serbia from the 1 January 2024. EU Directive 2008/50, as well as the Regulation on monitoring conditions and air quality requirements, does not define the need to monitor ambient air quality at municipal waste landfill sites, or in their immediate vicinity. Data on gas emission monitoring at landfills prescribed by the EU Directive on Landfills 1999/31/EC, i.e. the Regulation on Landfill Waste is only submitted to the Environmental Protection Agency (Article 27 of the Regulation) for some of the sanitary landfills; EU legislation does not recognize landfill and dump site accidents in its regulations. Moreover, Directive 2012/18/EU on the control of major-accident hazards involving hazardous substances explicitly excludes landfills, including underground waste storage facilities from the focus of the Directive. EU as well as national regulations do not prescribe 1-hour or short-term concentration limits for PM_{10} and $PM_{2.5}$ (for $PM_{2.5,}$ there are no prescribed 24-hour concentrations), even in accident situations such as fires, which makes risk assessment difficult.

In EU countries, there is no dedicated ambient air quality monitoring within national or local ambient air networks close to landfills and/or dump sites. Quality monitoring takes place as scientific research in the context of the release of pollutants from the landfill body in daily operation, i.e. in accident situations when emergency monitoring is performed and data available from "stationary" monitoring is analyzed. In Serbia as well there is no dedicated ambient air quality monitoring within national or local ambient air networks close to landfills, except in Belgrade. Bearing in mind that all cities, except Belgrade, usually have only one automatic station, except in the case of the largest or "industrial" cities, the coverage of a large number of unsanitary landfills/dump sites by "state" air quality monitoring can be taken into account as negligible.

Furthermore, in Serbia there is no dedicated measurement of unintentionally produced POPs – PCDD/PCDFs and dioxin-like PCBs in ambient air within state or local networks, but only in air/waste gas from stationary sources. At the global level, in order to monitor the effectiveness of the implementation of international conventions and programs (Stockholm Convention, CLRTAP/EMEP program), airborne POPs are monitored within international networks, as well as special programs at the EU level by individual research institutions and government agencies.

Operation of mobile ecotoxicological units is inadequate in terms of their institutionalization, adequate equipment and training, as well as regular funding. Operational planning is necessary for mobile ecotoxicological units/laboratories at public health institutes in case of accidents or landfill fires. These prescribe protocols for monitoring selected pollutants, the manner of informing the public and ensuring timely availability of data in digital format.

Living near a landfill can pose a risk to health of the population, as residents are exposed to pollutants in several ways: by inhalation from ambient air, by consuming contaminated water or food grown on land contaminated with pollutants from the landfill. Landfill fires are a public health problem and deterioration of ambient air quality is among the most significant indirect consequences of landfill fires. Safeguards should be put in place to protect the most vulnerable groups in society who reside close to landfills and have no resources to protect themselves from pollution.

Written procedures are not in place in order to secure appropriate environmental and public health surveillance (SOPs, Standard Operative Procedures). These include procedures for public health supervision for protecting the population from pollutants emitted during fires, procedures for public health surveillance in open waste incineration, communication strategies, including communication with vulnerable groups.

In areas close to landfills, whether sanitary or unsanitary, where waste is often burnt in the open air, the soil is probably not suitable for raising livestock for food production due to possible PCDD/PCDFs and PCBs contamination. Due to the seriousness of the long-term consequences that can develop after exposure to PCDD/PCDFs and PCBs as well as much later, rapid implementation of prevention measures in reducing exposure is a priority. Therefore, it is necessary to consider the need to monitor the presence of PCDD/PCDFs in food of animal origin grown on farms around landfills, with well-defined parameters in the procedure for public health surveillance during landfill fires. In Serbia, there is a regulation that prescribes maximum concentrations of PCDD/PCDFs in food, which is harmonized with EU regulations as well as a national reference laboratory for PCDD/PCDFs and dioxin-like PCBs in food, as well as appropriate laboratory equipment for the detection and quantification of PCDD/PCDFs, but the method for testing the presence of PCDD/PCDFs in food is not yet accredited.

The Ministry of Agriculture, as the competent authority, adopts the Annual Monitoring Program for Domestic Food of Animal Origin Produced in the Republic of Serbia, but also for certain type of imported food, which envisages monitoring of food for the presence of dioxins in cow's milk and fish (sardines, trout, tuna, herring and salmon).

Human exposure to PCDD/PCDFs by inhalation is generally low, with the main source of dioxin intake being through food, and that the method for sampling and quantification of dioxins in ambient air is demanding and expensive. The operating costs of HRGC/HRMS equipment are high, and quality control of laboratory analyses includes the use of certified reference materials and participation in interlaboratory comparison programs or proficiency testing (PT) programs. However, taking into account the fact that an incinerator for municipal waste is being built at the Vinča landfill near Belgrade, monitoring of PCDD/PCDFs concentrations in the ambient air will be needed soon. Therefore, although is not profitable to invest in equipment and measurement for PCDD/PCDFs analysis due to the high price and the small number of samples, it is necessary for the state to consider taking over this activity using state labs that have the appropriate equipment.

In the last ten years, there have been several scientific papers analyzing pollutant emissions after landfill fires using simulation models to assess the exposure of the population to pollutants. One of the measurable effects of fire at an unsanitary landfill on air quality which could be taken into account is the PM concentration, since PM_{10} is emitted during the combustion of any type of material.

A good example of organizing an emergency response service for appropriate public health protection, based on PM measuring and potential use of 1-h thresholds PM concentrations, is the example of United Kingdom.

5.2. Recommendations for Landfill Fire Prevention

5.2.1. Prevent further disposal of waste in illegal landfills, by introducing 100% coverage of the population with a system of waste collection, transport and disposal, with increased inspection oversight;

5.2.2. Determine the exact number of illegal landfills, clean them out and remediate them, and introduce mandatory inspection oversight in order to prevent waste disposal at the same site again, or the creation of illegal landfills at another location;

5.2.3. Determine the exact number, location, spatial data, type and amount of waste deposited in unsanitary landfills/dumpsites;

5.2.4. Carry out fire risk assessments at unsanitary landfills in the country and prescribe fire prevention measures;

5.2.5. Reduce the amount of biodegradable waste, plastic waste and lithium batteries that is disposed of by introducing a system for reducing waste generation, selection and treatment of waste before disposal and creating economic mechanisms that discourage waste disposal in landfills;

5.2.6. By selecting waste before disposal, ensure that widely used products that contain persistent, bio accumulative and toxic substances do not end up in unsanitary landfills/dumpsites;

5.2.7. Ensure that waste that cannot be recycled or reused but has a calorific value is used for energy recovery in accordance with the waste management hierarchy, with adequate environmental protection measures;

5.2.8. Monitor indicators of fire occurrence at unsanitary landfills and enable visual control of the landfill body, as a measure of rapid fire detection;

5.2.9. Ensure proper management of unsanitary landfills/dump sites through regular and proper coverage of the landfill body with inert material; compaction of landfilled waste; introduction of landfill gas extraction systems; preventing unauthorized persons from accessing the landfill body; increased inspections; continuous training of employees on occupational safety and fire protection measures;

5.2.10. Build the capacities of local women and men as key stakeholders in waste management, as well as providing formal paying and removing children from such roles.

5.2.11. Close, remediate, reclaim and monitor unsanitary landfill sites;

5.3. Recommendations for Minimizing the Consequences of Landfill Fires

5.3.1. Improve the capacities of the Emergency Situations Sector of the Ministry of Internal Affairs in order to react faster and better to landfill fires (education, infrastructure, cooperation with the local self-government unit, resources, etc.), taking into account that an increase in landfill fires can be expected in the coming period;

5.3.2. Develop a clear reaction plan in case of fire with the provision of stationary and mobile firefighting equipment and a sufficient amount of cover and mechanization, in order to reduce the duration and scope of any fires to a minimum, and thus the consequences of air pollutants and sediment, i.e. the risk to human health and the environment;

5.3.3. Facilitate the retention and purification of leachate generated as part of firefighting efforts, which is contaminated with fire extinguishing agents (barriers, receiving lagoons/pools);

5.3.4. Revise existing digital maps of existing unsanitary and illegal landfills (border areas) and link them to publicly available services (e.g. NASA and Copernicus) for integration into the notification and alert system.

5.4. Recommendations for Improving the Monitoring System in Order to Assess the Impact of Landfill Fires on Air Pollution in Serbia

5.4.1. Improve the landfill fire recording system so that data is consolidated, easily accessible and used for analysis of consequences and prediction of future fires. The data that must be collected about each fire is as follows: time of fire breakout; cause of fire; duration of fire; location coordinates, i.e. the boundary area of the fire; affected area and estimated depth of fire; waste density; estimated mass of burning waste; mechanization, equipment, means and personnel called in to fight the fire;

5.4.2. Measure pollutants in the ambient air in accordance with the operational work plan of mobile ecotoxicological units in accident situations; make the report on the measurement results publicly available in a timely manner;

5.4.3. Continue to improve the network of measuring stations and data obtained from the network, especially in the direction of expanding and setting up stations in areas where official measurements are not currently taken;

5.4.4. Include all large urban areas into a system for automatic monitoring of particulate pollution, so that citizens are informed in a timely manner about the state of air quality;

5.4.5. Ensure appropriate maintenance of measurement systems and data availability, and finance the smooth operation of air quality monitoring networks, especially for urban agglomerations;

5.4.6. Improve the environmental media monitoring system by expanding the range of parameters in standard and accident situations;

5.4.7. Establish a system for monitoring gases at unsanitary landfills where feasible, in accordance with the regulation on waste disposal in landfills and regularly submit data on measurements to the competent authorities;

5.4.8. Establish adequate operational capacities of mobile ecotoxicological units for the entire territory of the country in terms of their institutionalization, appropriate equipment and training, as well as regular funding;

5.4.9. Clearly define operational plans of mobile ecotoxicological units/laboratories at public health institutes in case of accidents or fires at landfills/dump sites, prescribing protocols for monitoring selected pollutants, manner of informing the public and ensuring timely availability of data in a digital readable format;

5.4.10. It is necessary to consider whether and in what situations measurements of PCDD/PCDFs in ambient air should be taken, including accident situations, such as landfill fires, given the fact that human exposure to PCDD/PCDFs by inhalation is generally low, with the main source of dioxin intake being through food, and that the method for sampling and quantification of dioxins in ambient air is demanding and expensive. However, taking into account the fact that an incinerator for municipal waste is being built at the Vinča landfill near Belgrade, monitoring of PCDD/PCDFs concentrations in the ambient air will be needed soon.

5.4.11. Although is not profitable to invest in equipment and measurement for PCDD/PCDFs analysis due to high operational cost, it is necessary for the state to consider taking over this activity using state labs that have the appropriate equipment. For that matter, the methods have to be accredited and analysts must be specially trained to work on this apparatus and ready to solve problems, which is why participation in interlaboratory comparison programs or proficiency testing programs is of great importance.

5.4.12. Based on the collected information on landfill/dump site fires, make an assessment of PCDD/PCDFs emissions into the air in accordance with the prescribed methodologies for reporting purposes according to the Stockholm and CLRTAP conventions. It also needs to be updated an Action plan to reduce or eliminate releases from uPOPs according to Article 5 of the Stockholm convention.

5.5. Recommendations for Reducing the Risk to Public Health During and After Fires

5.5.1. Provide a system of notifying and possibly evacuating populations directly endangered by fires at landfills/dumpsites and plan contingency measures for the most vulnerable women, men and children who have little to no resources and thus have the least adaptive capacities to any sort of peril or disaster.

5.5.2. Develop written procedures/operational plans for establishing public health surveillance based on defined parameters for measuring pollutants in environmental media for fires at landfills/dumpsites;

5.5.3. Within the public health supervision procedure during landfill fires, clear communication channels about risks to the health of the endangered population must be established, guided by the principle of precaution and identified facts about the fire, where such communication would focus on vulnerable groups, taking into account the types and concentrations of pollutants emitted from landfills;

5.5.4. In the event of landfill/dump site fires, the need to test for the presence of PCDD/PCDFs in food (eggs, milk, meat), free-range livestock and poultry reared on farms around landfills or in the impact zone should be considered (e.g. consider a ban on the use and sale of food of animal origin with PCDD/PCDFs accumulation potential until proven safe for use);

5.5.5. Include breast milk samples from Serbia in future PCDD/PCDFs (and dl-PCBs) testing when testing the effectiveness of the WHO/UNEP measures for implementing the Stockholm Convention;

5.5.6 Assess groundwater and well contamination, as well as surface reservoirs and lakes in the wider surroundings of landfills/dump site for water-soluble pollutants, such as PFAS;

5.5.7. For particularly affected areas where the population was significantly exposed to pollutant emissions during landfill/dump site fires, biomonitoring is recommended for potentially affected populations via DRCalux bioassay for PCDD/PCDFs and PCBs (similar to a recent population survey in Campania, Italy (IZSdM,2021) and data collected on the affected populations should be disaggregated by age, sex and socioeconomic status as well as other vulnerabilities;

5.5.8. Carry out research regarding the degradation of plastics in landfills (polycarbonates, polystyrene, polyurethane, PVC) and the associated risk of emissions of the resulting compounds;

5.5.9. Due to a large number of fires at landfills/dump sites in the country, in order to assess the risk to human health, it is necessary to consider the introduction of a simulation model applied in Poland (Bihałowicz JS et al. 2021a, 2021b) and/or approach based on measuring PM and potential use of 1-h thresholds PM concentrations in Great Britain (Griffiths SD et al. 2018, 2022) etc.

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