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REVIEW PAPER

Landfill fires and associated environmental and health risks*

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Abstract

A fire or open burning of waste are significant sources of emissions that contribute to environmental pollution and can have negative impacts on public health. The objective of this publication is to highlight the potential health effects associated with emissions from landfill fires, and to organize existing knowledge while incorporating the results of the recent studies. Research methods: A review of studies on the adverse health effects of landfill fires has been conducted. The literature review was carried out by searching through databases such as PubMed, Scopus, and Google Scholar, covering the years 2020-2024. The selection of subject classification entries was used as a criterion for analyzing bibliographic data. Additionally, a thorough examination of the literature, references and relevant legislation was conducted to identify the specific risks associated with exposure to hazardous substances released into the environment during landfill fires. Results: Based on the conducted review of the literature, correlation between health outcomes and environmental pressure from landfill fires has been observed. Conclusions: To enhance the fire safety of landfills, it is crucial to take measures to reduce the amount of landfilled waste. Inspection activities in the organization of fire safety of landfills should be strengthened. Educational activities aimed at raising public awareness of landfills, including the possible health effects associated with landfill fires, should be implemented.

Keywords: fire, waste, landfills, environment, health

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INTRODUCTION

Most generally, waste means any substance or object that the holder disposes of, intends to dispose of or is obliged to dispose of. The World Bank estimates that the level of solid waste generation will increase to 2.2 billion tons per year in 2025 (Chen et al. 2020).

In Poland, the most common method of waste management, including municipal, industrial and hazardous waste, is through landfilling. However, this practice is incompatible with current laws, as reported by the Central Statistical Office (Polish abbreviation: GUS) and the Supreme Chamber of Control (Polish abbreviation: NIK). The occurrence of landfill fires poses a significant challenge for the waste industry, local governments and institutions responsible for environmental protection and public health.

According to the Central Statistical Office (GUS), 122.8 million tons of waste were generated in Poland in 2023, of which 11% was municipal waste (13.4 million tonnes) and 109.309 tonnes of waste (excluding municipal waste) originated from various economic activities. In the same year, more than 9,800 wild dumps, on which a total of 63.700 tonnes of municipal waste were disposed of, were eliminated. Most of them (78%) were located in cities. Additionally, at the end of the year, 2.154 existing illegal dumps with a total area of more than 2 square kilometres were catalogued, of which 1.168 wild dumps (54%) were located in rural areas and 986 in urban ones.

The scale of waste generated and landfilled (accumulated) to date by section of the Polish Classification of Activities for the years 2020-2023 is presented in Table 1. The scale of municipal waste generated according to treatment operation and voivodeships for the years 2020-2023 is shown in Table 2 (GUS).

Landfilling remains the most prevalent and traditional approach to waste disposal. It is also a relatively efficient and cost-effective method. The three main types of landfills are municipal solid waste landfills, industrial waste landfills and hazardous waste landfills. However, even with careful planning and management, landfills pose potential environmental hazards, particularly when fires occur. Epidemiological studies have shown that landfills and waste fires can have adverse health effects on nearby populations (Ozbay et al. 2021, Siddiqua et al. 2022).

The Supreme Chamber of Control (Polish abbreviation: NIK) has released a report on landfill site fires, stating that they are often caused by criminal activity (such as intentional or accidental arson) or negligence that leads to spontaneous ignition of waste. The report also highlights the need for better supervision of waste sites, as identified by NIK.

Unfortunately, waste incineration is a popular method of waste disposal in both Poland and around the world, particularly among individuals with low incomes and limited awareness of the associated risks. This issue is fur-

Table 1

Waste generated and landfilled (accumulated) to date according to section of the Polish Classification of Activities in 2020-2023

Specification	2020		2021		2022		2023	
	Grand total	Waste landfilled (accumulated)	Grand total	Waste landfilled (accumulated)	Grand total	Waste landfilled (accumulated)	Grand total	Waste landfilled (accumulated)
TOTAL	109 466	1 787 847	107 712	1 811 430	115 039	1 828 940	109 309	1 842 337
Mining and quarrying	60 838	828 302	61 879	840 959	61 315	850 051	61 996	853 907
Manufacturing	23 123	282 500	22 023	284 338	21 342	285 859	20 300	293 861
Electricity, gas, steam and air conditioning supply	11 591	307 030	12 677	315 630	13 331	323 419	9 269	322 385
Water supply; sewerage; waste management and remediation activities	5 465	357 598	6 100	357 563	6 110	356 527	6 224	359 259
Construction	7 352	-	3 504	5 925	12 018	5 925	10 712	5 925
Other sections	1 097	12 418	1 529	7 016	924	7 158	826	7 000

Source: the authors' own compilation based on GUS data for the years 2020-2023

Table 2

Municipal waste generated according to the treatment operation by voivodships in 2020-2023

Voivodeship	Designated for in thousand tonnes							
	2020		2021		2022		2023	
	Total	land-filling	Total	land-filling	Total	land-filling	Total	land-filling
Poland	13 117	5 218	13 674	5 296	13 420	5 108	13 448	4 067
Dolnośląskie	1 160	539	1 262	564	1 220	514	1 196	522
Kujawsko-Pomorskie	714	236	733	218	717	237	715	168
Lubelskie	522	181	543	171	519	167	519	165
Lubuskie	390	168	403	175	391	198	400	182
Łódzkie	851	449	876	413	849	333	845	380
Małopolskie	1 130	331	1 177	349	1 156	338	1 185	270
Mazowieckie	1 879	764	1 971	922	1 974	944	2 046	479
Opolskie	372	191	378	187	361	153	361	116
Podkarpackie	502	219	523	228	505	230	506	144
Podlaskie	339	95	351	66	339	42	336	81
Pomorskie	830	344	910	366	904	322	878	363
Śląskie	1 780	823	1 795	770	1 713	764	1 690	632
Świętokrzyskie	315	197	328	204	325	177	332	142
Warmińsko-Mazurskie	432	175	448	154	438	146	421	91
Wielkopolskie	1 255	306	1 297	320	1 331	378	1 362	191
Zachodniopomorskie	647	199	678	188	677	167	656	141

Source: the authors' own compilation based on GUS data for the years 2020-2023

ther exacerbated in countries where frequent fires at landfills are common, and open burning of municipal waste, garden waste, and agricultural residues is a widespread practice (Ozbay et al. 2021, Chmielewski et al. 2022). The severity of fires at waste collection sites is demonstrated in Table 3.

When a landfill fire occurs, the environment becomes contaminated with hazardous, often toxic, chemical compounds. This type of event may cause various primary effects, such as the ones affecting human health and safety, groundwater resources, and biological life, or the ones influencing the ground, soil or surface water. Moreover, there may be secondary effects, such as the impact of contaminated groundwater on the quality of drinking water, water for agricultural or recreational purposes. The total amount of pollutants carried away from landfills depends on the type of waste deposited on it, physical and chemical transformations taking place in the slope of the landfill as well as the protection of the ground. The amount of pollutant emissions during a fire, in addition to the deposited waste, is also influenced

Table 3

Number of fires of waste gathering sites in 2019-2023

Voivodships	2019	2020	2021	2022	2023
Poland	177	111	62	38	105
Dolnośląskie	13	10	4	1	12
Kujawsko-Pomorskie	7	8	8	6	2
Lubelskie	25	4	4	1	6
Lubuskie	34	9	3	1	6
Łódzkie	12	11	9	5	9
Małopolskie	8	2	1	4	9
Mazowieckie	29	8	7	3	19
Opolskie	6	1	3	1	6
Podkarpackie	9	2	2	1	8
Podlaskie	11	11	-	-	2
Pomorskie	12	5	6	4	1
Śląskie	8	15	4	-	13
Świętokrzyskie	1	8	-	3	3
Warmińsko-Mazurskie	1	7	4	4	2
Wielkopolskie	1	7	6	4	6
Zachodniopomorskie	13	3	1	-	1
Total	493				

Source: the authors' own compilation based on GUS data for the years 2020-2023

by the speed of initiation and course of the firefighting operation as well as the type and amount of extinguishing agents applied during it (Chmielewski et al. 2020, Amon et al. 2021, Oleniacz et al. 2023).

MATERIAL AND METHODS

A range of scientific content taken from PubMed, the English-language online database of the National Library of Medicine, National Institutes of Health, Bethesda, MD, USA (http://www.ncbi.nlm.nih.gov/PubMed), SCOPUS, and Google Scholar, covering articles in medicine with a focus on adverse health effects from landfill fires was subjected to our analysis. The literature published in available scientific information databases between 2020 and 2024 was reviewed, assuming that it includes the latest scientific reports on the subject in question. In the process of searching for scientific articles, advanced search options were used, based on keywords or their combination (fire, waste, landfills, environment, health). Reviews, conference materials, letters to the editor, book chapters as well as confe-

rence and training notes were not included in the review and were excluded from the analysis. Searches were limited to literature in English language. The analysis included 20 open access articles.

THE IMPACT OF FIRES ON THE ENVIRONMENT

Landfill fires pollute the environment and devastate an already stressed ecosystem. Emissions of pollutants into the environment constitute an inherent problem in the landfill process, weighing down the threat to the atmosphere, surface and groundwater as well as the ground. Waste incineration increases concentrations of organic aerosols in the air, especially particulate matter (PM) of the smallest size PM 2.5. Gases, such as methane, carbon dioxide, ammonia, oxides of sulfur, nitrogen, carbon, nitrous oxide and dust are released into the atmosphere. As a flammable and explosive gas, methane also carries a potential fire hazard. When a fire occurs, toxic gases that are products of incomplete combustion as well as carcinogenic dioxins and furans are emitted. The threat to water and land is primarily related to leachate from landfills. These are waters that enter a landfill and flush out contaminants, having their source in precipitation, inflowing surface and groundwater and – to a lesser extent – water delivered with the waste. The composition of leachate varies depending on a landfill, type of buried waste, degree of degradation, climatic conditions, landfill characteristics, socio-economic factors and landfill technology. Discussed contaminants include mainly organic matter, organic pollutants (e.g. phenols, detergents, aromatic hydrocarbons), inorganic ions (e.g. chlorides, sulfates) and heavy metals (e.g. cadmium, lead, zinc). Under specific landfill-dependent fire conditions, pollutants, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) as well as polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) can be emitted into the atmosphere (Chmielewski et al. 2020, Ozbay et al. 2021, Ramadan et al. 2022, Rykała et al. 2022). Table 4 presents emissions that can occur during landfill fires (Chmielewski et al. 2020).

As shown by the U.S. Environmental Protection Agency (EPA), open burning of waste releases carbon monoxide and dioxide (CO and CO_2), nitrogen oxides (NOx), hydrochloric acid (HCl), hydrogen cyanide (HCN), volatile organic compounds (VOCs), persistent organic pollutants (POPs), ketones, aldehydes and particulate matter. Furthermore, the report by the European Environment Agency (EEA), indicates emissions of metals, such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), copper (Cu), nickel (Ni), selenium (Se) and zinc (Zn) during waste incineration (Bihałwicz et al. 2021).

Research by Rykała et al. (2022) shows that burnt solid waste in a wild landfill poses a potentially persistent threat to the environment. Samples taken even long after a fire broke out in the examined area contain significant concentrations of hazardous organic compounds, particularly PAHs. This is the case with both soil and solid waste samples transformed by the

Table 4

Emissions of pollutants during landfill fires, ng/m^3

Pollution	Controlled landfill fire	Controlled landfill fire
Acenaphthylene	90	60
Acenaphthene	50	30
Fluoranthene	100	50
Phenanthrene	520	30
Anthracene	160	85
Fluorene	120	180
Pyrene	120	170
Benz[a]anthracene	60	60
Chrysene	80	70
Benzo[a]pyrene	20	15
Indeno[1,2,3-cd]pyrene	10	10
Dibenz(a,h)anthracene	10	10
Benzo[ghi]perylene	10	10
Total PAHs	1480	810
Total PCBs	15,5	590

Source: (Chmielewski et al. 2022)

fire. The results indicate high total PAH concentrations in the samples. These results confirm that the soils at the wildfire landfill have similar levels of contamination to soils heavily polluted by industry, even though there are not industrial facilities on the site itself or in the vicinity (Rykała et al. 2022).

Evaluation of the air quality implications of three major fire events that occurred at the Brahmapuram Municipal Solid Waste Treatment Plant (BMSWTP) in Kochi, India emission estimates showed that the combustion of waste caused the release of 909.3 MT of PM10, 938.8 MT of PM2.5, 5832.9 MT of CO, 43.6 MT of SOx, 284.2 MT of NOx, 138,941.9 MT of CO2, 426.8 MT of CH4, and 2665.1 MT of VOC (Kannankai, Devipriya 2024).

Post-fire, findings demonstrated a substantial increase in microplastic (MP) concentrations in surface waters, with levels rising from an average 25793.33 to 44863.33 particles/m^3, featuring a notable presence of larger, predominantly black MPs. Sediment samples did not show significant change in MP count; however, there was a significant increase in mass concentration. SEM/EDS analysis revealed changes in surface morphology and elemental composition, suggesting thermal degradation. Risk assessment using the Microplastic Pollution Index (MPI) and Risk Quotient (RQ) methods indicated heightened MP pollution risk in post-fire surface water (Amal et al. 2024).

Following the occurrence of a fire at a tire landfill in the surrounding area of Madrid City (Spain), the content of clay minerals showed a strong correlation with the pollutants potentially released in the tire fire, acenaphthene, pyrene, benzo(a)pyrene and benzo(a)fluoranthene. Trace metals Zn and Se were related to the proximity of the tire fire without any relationship with the clay mineral content (Cuevas et al. 2020).

HEALTH RISKS

Open burning of municipal waste is a major source of particulate air emissions, polycyclic aromatic hydrocarbons and more exotic hazardous organic pollutants, including polychlorinated biphenyls and brominated flame retardants. However, the adverse effects of municipal waste incineration emissions on the health of the general population are unknown (Adetona et al. 2020). There is a lack of reliable information on the health effects associated with exposure to toxic substances released from landfills, including landfill fires, which is primarily the result of methodological difficulties in conducting the above-mentioned studies. Difficulty in studying and estimating the level of exposure of the general population to the chemical substances found in landfilled waste may also be the reason. Small doses of xenobiotics ingested by the human body over an extended period of time are often difficult to link to a well-defined health effect. The ability of chemicals to migrate into specific environmental elements (soil, water, air) is further evidence of the methodological difficulties associated with estimating exposure of the general population (Ozbay et al. 2021, Rykała et al. 2022).

Landfill fires or landfill decomposition can release chemicals into the environment, leading to serious health problems in humans. The health effects of landfill fires are far-reaching and can have long-term consequences. Waste fires produce toxic gases and chemicals, including particulate matter (PM), nitrogen oxides, carbon monoxide, volatile organic compounds and polycyclic aromatic compounds. Exposure to chemicals from landfill fires has a particularly negative impact on health of the elderly, pregnant women and children, who are more vulnerable to the dangerous effects of environmental pollution. Air pollution caused by landfill fires in exposed people usually causes headaches, coughing, eye and nose irritation and respiratory problems. People with respiratory diseases, including emphysema, asthma and heart disease, are particularly vulnerable to environmental pollution. Environmental pollution can also exacerbate allergies, lung infections, bronchiolitis and pneumonia. Studies attribute premature deaths to susceptibility to smoke from landfill fires through increased risk of respiratory-related diseases, such as hypertension, asthma, respiratory infections and cardiac arrest. Landfill fires can affect the reproductive system, fetuses, newborns, cause congenital abnormalities and contribute to development of reproductive anomalies (Kumari et al. 2017, Chmielewski et al. 2020, 2020a, 2020b, Walosik et. al. 2021, Chmielewski et al. 2021, 2021a, Rykała et al. 2022, Page et al. 2023, Yu et al. 2024).

The literature on the subject shows a link between the concentration of PM10 in the air and a relative increase in the risk of death. Particles from waste incineration also contain varying amounts of sulfur and acidic nature of sulfur compounds (e.g. ammonium sulfate, ammonium bisulfate, or sulfuric acid) makes the transition metals in the particles more bioavailable, significantly increasing the potential for PM2.5 from waste incineration to cause oxidative stress and systemic health effects (Jakhar et al. 2023).

A study on 551 live-born and stillborn children whose mothers lived in fire-exposed suburban areas and who were conceived during the 40-week period during which the peak of the fire may have affected the pregnancy showed an increased number of premature and very low birth weight of infants of mothers exposed to emissions from landfill fires at conception or early in pregnancy (Mazzucco et al. 2019).

Uncontrolled waste incineration in Poland contributes to additional deterioration of air quality in these areas as a result of increased emissions of numerous pollutants as well as soil and groundwater contamination. The results of epidemiological studies on the health effects of environmental exposure to chemical agents emitted during landfill fires in many cases indicate a cause-and-effect relationship. However, this should be treated with caution due to the relatively small size of the study groups and the lack of documented exposure to chemicals. Therefore, it is important to make the public aware of the significance of the problem through a series of educational activities, which will undoubtedly contribute to the protection of the environment and human health.

CONCLUSIONS

On the basis of the conducted analysis, the following conclusions can be made:

1. There is a need to structure cooperation between the various institutional entities involved in activities related to environmental protection and public health.

2. The number of official inspections of landfill and waste management facilities as well as community monitoring of sensitive sites where illegal dumping and subsequent fires are possible should be increased.

3. Environmental monitoring of post-fire landfill sites for soil and groundwater contamination should be introduced.

4. Voluntary health assessment monitoring near landfill fire sites should be implemented.

5. Scientific research on the impact of landfill fires on the health of the population living near occurrence of the fires should be continued.

6. Penalties for organized environmental crime should be tightened.

Author contributions

I.Ż.D., J.C. – designed research. I.Ż.D., J.B.B., B.W., K.M., J.C., – analyzed data and wrote the manuscript. All authors read and approved the manuscript.

Conflicts of interest

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