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ASSESSMENT OF SELECTED LANDFILL IMPACTS ON SELECTED SEGMENTS OF THE ENVIRONMENT – A CASE STUDY

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ABSTRACT

Landfilling is the oldest method of waste management. A number of biological, chemical, and physical reactions occur at the landfills, which cause a threat to the environment. For this reason, landfill monitoring is necessary, and biomonitoring is increasingly beginning to be used. The aim of this study is to (i) determine some effects of the landfill on the surrounding environment, (ii) analysis of plant bioindicators and (iii) biomonitoring based on the occurrence of plant species producing allergenic pollen. Furthermore, plants producing fruits and seeds were also analysed. During biomonitoring, no serious effects of the landfill on the surrounding environment were detected. The plant species found were evaluated based on the frequency of occurrence, pollination vector, distribution of fruits and seeds, and intensity of allergen effects. Thanks to the occurrence of plant allergens, there is a potential risk of the spread of allergens to the landfill surroundings. Furthermore, some species of non-native and invasive plants were found on the active part of the landfill. These species spread their seeds and fruits, and they pose a potential risk to the ecosystems.

Keywords: municipal solid waste, landfill impact, biomonitoring

INTRODUCTION

Landfilling as a method of waste management

The growing human population and the growth of consumer lifestyles place ever-greater demands on waste management (WM), (Das et al., 2019; Noor et al., 2020; Kurniawan et al., 2021). Landfilling is one of the oldest waste management methods (Adamcová, 2019; Sadhasivam, Sheik Mohideen & Alankar, 2020) and the dominant waste disposal method (Ma et al., 2022); however, there are increasing efforts to develop other waste disposal methods. Above all, this concerns the energy use of waste and recycling (Hahladakis & Iacovidou, 2019; Mukherjee, Denney, Mbonimpa, Slagley & Bhowmik, 2020; Shah, Srivastava, Mohanty & Varjani, 2021). Despite the development of other waste disposal methods, the current state allows concluding that some waste will always be disposed of in landfills (Vaverková, 2019). For example, the bottom ash generated during energy utilisation of waste (incineration) is further landfilled (Kumar & Singh, 2021; Nag & Shimaoka, 2023). Therefore, the attention is now shifting to the so-called circular economy. In this context, emphasis is placed on minimising waste production and maximising the use of waste (Fogarassy & Finger, 2020; Kern, Sharp & Hachmann, 2020). One of the main reasons why landfilling is among the most used waste disposal methods is its relatively low price for disposal – economic advantages (Vaverková, 2019; Liu, Liu & Wang, 2020).

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Landfill impact on the environment

A number of biological, chemical, and physical reactions occur at the landfill sites, which cause a potential threat to the environment (Vaverková, 2019; Nanda & Berruti, 2021). This is primarily due to the creation of leachate and landfill gas (Vaverková, 2019; Shammas, Wang, Wang & Chen, 2020; Rasapoor, Young, Brar & Baroutian, 2021). These two factors can negatively affect the surroundings of the landfill (Podlasek, Jakimiuk, Vaverkova & Koda, 2021; Winkler et al., 2021; Koda et al., 2022; Vaverková et al., 2022). Although nowadays landfills are designed and operated in such a way as to eliminate this risk, the problem lies in the lifetime of the landfill, which is many times longer than the operation of the landfill (Madon et al., 2019; Kamaruddin et al., 2021). It means that the landfill is active for a long time, even after it is closed and reclaimed (Madon, Drev & Likar, 2019; Abiriga, Jenkins, Vestgarden & Klempe, 2021). Thus, a landfill is a continuous potential source of environmental pollution that is passed on to future generations.

Monitoring of landfills with particular emphasis on biomonitoring

Landfill monitoring is necessary after the closure of a landfill, and in recent years, the interest of the scientific community in issues related to the responses of living organisms to the emitted pollutants – the so-called biomonitoring – is growing (Rumbold & Mihalik, 2002; Winkler et al., 2021; Jafarova, Contardo, Aherne & Loppi, 2022; Koda et al., 2022; Vaverková et al., 2022). Plant reactions are manifested, for example, by changes in behaviour, appearance, or frequency of occurrence (Winkler et al., 2021; Koda et al., 2022; Vaverková et al., 2022). Thanks to this, possible negative environmental effects can be recognised early on, and thus solved. For these reasons, the importance of biomonitoring is not negligible and thanks to it, the presence and source of contaminants in the monitored environment can be detected and evaluated. Therefore, the aim of this study is to (i) determine the impact of a selected landfill on the surrounding environment, (ii) analysis of plant bioindicators and (iii) biomonitoring based on the occurrence of plant species producing pollen as an allergen. Furthermore, plants producing fruits and seeds that can spread unchecked into surrounding ecosystems were also analysed.

MATERIAL AND METHODS

Landfill site description

The Zdounky-Kuchyňky landfill (49.2490778 N, 17.3121181 E) is an active and sanitary (with a leachate protective layer) landfill site located in the Zlín Region, the eastern part of the Czech Republic. The landfill activity started in 1995. The landfill is situ-

Fig. 1. Landfill overview

Source: photo by Roman Vlček 2019.

ated in a pronounced morphological depression, and the existing roads III/428 17 Zdounky-Nětčice and III/432 15 Nětčice-Troubky demarcate its premises (Vaverková, Toman & Kotovicová, 2012). Altitudes ranging from 240–396 m a.s.l. indicate the rugged topography. The landfill itself is situated at an altitude of 251–280 m a.s.l. (Fig. 1).

The designed area of the landfill is 70,700 m^2 with a total volume of 907,000 m^3. The planned service life of the facility is up to 2027. The landfill receives waste from a catchment area with a population of around 75,000 residents. The deposited waste is from the communal sphere, non-hazardous waste, including municipal solid waste (MSW). The surrounding area is bordered by agricultural fields. The leachate is collected via a draining system and stored in a leachate pond – a receiving system (Podlasek et al., 2021; Podlasek, Vaverková, Koda, Jakimiuk & Barroso, 2023). The landfill is classified as falling in the S-OO group (other waste), subgroup S-OO3. It is intended for the storage of waste from the category of other waste, including waste materials with a substantial content of organic, biologically decomposable substances, which cannot be assessed based on their aqueous leachates. Hazardous waste is not being deposited in the landfill. Landfill gas is burnt in the motor-generator unit producing electric energy. Part of the landfill body crown is operated as a composting plant. There is a recycling area on the part of the landfill site on which inert demolition waste material is processed and stored (Vaverková et al., 2012; 2019; 2020; 2022).

Natural conditions

The area on which the landfill is situated was formerly used for agriculture – mainly plant production (Fig. 2). The terrain is formed by a wide valley with an elevation of up to 30 m, and the valley bottom descends in an approximately westerly direction. The area's hydrographic axis is the surface watercourse of Lipinka, which opens into the Olšinka on the western limit of Zdounky. After approximately 500 m, the Olšinka opens in the Kotojedka surface stream. All these watercourses are of little importance for water management in the area.

Climatically, the area belongs in the T2 warm zone with warm to mildly warm springs, long warm and dry summers, very short transitional periods of autumn, and mildly warm, dry to very dry winters with a very short period of snow cover (Vaverková et al., 2012; 2019).

Technical description of the landfill

The landfill site is fenced and located on an area of 18.4 ha. The body of the landfill in Stage I occupies 1.92 ha, Stage IIa 0.55 ha, Stage IIb 0.47 ha, Stage III 0.75 ha, Stage IIIb 0.71 ha, Stage IV 0.58 ha, Stage V 0.69 ha, and Stage VI 0.61 ha.

Fig. 2. Landfill body and landfill surrounding

Source: photo by Roman Vlček 2019.

The entire complex consists of the following: (i) operational building; (ii) landfill body; (iii) leachate pond; (iv) surface water; (v) final embankment; (vi) catchment ditches; (vii) weighbridge; (viii) monitoring system; (ix) composting facility; (x) landfill degasification.

The operational building (i) is situated to the left of the service road before arriving at the landfill itself. It is a one-story building without a basement. There are employee changing rooms, sanitary facilities, a kitchen, a warehouse, an office and a weight room. During Stages I and II, a 5 × 200 mm mineral seal ($kf = n \cdot 10^{-10}$ m·s^{-1}), a 2 mm thick insulating film and a non-woven geotextile were placed on the compacted plain of the landfill body (ii). The entire system was completed with a 300 mm thick surface drainage made of river gravel (fraction 16–32 mm) at a 5% slope to the central leachate collector – the downspout. During Stage IIb, a 2 × 250 mm mineral seal, a 2 mm thick polyethylene high-density (PEHD) film and a non-woven geotextile were placed on the compacted plain. The system is complemented by surface drainage from the sorted river gravel (fraction 16–32) with a thickness of 300 mm. During Stage III, a 2 × 250 mm mineral seal, a 1.5 mm thick PEHD film and a non-woven geotextile were placed on the compacted plain. The system is complemented by a 500 mm thick surface drainage made of river gravel (fraction 16–32 mm). During Stage IIIb bentonite mats, a 2 mm thick PEHD film and a geotextile were placed on the compacted plain. The system was supplemented with surface drainage with a thickness of 500 mm from river gravel (fraction 16–32 mm). During Stage IV, bentonite mats, a 2 mm thick PEHD film and a geotextile were placed on the compacted plain. The system is completed with used tyres and surface drainage with a thickness of 300 mm from gravel (fraction 16–32 mm). During Stage V, bentonite mats, a PEHD film with a thickness of 2 mm and a non-woven geotextile (1,200 g·m^{-2}) were placed on the compacted plain. The system is completed with used tyres and surface drainage with a thickness of 300 mm from natural quarried aggregate. During Stage VI, bentonite mats, a PEHD film with a thickness of 2 mm and a non-woven geotextile were placed on the compacted plain. Used tyres are placed on it and covered with surface drainage (natural mined aggregate) 300 mm thick (DEPOZ, 2018). The leachate pond (iii) is a drainless and reinforced concrete structure. It consists of three tanks, of which the middle one (the so-called dry one) is covered and houses the pipelines, valves, and a pump for reverse discharge. Both open tanks are equipped with an insulating PEHD foil. The total size of the pit is 41 × 11 m. The surface water (iv) well consists of two open, interconnected reinforced concrete tanks with a total dimension of 38 × 16 m. The landfill body itself is supported on the slopes of the terrain depression and on the south side in an earthen embankment (v) designed to meet the requirements of static and deformational stability. Catchment ditches (vi) are around the perimeter of the entire landfill that collect runoff from the catchment area and the area above the landfill. Other branches are led along the perimeter of Stages I, II, IIIb, IV and VI, and capture the inflow to these stages. The branch above the technical background prevents the possible inflow of water onto the paved surfaces. All ditch profiles are trapezoidal and equipped with grooves. The weighbridge (vii) is located in the area in front of the operational building. The entire weighing system is stored below ground level in a reinforced concrete sump, forming the basis of the scale. The monitoring system (viii) is implemented by four monitoring wells: MV1 – depth 15 m, MVb – depth 11 m, MV4 – depth 15 m, MV5 – depth 15 m and well MV6 – depth 10 m. The composting facility (ix) is located within the body of the landfill. Landfilling was completed at the site. The area was covered with recycled material and compacted with a vibrating roller. Landfill degasification (x) using 12 vertical gas wells have been installed in the Stage I area, 3 wells in the Stage IIa area, 4 wells in Stage IIIa, 2 wells in Stage IIb, 5 wells in Stage IIIb, 3 wells in Stage IV, 4 wells in Stage V and 4 wells in Stage VI. Landfill gas is transported via a collection and conveyance system through a condensing and control shaft to the cogeneration unit. Here, electricity is generated and supplied to the public grid. The individual gas wells are gradually connected to the collection system depending on the quality and quantity of the gas and in connection with the closure of the landfill on the individual cassettes. Some of the wells where the gas permeability has been reduced due to casing movement are plugged, and new wells drilled in their vicinity. The cogeneration unit consists of two separate containers (3 × 5 m) fitted with a pump, an internal combustion engine and a control unit. The installed capacity is 2 × 160 kW (DEPOZ, 2018).

Vegetation monitoring at the landfill

Vegetation monitoring took place in the Zdounky locality at the MSW landfill, at two locations. The first site was a landfill with active waste disposal (Fig. 3), and the second was a reclaimed part of the landfill (Fig. 4).

Vegetation was evaluated using a floristic inventory of the species found. Vegetation was determined in the selected area of the MSW landfill. The identified plant species were recorded. Biological monitoring was carried out in July 2019. The scientific names of individual plant species were used according to Danihelka, Chytrý, Kučera and Palice (2017). The occurrence of each species found was evaluated on a simple three-point scale.

Scale evaluating the intensity of species occurrence: 3 – very abundant species with dominant

Fig. 3. The active part of the landfill with a composting plant

Source: photo by Magdalena D. Vaverková 2022.

Fig. 4. The reclaimed part of the landfill

Source: photo by Magdalena D. Vaverková 2022.

occurrence (dominant species); 2 – a common species with an abundant occurrence only in some parts of the landfill (subdominant species); 1 – a rare species with a small and rare occurrence.

Each plant species was classified according to the method of pollen transfer, the evaluation of the pollen as an allergen, and according to the method of dispersal of fruits and seeds. This information was taken from the database of Czech flora and vegetation, Pladias (Pladias, 2014–2023). The plant species producing allergenic pollen were taken from the database of the Czech Pollen Information Service (*Česká pylová informační služba* – PIS), which was founded in 1992 in Brno and monitors the occurrence of pollen and other biological objects in the air. The processed data serves doctors and patients to improve the quality of treatment. The PIS monitors the situation of 11 monitoring stations (Česká pylová informační služba [PIS], 2022).

According to the method of pollen transfer, the species were divided into: H – insect-borne (animal transmission); V – wind-borne (wind-borne); A – autogamy (self-fertilisation).

According to pollen as an allergen, the species were divided into three categories: 3 – species producing allergenic pollen that is monitored by PIS; 2 – wind-borne species, in which pollen is spread by the wind, but does not belong to strong allergens; 1 – insect-pollinating species, in which pollen is transmitted by insects and only gets into the air to a limited extent.

According to the method of transmission of fruits and seeds, the species were divided into: H – zoochoric (animal transmission); V – anemochoric (wind transmission); S – other mechanisms.

RESULTS AND DISCUSSION

Possible environmental impacts of the landfill

Impact on air and climate. The MSW Zdounky landfill is classified as a stationary source with respect to Czech Act No 201/2012 Coll. on air protection (Zákon ze dne 2. května 2012 o ochraně ovzduší). In accordance with this Act, the operating rules are laid down, and the landfill is operated in accordance with them. The operating rules include steps to minimise dust and odours (DEPOZ, 2018). These include primarily depositing waste in layers and continuous compaction with a compactor, then covering it with an inert material to prevent light particles from drifting and the release of particulate matter. Overlaying with inert material is also of hygienic importance. In addition, catch nets are installed, and greenery planted around the perimeter of the landfill to prevent materials from escaping from the landfill site. These measures are monitored daily. Emissions from transport and handling equipment at the landfill are not significant (portal.cenia.cz). Municipal solid waste landfill produces landfill gas (Adamcová, 2019; Purmessur & Surroop, 2019; Vaverková, 2019; Anshassi, Smallwood & Townsend, 2022), which is composed of gases (CH_4, CO_2, O_2, H_2S and others). The most important is CH_4, in terms of calorific value and, therefore, recoverability (Vaverková, 2019; Lee, Kim, Kim, Kwak & Kim, 2020). Methane is also a major greenhouse gas (Allen et al., 2020; Chetri, Reddy & Grubb, 2022). At the MSW Zdounky landfill, a landfill gas collection system is created and then burned in a cogeneration unit to produce electricity. In case of failure of the cogeneration unit or for other reasons, the degasification system is equipped with a flare to burn the gas so that it does not enter the air. As the landfill body expands, the degasification system is gradually enlarged (DEPOZ, 2018).

The effect of noise. Noise in the landfill area is mainly caused by the transport of waste and the place of its permanent storage and the subsequent handling of waste, including, for example, spreading and compaction (Vaverková, 2019; Hoang, Pham, Mai, Nguyen & Tran, 2022). A dense belt of greenery around the perimeter of the landfill helps to prevent the transmission of noise from the body of the landfill. It also helps the distribution of the terrain, namely, the mechanisation mostly moves below the level of the surrounding terrain. Noise does not spread outside the landfill, and the landfill area is located outside the built-up area (portal.cenia.cz).

Impact on water resources. Water quality is a good indicator of the spread of potential pollution from a landfill (Guo, Li, He & Wang, 2022; Podlasek et al., 2023). At the same time, water is also a good spreader of these pollutions (Pan, Ng & Richter, 2019). It is formed by biological decomposition, underground water inflows and rainfall (Vaverková, 2019; Koda et al., 2022; Podlasek et al., 2023). Water monitoring is carried out twice a year at the MSW Zdounky landfill. In addition to quality, other indicators of underground and leachate are monitored in four monitoring wells (MV1, MV2b, MV4 and MV5), (portal.cenia.cz). Long-term groundwater monitoring shows that the water quality in the area below the landfill is slightly worse than in the area below the landfill (Podlasek et al., 2023). The increased concentration of some substances, caused, for example, by agriculture, will manifest itself in the area under the landfill after at least a year, sometimes even longer. The landfill drainage system solution is designed to separate landfill and other waters from each other. Landfill waters are all waters that have come into contact with waste or could potentially come into contact with and are, therefore, contaminated leachates from waste. Thanks to the observance of the given procedures, the potential risk of leakage of landfill water is minimised. Leachate is collected and then transported to the wastewater treatment plant (DEPOZ, 2018).

Impact on soil. The agent that could cause soil contamination is water. To prevent the bedrock from coming into contact with landfill water, which is a potential spreader of contamination, the body of the landfill is secured with a two-layer waterproofing. Water that has come into contact with waste is channelled into a leachate pond using a drainage system so that it does not come into contact with rainwater (Vaverková, 2019). There was no evidence of any influence on the surrounding agricultural land by the landfill operation (Vaverková et al., 2019; 2020; Podlasek et al., 2021).

Results of vegetation surveys on the landfill under investigation

From the floristic inventory of plants at the Zdounky landfill, the most important plant species were selected and ranked according to their intensity of occurrence and allergen strength (Tables 1 and 2).

From Tables 1 and 2, it is clear that the Zdounky landfill, both in the reclaimed and active parts, contains a wide variety of abundant vegetation. Some significant allergenic plants were found, identical to the biomonitoring of Vaverková et al. (2019). These plants include: *Atriplex sagittata*, *Amaranthus retroflexus*, *Artemisia vulgaris*, *Bromus sterilis*, *Echinochloa crus--galli* and *Elytrigia repens*.

Since pollen can spread even several kilometres away, a waste landfill that has been recultivated with grass, from an anthropocentric point of view, represents a potential risk of developing allergies in the vicinity of the landfill. According to Vaverková et al. (2019), reforestation reduces the proportion of allergens in the

Table 1. List of selected plant species from the reclaimed part of the landfill

Plant	Intensity of occurrence	Pollination vector	Allergies	Propagation of fruit and seeds
Arrhenatherum elatius	3	A, V	3	S, V
Calamagrostis epigejos	3	V	3	V
×*Festulolium*	3	V	3	S, V
Artemisia vulgaris	2	V	3	V
Dactylis glomerata	2	A, V	3	S, V
Elytrigia repens	2	V	3	S
Festuca pratensis	2	V	3	S, V
Festuca rubra	2	V	3	S, V
Lolium perenne	2	V	3	S, V
Phleum pratense	2	A, H, V	3	S, V
Phragmites australis	2	V	3	S, V
Plantago lanceolata	2	H, V	3	S
Poa pratensis	2	A, V	3	S, V

H – insect-borne (animal transmission), V – wind-borne (wind-borne), A – autogamy (self-fertilization), S – other mechanisms.

Source: own work.

Table 2. List of selected plant species from the active part of the landfill

Plant	Intensity of occurrence	Pollination vector	Allergies	Propagation of fruit and seeds
Atriplex sagittata	3	V	3	S
Amaranthus powellii	2	V	3	S
Amaranthus retroflexus	2	V	3	S
Artemisia vulgaris	2	V	3	V
Bromus sterilis	2	A	3	S, V
Calamagrostis epigejos	2	V	3	V
Echinochloa crus-galli	2	V	3	S, V
Elytrigia repens	2	V	3	S
Chenopodium album	2	V	3	S, V
Robinia pseudoacacia	2	H	3	S
Rumex obtusifolius	2	V	3	V
Sambucus nigra	2	H	3	S, H
Urtica dioica	2	H, V	3	S, V
Tripleurospermum inodorum	2	H, V	2	S

H – insect-borne (animal transmission), V – wind-borne (wind-borne), A – autogamy (self-fertilisation), S – other mechanisms.

Source: own work.

air and, at the same time, contributes to the improvement of air quality. Due to the fact that the reclamation of the landfill by planting grass poses a potential threat in the presence of various allergenic pollens, reclamation by afforestation is recommended, if possible (Vaverková et al., 2022). Nevertheless, grasses are of great importance in terms of nutrient exchange in the soil and water infiltration. An advantage is the speed of growth, the ability to survive on waste material (Winkler et al., 2021), and resistance to adverse pH and toxic metals. Their abundant root system prevents soil erosion. Therefore, if the situation requires recultivation of the landfill by grassing, it is recommended to use plant species of the *Fabaceae* family in the seeding mixture, because during growth, grasses are demanding on nitrogen, and this family is able to supply atmospheric nitrogen to the cycle. At the same time, they are among the entomophilous species, which means that their pollen only enters the air in limited quantities, and therefore they are not among the significant producers of allergenic pollen. Examples of such species can be *Medicago lupulina* and *Lotus corniculatus*.

The propagation of fruits and seeds of plants is of great importance from the point of view of succession. During succession, there is an alternation of individual plant species with different life strategies and properties. The course of succession is influenced by a number of circumstances, for example, the surrounding seed source, meteorological conditions, soil composition, etc. (Winkler et al., 2021; Koda et al., 2022). The vast majority of vegetation found at a waste landfill is the type commonly found in human-impacted environments (Winkler et al., 2021; Vaverková et al., 2022). However, the existence of this vegetation is of great importance – especially ecologically – due to the creation of conditions for the next stage of succession. In the vicinity of the Zdounky landfill, there is predominantly agricultural land. The floristic surveys confirmed that the area of the landfill has a higher species diversity than the surrounding landscape. This was confirmed by Vaverková et al. (2019; 2020; 2022).

However, there is also a potential risk of the positive effect of the landfill on the species diversity of the landscape (Vaverková et al., 2019; 2020; 2022; Winkler et al., 2021). Several invasive and non-native plant species were found in the active part of the Zdounky landfill. Specifically: *Acer negundo*, *Arrhenatherum elatius*, *Conyza canadensis* and *Reynoutria japonica*.

Their potential risk lies in endangering the preservation of biological diversity, both at the species level (danger of crossbreeding and loss of genetic variability and competition) and at the community level. If a non-native species has abilities that can give it an advantage over native species, it starts to expand intensively (invasive species). These are plant species that spread with the help of the wind, and there is a great potential risk of spreading to the surroundings of the landfill (Winkler et al., 2021).

During the floristic survey by Vaverková et al. (2012) several species were found on the reclaimed part of the landfill: (i) *Plantago major* – the soil eutrophication indicator indicates an increased concentration of inorganic nutrients in the soil (mainly nitrogen and phosphorus). These conditions in the soil can also be influenced by the fact that the land around the landfill is intensively used for agriculture. These inorganic substances can also affect the reclaimed part of the landfill; (ii) *Symphytum officinale* and *Urtica dioica* – are indicators of elevated or high nitrogen in the soil; (iii) *Silene vulgaris* – indicates an increased or high occurrence of heavy metals in the soil. The types of waste deposited at the landfill can play a role here, potentially affecting the soil in the reclaimed part of the landfill.

CONCLUSIONS

Waste landfills already have an impact on the environment during construction, mainly due to noise and dust caused by increased traffic and mechanisation in the vicinity of the landfill. During the operation of the landfill, there is a risk of landfill gas and leachate generation, dust and fine particles floating from the body of the landfill, noise, etc. After the completion of exploitation and reclamation of the landfill, efforts are made to integrate it into the landscape in the most appropriate way and to minimise the impact on the surrounding ecosystems. In this context, choosing the right reclamation method is very important. Despite the fact that landfilling of waste is abandoned, this does not mean that this potential risk and impact on the surrounding landscape that landfills represent will disappear. Reclaimed landfills still need to be monitored. In addition to continuous monitoring of leachate and gas, biomonitoring using plant bioindicators can also serve this purpose. Thanks to appropriately selected bioindicators, the impact of the landfill load on the surrounding landscape can be determined.

During the landfill biomonitoring, no significant impacts of the landfill on the surrounding environment were detected. The plant species found were recorded and evaluated based on the frequency of occurrence, pollination vector, distribution of fruits and seeds, and intensity of allergen effects. However, thanks to the occurrence of 23 strong plant allergens at the landfill, there is a potential risk of the spread of allergens to the surroundings of the landfill, which appears to be a risk for humans. Furthermore, some species of non-native and invasive plants were found on the active part of the landfill, which were most likely brought to the landfill together with the waste. These species spread their seeds and fruits with the help of the wind; therefore, they pose a potential risk to the surrounding ecosystems. It is evident that the landfill can become a source of weeds in agricultural land and other areas.

Despite this, several new species of plants were also found at the monitored landfill, which highlights the ongoing succession at the landfill. In some circumstances, landfills can be considered a favourable environment for the development of a range of plants and a refuge for animals. These results show that the landfill can, on the contrary, have a positive effect on the surrounding landscape, as it exhibits a higher degree of biodiversity than the surrounding intensively agriculturally-used landscape. Although landfilling is last in the hierarchy of waste management and, therefore, the least suitable way to manage waste, it can be of some benefit to the landscape if it is operated in accordance with regulations and properly monitored. In this case, it does not pose a significant threat to the surroundings, and on the contrary, it can be integrated into the surrounding landscape and become part of the surrounding ecosystems.

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REFERENCES

Abiriga, D., Jenkins, A., Vestgarden, L. S. & Klempe, H. (2021). A nature-based solution to a landfill-leachate contamination of a confined aquifer. *Scientific Reports*, *11* (1), 14896.

Adamcová, D. (2019). Comparison of technical methods of securing closed landfills in the Czech Republic and Poland. *Acta Scientiarum Polonorum. Architectura*, *18* (4), 61–71.

Allen, G., Hollingsworth, P., Kabbabe, K., Pitt, J. R., Mead, M. I., Illingworth, S., Roberts, G., Bourn, M., Shallcross, D. E. & Percival, C. J. (2019). The development and trial of an unmanned aerial system for the measurement of methane flux from landfill and greenhouse gas emission hotspots. *Waste Management*, *87*, 883–892.

Anshassi, M., Smallwood, T. & Townsend, T. G. (2022). Life cycle GHG emissions of MSW landfilling versus Incineration: Expected outcomes based on US landfill gas collection regulations. *Waste Management*, *142*, 44–54.

Česká pylová informační služba [PIS] (2022). Retrieved from: https://www.pylovasluzba.cz [accessed: 10.04.2020].

Chetri, J. K., Reddy, K. R. & Grubb, D. G. (2022). Investigation of different biogeochemical cover configurations for mitigation of landfill gas emissions: laboratory column experiments. *Acta Geotechnica*, *17*, 5481–5498.

Das, S., Lee, S. H., Kumar, P., Kim, K. H., Lee, S. S. & Bhattacharya, S. S. (2019). Solid waste management: Scope and the challenge of sustainability. *Journal of Cleaner Production*, *228*, 658–678.

Danihelka, J., Chytrý, M., Kučera, J. & Palice, Z. (2017). History of botanical research in the Czech Republic. In M. Chytrý, J. Danihelka, Z. Kaplan & P. Pyšek (Eds), *Flora and vegetation of the Czech Republic* (pp. 25–87). Cham: Springer.

DEPOZ, spol. s r.o., 768 02 Zdounky 27. Registration in OR at KS in Brno, dept. C, insert 1224. Operating procedures, 2018.

Fogarassy, C. & Finger, D. (2020). Theoretical and practical approaches of circular economy for business models and technological solutions. *Resources*, *9* (6), 76.

Guo, Y., Li, P., He, X. & Wang, L. (2022). Groundwater quality in and around a landfill in northwest China: characteristic pollutant identification, health risk assessment, and controlling factor analysis. *Exposure and Health*, *14* (4), 885–901.

Hahladakis, J. N. & Iacovidou, E. (2019). An overview of the challenges and trade-offs in closing the loop of post--consumer plastic waste (PCPW): Focus on recycling. *Journal of Hazardous Materials*, *380*, 120887.

Hoang, A. N., Pham, T. T. K., Mai, D. T. T., Nguyen, T. & Tran, P. T. M. (2022). Health risks and perceptions of residents exposed to multiple sources of air pollutions: A cross-sectional study on landfill and stone mining in Danang city, Vietnam. *Environmental Research*, *212*, 113244.

Jafarova, M., Contardo, T., Aherne, J. & Loppi, S. (2022). Lichen biomonitoring of airborne microplastics in Milan (N Italy). *Biology*, *11* (12), 1815.

Kamaruddin, M. A., Norashiddin, F. A., Yusoff, M. S., Hanif, M. H. M., Wang, L. K. & Wang, M. H. S. (2021). Sanitary Landfill Operation and Management. *Solid Waste Engineering and Management*, *1*, 525–575.

Kern, F., Sharp, H. & Hachmann, S. (2020). Governing the second deep transition towards a circular economy: How rules emerge, align and diffuse. *Environmental Innovation and Societal Transitions*, *37*, 171–186.

Koda, E., Winkler, J., Wowkonowicz, P., Černý, M., Kiersnowska, A., Pasternak, G. & Vaverková, M. D. (2022). Vegetation changes as indicators of landfill leachate seepage locations: Case study. *Ecological Engineering*, *174*, 106448.

Kumar, S. & Singh, D. (2021). Municipal solid waste incineration bottom ash: a competent raw material with new possibilities. *Innovative Infrastructure Solutions*, *6*, 1–15.

Kurniawan, T. A., Lo, W., Singh, D., Othman, M. H. D., Avtar, R., Hwang, G. H., Albadarin, A. B., Kern, A. O. & Shirazian, S. (2021). A societal transition of MSW management in Xiamen (China) toward a circular economy through integrated waste recycling and technological digitization. *Environmental Pollution*, *277*, 116741.

Lee, J., Kim, S., Kim, Y. T., Kwak, G. & Kim, J. (2020). Full carbon upcycling of landfill gas into methanol by integrating CO_2 hydrogenation and methane reforming: Process development and techno-economic analysis. *Energy*, *199*, 117437.

Liu, J., Liu, Y. & Wang, X. (2020). An environmental assessment model of construction and demolition waste based on system dynamics: a case study in Guangzhou. *Environmental Science and Pollution Research*, *27*, 37237–37259.

Ma, S., Zhou, C., Pan, J., Yang, G., Sun, C., Liu, Y., Chen, X. & Zhao, Z. (2022). Leachate from municipal solid waste landfills in a global perspective: Characteristics, influential factors and environmental risks. *Journal of Cleaner Production*, *333*, 130234.

Madon, I., Drev, D. & Likar, J. (2019). Long-term risk assessments comparing environmental performance of different types of sanitary landfills. *Waste Management*, *96*, 96–107.

Mukherjee, C., Denney, J., Mbonimpa, E. G., Slagley, J. & Bhowmik, R. (2020). A review on municipal solid waste-to-energy trends in the USA. *Renewable and Sustainable Energy Reviews*, *119*, 109512.

Nag, M. & Shimaoka, T. (2023). A novel and sustainable technique to immobilize lead and zinc in MSW incineration fly ash by using pozzolanic bottom ash. *Journal of Environmental Management*, *329*, 117036.

Nanda, S. & Berruti, F. (2021). Municipal solid waste management and landfilling technologies: a review. *Environmental Chemistry Letters*, *19*, 1433–1456.

Noor, T., Javid, A., Hussain, A., Bukhari, S. M., Ali, W., Akmal, M. & Hussain, S. M. (2020). Types, sources and management of urban wastes. In *Urban ecology* (pp. 239–263). Elsevier.

Pan, C., Ng, K. T. W. & Richter, A. (2019). An integrated multivariate statistical approach for the evaluation of spatial variations in groundwater quality near an unlined landfill. *Environmental Science and Pollution Research*, *26*, 5724–5737.

Pladias: Database of Czech Flora and Vegetation (2014––2023). Retrieved from: www.pladias.cz [accessed: 07.04.2020].

Podlasek, A., Jakimiuk, A., Vaverková, M. D. & Koda, E. (2021). Monitoring and assessment of groundwater quality at landfill sites: selected case studies of Poland and the Czech Republic. *Sustainability*, *13* (14), 7769.

Podlasek, A., Vaverková, M. D., Koda, E., Jakimiuk, A. & Barroso, P. M. (2023). Characteristics and pollution potential of leachate from municipal solid waste landfills: Practical examples from Poland and the Czech Republic and a comprehensive evaluation in a global context. *Journal of Environmental Management*, *332*, 117328.

Portal.cenia.cz (2019). Retrieved from: https://portal.cenia.cz/eiasea/view/eia100_cr [accessed: 29.04.2020].

Purmessur, B. & Surroop, D. (2019). Power generation using landfill gas generated from new cell at the existing landfill site. *Journal of Environmental Chemical Engineering*, *7* (3), 103060.

Rasapoor, M., Young, B., Brar, R. & Baroutian, S. (2021). Enhancement of landfill gas generation from aged waste by a combination of moisture adjustment and application of biochar and neutral red additives: A field-scale study. *Fuel*, *283*, 118932.

Rumbold, D. G. & Mihalik, M. B. (2002). Biomonitoring environmental contaminants near a municipal solid--waste combustor: a decade later. *Environmental Pollution*, *117* (1), 15–21.

Sadhasivam, N., Sheik Mohideen, A. R. & Alankar, B. (2020). Optimisation of landfill sites for solid waste disposal in Thiruverumbur taluk of Tiruchirappalli district, India. *Environmental Earth Sciences*, *79* (23), 522.

Shah, A. V., Srivastava, V. K., Mohanty, S. S. & Varjani, S. (2021). Municipal solid waste as a sustainable resource for energy production: State-of-the-art review. *Journal of Environmental Chemical Engineering*, *9* (4), 105717.

Shammas, N. K., Wang, L. K., Wang, M. H. S. & Chen, S. L. (2020). Ecological impact and management of solid waste landfill gas. In Y-T. Hung, L. K. Wang & N. K. Shammas (Eds), *Handbook of environment and waste management: Acid rain and greenhouse gas pollution control* (pp. 455–482). Singapore: World Scientific.

Vaverková, M. D. (2019). Landfill impacts on the environment. *Geosciences*, *9* (10), 431.

Vaverková, M. D., Adamcová, D., Winkler, J., Koda, E., Červenková, J. & Podlasek, A. (2019). Influence of a municipal solid waste landfill on the surrounding environment: landfill vegetation as a potential risk of allergenic pollen. *International Journal of Environmental Research and Public Health*, *16* (24), 5064.

Vaverková, M. D., Elbl, J., Koda, E., Adamcová, D., Bilgin, A., Lukas, V., Podlasek, A., Kintl, A., Wdowska, M., Brtnický, M. & Zloch, J. (2020). Chemical composition and hazardous effects of leachate from the active municipal solid waste landfill surrounded by farmlands. *Sustainability*, *12* (11), 4531.

Vaverková, M. D., Paleologos, E. K., Adamcová, D., Podlasek, A., Pasternak, G., Červenková, J., Skutnik, Z., Koda, E. & Winkler, J. (2022). Municipal solid waste landfill: Evidence of the effect of applied landfill management on vegetation composition. *Waste Management and Research*, *40* (9), 1402–1411.

Vaverková, M., Toman, F. & Kotovicová, J. (2012). Research into the Occurrence of Some Plant Species as Indicators of Landfill Impact on the Environment. *Polish Journal of Environmental Studies*, *21* (3), 755–762.

Vaverková, M. D., Winkler, J., Adamcová, D., Radziemska, M., Uldrijan, D. & Zloch, J. (2019). Municipal solid waste landfill – Vegetation succession in an area transformed by human impact. *Ecological Engineering*, *129*, 109–114.

Winkler, J., Koda, E., Skutnik, Z., Černý, M., Adamcová, D., Podlasek, A. & Vaverková, M. D. (2021). Trends in the succession of synanthropic vegetation on a reclaimed landfill in Poland. *Anthropocene*, *35*, 100299.

Zákon ze dne 2. května 2012 o ochraně ovzduší. Zákon č. 201/2012 Sb.

OCENA ODDZIAŁYWANIA WYBRANEGO SKŁADOWISKA ODPADÓW NA ŚRODOWISKO – STUDIUM PRZYPADKU

STRESZCZENIE

Składowanie jest najstarszą metodą unieszkodliwiania odpadów. Na składowiskach zachodzi wiele reakcji biologicznych, chemicznych i fizycznych, które powodują zagrożenie dla środowiska. Z tego powodu monitoring składowisk jest niezbędny, a biomonitoring zaczyna być coraz częściej wykorzystywany. Niniejszy artykuł ma na celu: (a) określenie niektórych oddziaływań składowiska odpadów na otaczające środowisko, (b) analizę bioindykatorów roślinnych oraz (c) biomonitoring na podstawie występowania gatunków roślin produkujących alergogenny pyłek. Ponadto analizie poddano występowanie roślin produkujących owoce i nasiona. Podczas badań nie wykryto poważnego oddziaływania składowiska na otaczające środowisko. Stwierdzone gatunki roślin oceniono na podstawie częstości występowania, wektora zapylania, rozmieszczenia owoców i nasion oraz intensywności działania alergenu. Ze względu na występowanie roślinnych alergenów istnieje potencjalne ryzyko ich rozprzestrzeniania się w otoczeniu składowiska. Ponadto na eksploatowanej części składowiska stwierdzono obecność niektórych gatunków roślin nierodzimych i inwazyjnych. Gatunki te rozprzestrzeniają nasiona i owoce, więc stanowią potencjalne zagrożenie dla ekosystemów.

Słowa kluczowe: stałe odpady komunalne, oddziaływanie składowisk, biomonitoring