Impact of fires at illegal landfills on the soil and water environment

The increase in solid waste production is an ongoing problem around the world. Their number increases as the population increases. At the same time, illegal landfills are being created, which pose a potential threat to the environment and the health of the inhabitants of a given area. They are most often created in forests, on the outskirts of inhabited areas, or in private plots and vacant lots. The reasons for their creation include, among others: the lack of appropriate waste processing facilities or the desire to get rid of inconvenient waste cheaply.

One of the most serious dangers that may arise at illegal landfills is fire. This phenomenon may occur through spontaneous ignition, related to, among others, weather conditions or a chemical reaction of solid waste with oxygen, a spark from a machine operating in a landfill, or intentional ignition by third parties. Arson is usually done to get rid of solid waste that is expensive to dispose of quickly and cheaply. Data from the State Fire Service indicate that since 2012, the number of fires at waste collection sites in Poland has been increasing from 75 cases to 243 in 2018.

Solid waste that has undergone incomplete combustion during a fire becomes a new source of environmental pollution, often much more dangerous than substances originally deposited in a landfill. During rainfall, they are washed out from illegal landfills and the resulting leachates infiltrate deep into the ground. Depending on the geological structure of the substrate and the aquifer, the "cloud of pollutants" that forms moves in a manner specific to a given area. The quantity and quality of leachates produced, the rate of solid waste deposition in a specific area and hydrogeological conditions have a significant impact on the extent of the spread of pollutants. The consequences of such events may be long-term and costly contamination of the nearby soil and water environment and additional work related to monitoring groundwater in a given area.

The type and quantity of products from incomplete combustion of solid waste depend on the type of materials deposited. The most common substances include aliphatic hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and their derivatives substituted with functional groups, e.g. phenols and chlorinated PAHs. The type of solid waste collected and burned also matters in the case of inorganic substances.

The presented research areas include the location: (i) in the southern part of Poland (Trzebinia) and (ii) in the southwestern part of Poland (village near Wrocław). In both cases, several dozen samples of soil and burned solid waste were collected. Additionally, using burnt solid waste in Trzebinia, their washing was simulated, resulting in leachates imitating the infiltration of water into the ground.

There are three basic environmental categories for the consequences of fires at illegal landfills. The first is a situation in which, during waste combustion, some of the pollutants enter the atmosphere through the formation of thick, dark smoke that spreads hundreds of meters beyond the fire's epicenter. The level of toxic substances released into the atmosphere depends on the size of the fire, the type of solid waste and atmospheric conditions during the incident. Another consequence is the threat to groundwater in the area of the illegal landfill. The reason may be the washing out of burnt solid waste by atmospheric precipitation and the subsequent infiltration of the resulting leachate into the aquifer. The final issue is soil contamination around the fire area, which can lead to costly and long-term negative consequences. The most common

ones include the need to remediate contaminated soil and exclude the area from use for many months. Another very serious consequence of fires at illegal landfills is the threat to human health and life. Many of the pollutants generated during fires are toxic, carcinogenic and mutagenic. Additionally, they can lead to skin irritation, asthma, heart attacks and respiratory failure.

The conducted research allowed for the identification of organic substances released during fires in illegal landfills where solid waste of various origins was deposited. In order to determine the potential threat of fires from illegal landfills to the soil and water environment, the concentrations of PAHs, methylphenanthrenes and their diagnostic indicators were determined in soils and samples of burned solid waste. However, concentrations of anthropogenic organic phosphates and inorganic compounds were detected in the leachates obtained from washing burned solid waste. Additionally, in order to assess the risk to human health, PAH toxicity indicators were determined, such as: RTBaP toxicity equivalent (TEQ), mutagenicity equivalent (MEQ) and carcinogenicity equivalent (TCDD-TEQ), and the negative effect of PAHs ($\Sigma WWA_{carc}/\Sigma WWA$).

The results of the sum of PAH concentrations (ppm/g of soil) from landfills show their relatively higher content in soil samples than in samples of burned solid waste, most likely due to the strong accumulation of pollutants caused by the fire. However, lower sums of PAH concentrations in samples of burned solid waste may indicate a lower ignition temperature and, consequently, a less intense combustion process. The results of the PAH diagnostic coefficients used for calculations indicate that a fire at illegal landfills had a potential impact on the pollution of the nearby natural environment. However, attention should also be paid to the aspect of long-term pollution of areas by external factors. The MEQ index in both fire cases (except for the S5S soil sample) did not indicate any threat to humans further away. The maximum value of $\sum PAH_{carc}/\sum PAH$ observed in the tested samples was 0.487. This means an average risk ratio of carcinogenic PAHs to human health, where the highest risk ratio is 1. However, with the generally high level of PAH concentrations in the tested soils, special personal protective equipment (protective clothing, gloves, mask) should be used when working in these areas, especially when overall PAH levels are high. There was no presence of PAHs in the tested samples of leachate from burnt solid waste, which is due to their low solubility in water.

During examing methylphenanthrenes, high R_c values over 2.0 were detected in soil samples from both study areas. This may once again indicate strongly accumulated organic pollutants in the soil in and around the landfill site, caused by the fire. However, the R_c index in samples of burned solid waste was in most cases around 2.0 and lower. This suggests places where incomplete combustion occurred, most likely due to reduced access to oxygen. However, the average values of MPI-3 and MPI-1 may correspond to high-temperature thermal transformations of the samples. There were no R_c results in the range of 0.7-0.9, which could indicate pollution from coal combustion in private homes and car traffic, or oil and coal-derived waste that has not been thermally transformed. These results indicate that organic pollutants present in the tested samples are related to the fire of an illegal landfill.

Three organophosphorus compounds were detected in eight leachates from incinerated solid waste: TCPP - tris(2-chloroisopropyl) phosphate, TPP - triphenyl phosphate and TCEP - tris(2-chloroethyl) phosphate. Organophosphate compounds are relatively soluble in water. This means that they pose a potential threat to groundwater contamination in such areas. TCPP was

detected in leachates from burnt black rubbers, sponges and wallpapers. However, its highest concentration was detected in leachate from samples of burned textiles T8.L (0.037 µg/l) and T9.L (0.671 µg/l). In turn, the TPP concentration was the highest in leachates from burned T7.L wallpapers (0.024 µg/l). TCEP was dominant in two samples of leachate from burnt black rubbers, T4.L (0.902 µg/l) and T5.L (1.366 µg/l). No OPEs were detected in leachate from burnt waste tires. These substances are dangerous to humans because they irritate the skin and eyes and are carcinogenic.

The examined leachates from burnt solid waste were mostly contaminated with ions such as sulphates and chlorides. Among the heavy metals, zinc had the highest concentration. The highest concentrations of pollutants were observed in samples WR5.O and WR8.O. These are mainly samples of burnt black rubber and textiles. The sulphide contents in these samples exceeded 1000 mg/l and the chloride contents were 85 and 320 mg/l, respectively. Sample WR5.O also had a high zinc concentration of 100 mg/l, while WR8.O had more than 50 mg/l. The concentrations of the remaining heavy metals tested: arsenic, boron, lead, cadmium and copper were relatively low in the tested leachate samples. Most likely, as a result of the fire, the salts transformed into oxide forms, most of which are poorly soluble in water. Additionally, it cannot be stated that soluble forms of metals are formed as a result of fire of pure metals. Another issue is the negligible content of heavy metals in this type of solid waste samples tested. They may originate most likely from scaffolding inside used tires or aluminum barrels if solid waste is stored in them. It can be concluded that the leachates obtained from washing out incinerated solid waste in Trzebinia are of better quality than other leachates

Fires at illegal landfills pose a serious threat to the land and water environment and nearby residents due to their unpredictable course and lack of knowledge about solid waste that is present in a given area. These areas are additionally not protected from the ground, which leads to the infiltration of substances from the accumulated burnt solid waste and the migration of organic and inorganic compounds in the leachates into the aquifer. A consequence of fires is also the migration of pollutants into the atmosphere, which can be found at a considerable distance from the epicenter of the landfill fire.

The location of a potential fire in an illegal landfill and the type of waste lying there influences the final level of contamination of the nearby area. Petroleum wastes are larger emitters of heavier PAHs, which pose greater threats to the environment and human health.

It is recommended to constantly monitor illegal waste dumping sites after fires in terms of the potential impact of pollution on the natural environment. It is proposed to collect soil samples from the center and surroundings of the burned illegal landfill. This is to determine the impact of pollution and determine the possible need to remediate the area in order to avoid high costs in the future. In cases of large areas of illegal waste dumps, when it is not possible to remove them quickly, it is recommended to install lysimeters to constantly monitor pollutants that may enter the aquifer.

As part of future research on illegal solid waste dumps after a fire, it is planned to examine land in areas where previously burned waste was located. This will allow us to determine the possible long-term impact of residual pollutants in the environment and their ongoing impact. Additionally, it is planned to carry out controlled incineration of selected types of solid waste in order to determine possible pollutants that may arise and, as a result, be released into the ground and water environment.