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Original Research

Evaluation of Waste Landfills' Impact on the Environment Using Bioindicators

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Abstract

Our paper focuses on examination and determination of bioindicators. From their existence, condition or behavior judgments might be carried out on the existence of specific environmental indicators and on environmental conditions and changes. The goal of this study was to investigate if and how plants may be used to indicate some of the emissions of landfill sites. Sampling was carried out in the middle of April 2007, 2008, and 2009. The obtained data were compared with a simple floristic list prepared in 1995. Selected bioindicators were used to estimate impact of the landfill on the close vicinity.

Keywords: bioindicators, landfill, waste

Introduction

Waste landfill issues and related impact on the surroundings are current topics not only in the Czech Republic, but all over the world [1]. Landfilling has been used for many years as the most common method for the disposal of solid waste generated by different communities [2]. Despite the intensive efforts that are directed to the recycling and recovery of solid wastes, landfills remain an integral part of most solid waste management plans. Solid waste disposed in a landfill usually is subjected to a series of complex biochemical and physical processes that lead to the production of both liquid and gaseous emissions [3].

Human activities have always generated waste. This was not a major issue when the human population was relatively small and nomadic, but became a serious problem with urbanization and the growth of large conurbations. Poor management of waste led to contamination of water, soil and atmosphere, and to a major impact on the environment and public health [4]. The impact can be evaluated in various ways. Among them is the possibility of using the living organisms as indicators of the environment state, so-called bioindicators, to evaluate the effects of human activities on organism health, the functioning of ecosystems, structure, and functioning of the whole region. Changes in ecosystems or reasons for these changes can be evaluated on the basis of alteration in the behaviour, appearance, or occurrence of some organism or their concentration. Bioindication and biomonitoring are the methods that enable us to evaluate these changes that are not visible at first glance [5].

Gadzała-Kopciuch et al. suggests [6] that phytoindicators are more and more frequently used for ecosystem quality assessment due to their sensitivity to chemical changes in environmental composition and the fact that they accumulate pollutants. The use of plants as bioindicators has many advantages, including low costs, the possibility of long-term sampling, and high availability. Their disadvantage is the necessity to take into account the physical conditions, impact, of environmental properties (growth rate disturbed by large amounts of pollutants, soil type and fertility, humidity) and genotype diversity in a given population. Lower plant organisms (grasses, mosses, lichens, fungi, and algae) are used most often in analyses of atmos-

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pheric depositions, soil quality, and water purity. Responses of trees and shrubs to the presence of pollutants are also observed. The assimilatory organs of trees, especially coniferous ones (pine, fir, spruce), are characterized by the capacity to accumulate air pollutants, which makes them suitable for the determination of residues of pesticides, polychlorinated biphenyls (PCBs), pentachlorophenol (PCP), hexachlorobenzene (HCB), hexachlorocyxlohexane iosmers, dioxins, and furans. Numerous and visible changes, like needle loss, crown thinning, changed bark color, and increased needle fragility, enable us to estimate the level of environmental pollution [6].

Mosses and lichens are applied as indicators of environmental pollution due to their capacity to accumulate and store heavy metals and other toxins. Typical examples of a biological indicator of air pollution are lichens. Their major advantage is response repeatability in various habitats. Regardless of the investigation site and differences in species composition, destruction zones are easy to distinguish. Due to their specific anatomic, morphological, and physiological characters, lichens are among the organisms that die first as a result of excessive air pollution [6].

High concentrations of xenobiotics in plants allow us to employ simple measuring methods, and the popularity of the above plant species enables biomonitoring in different geographical regions, on a continental or even global scale. The specific sensitivity of some species of land plants, e.g. pine (*Pinus silvestris*) or spruce (*Picea abies*) to the presence of SO_2 in the atmosphere allows us to determine the degree, range, and structure of environmental degradation [6].

This paper was intended to conduct ecological assessment of the environment in the vicinity of the landfill with the use of bionidication methods, e.g. lichen reactions, and awareness of some selected plant species on possible pollutants from landfill. The aim of this study was to investigate if and how plants can be used to indicate some of the emissions of landfill sites.

The potential indicators of exposure to pollutants studied were:

1. Bioindicator plant occurrence, which was observed before landfill construction, and during its exploitation.
2. Quantity of biomass, measured at various distances from the landfill.

Study Site and Methods

The landfill under investigation is located 1 km north of Štěpánovice commune and 1 km south of Dehtín commune. GPS coordinates of the test point are 49º26'15.934"N, 13º16'55.352"E. The landfill has been operating since summer 1996. It is situated in the northern part of a wide valley that runs W-E. The bottom part of this area is restricted with a nameless stream being the right tributary of Úhlava River. The upper part of the area is covered with woodland vegetation predominated by *Pinus silvestris*. The southern slope is used for agriculture. The landfill is located on the northern slope from the valley axis. In the past, the landfill area was used as meadow [8].

Sample Collection

After selecting the place and obtaining the permit for landfill construction, the present manager conducted simple floristic tests in 1995 (he prepared a list of plant and lichene species that were then present at the tested area). According to a prepared list, 57 taxa of vascular plants and lichens were identified in the place of constructed landfill and the nearest vicinity and described. This list does not cover all taxa of vascular plants and lichens observed during that period, but selected species [9].

In 2007-09, simple floristic tests were conducted in the vicinity of the landfill and the present list of vascular plant taxa and lichens was elaborated. The studies covered the near vicinity of the landfill, from its fencing to 60 metres from the fence. The profile of selected plants is from available literature data [11-13]. The photo documentation of selected and described taxa of vascular plants and lichens composes a part of floristic tests.

The list includes information on selected plants from eastern, southern and western parts in the vicinity of the landfill (which are still grown with grass), and from the northern part with woodland vegetation dominated by *Betula pendula*, *Acer pseudoplatanus*, *Pinus silvestris*, *Quercus robur*, and *Picea abies* (Table 1). A Braun-blanquet cover scale (Table 2) [14] was used to record the area. Vegetation was identified at the time of the survey and where species could not be identified in the field, samples were collected and pressed for later identification.

The studies conducted in 2007 and 2008 allowed us to identify 56 taxa of vascular plants and 2 lichens, and in 2009 57 taxa of vascular plants that are compatible with the list of plants prepared by the landfill manager in 1995 [9]. The vascular plants taxa and lichens from the submitted list were thoroughly monitored as their presence or their possible shortage could indicate the change in environmental conditions, e.g. landfill impact on the near vicinity.

Taxa of less common, rare or protected vascular plants seem to have the most significant meaning during the evaluation of landfill impact on the near vicinity.

Among 57 identified vascular plant taxa, two of them. namely *Polygala chamaebuxus* and *Juniperus communis*, belong to endangered species and are protected (C3/§3) in the Czech Republic. And *Epipactis helleborine* are among the endangered species from C4 group [29].

Also, lichens (e.g. *Cladonia arbuscula*) can be used as bioindicators of landfill effect on the near vicinity. *Polygala chamaebuxus* was identified only in 2009; its presence was not confirmed in 2007 and 2008.

Methodology for Determining Biomass Plants

The quantity of biomass plants was determined with the destructive method – harvesting. The plant samples are collected in selected points, dried until obtaining the constant weight and then weighed. The biomass results are expressed in gm^{-2}.

Table 1. Plant species observed in the vicinity of landfills.

Scientific name	Braun-blanquet Cover
Alopecurus pratensis	3
Amaranthus retroflexus	4
Armoracia rusticana	2
Artemisia absinthium	3
Betonica officinalis	2
Brachypodium pinnatum	5
Calamagrostis epigejos	4
Calluna vulgaris	3
Centaurea jacea	3
Cirsium arvense	4
Cirsium balustre	4
Cirsium oleraceum	4
Cladonia arbuscula	2
Dactylis glomerata	3
Danthonia decumbens	3
Daucus carota subsp. carota	3
Epilobium angustifolium	2
Epipactis helleborine	2
Equisetum arvense	4
Eriophorum angustifolium	2
Euphorbia pepouš	3
Fragaria vesca	4
Frangula alnus	2
Galeopsis pubescens	2
Galium album	4
Galium verum	4
Genista tinctoria	3
Geranium pretense	2
Gnaphalium sylvaticum	4
Gnaphalium uliginosum	3
Hieracium pilosella	3
Hypericum maculatum	2
Hypogymnia physodes	3
Chenopodium album	4
Chrysanthemum leucanthem	3
Juniperus communis	1
Pinus sylvestris	3
Plantago major	3
Poa pratensis	4
Polygala chamaebuxus	1
Populus tremula	2

Table 1. Continued.

Scientific name	Braun-blanquet Cover
Pteridium aquilinum	3
Quercus robur	2
Ranunculus repens	4
Rosa canina	3
Seneci inaequidens	4
Symphytum officinale	2
Symphytum tubersum	3
Tanacetum vulgare	3
Trifolium arvense	3
Trifolium medium	4
Trifolium pretense	4
Urtica dioica	5
Verbascum thapsus	3
Veronica persica	5
Vicia angustifolia	2
Vicia cracca	4
Xanthoria parietina	2

% cover abundance (BBcover): ± <1%, 1 – 1-5%, 2 – 6-25%, 3 – 26-50%,4 – 51-75%, 5 – 76-100%

The field studies were conducted in the middle of the vegetation period, i.e. in the middle of April 2007, 2008, and 2009. Biomass was collected from the area of 1.0 x 1.0 m. The samples containing biomass were divided into live and dead biomass. The live biomass samples were placed in perforated paper packaging with written collecting point and data and transported to a laboratory at Mendel University in Brno, Department of Applied and Landscape Ecology. Individual samples were dried in an Ecocell (BMT a.s.) drier at 80ºC until obtaining constant weight. Dried biomass samples were weighed using analytical, digital balance Precisa 4000C (240 g/0.0001 g, with internal calibration), and then underwent statistical analysis.

Results and Discussion

Selected Species of Plants Present in the Vicinity of Landfills

During the performance of field studies in 2007-09, 57 taxa of vascular plants and 2 lichens were identified in the landfill vicinity. Plants were tested using botanical-gravimetric analysis. Biomass quantity of over-ground plants was determined gravimetrically. *Cladonia arbuscula*, *Juniperus communis*, *Epipactis helleborine*, *Populus tremula,* and *Polygala chamaebuxus* were selected as bioindicators of the landfill effect on the near vicinity. All mentioned

Table 2. Braun-blanquet cover scale [14].

Class	Braun-blanquet	
+	< 1%	Foliage sparsely or very sparsely present, cover less than 5%
1	1-5%	Plentiful, foliage cover 1-5%
2	6-25%	6-25% foliage cover
3	26-50%	26-50% foliage cover
4	51-75%	51-75% foliage cover
5	76-100%	76-100% foliage cover

taxa of vascular plants and lichens were identified in consecutive years 2007, 2008, and 2009, except for *Polygala chamaebuxus*. *Polygala chamaebuxus* appeared in 2009. According to the manager description, this plant was commonly present in the area of constructed landfill and in its near vicinity (particularly on the northern side toward the landfill, in the wood) [9]. The construction of the landfill probably caused the changes in biotope and destruction of this plants growing sites. Its reappearance in 2009 can demonstrate that environmental conditions in the vicinity of the landfill have been stabilized. As the soil seed bank contained undamaged diaspores (seeds) of *Polygala chamaebuxus*, it reappeared in its initial place. Repeated observations of the occurrence of *Cladonia arbuscula*, which is very sensitive to environmental pollution, can indicate good quality of the environment in the close vicinity of the landfill. The presence of *Juniperus communis*, which is a protected species in the Czech Republic, demonstrates that the construction and exploitation of the landfill has not significantly altered natural conditions required by this plant. *Populus tremula* belongs to species that during a short time colonise places with affected soil structure. This plant is sometimes called the master of survival in difficult conditions. It is an ideal pioneer plant, extremely tolerable regarding habitat requirements, resistant to frost, drought, pests, and environmental pollutants. Its presence may indicate some changes, e.g. soil damages, deteriorated environmental conditions which occurred during landfill construction. It grows in the occupied area for a long time even though the environmental conditions are subject to significant changes. The reoccurrence of *Polygala chamaebuxus* and the presence of species originally growing in this area, namely *Cladonia arbuscula, Juniperus communis*, and *Epipactis helleborine* may indicate that the landfill does not have a significant impact on the close vicinity.

Biomass in the Close Vicinity of the Landfill

Weight of biomass samples collected in the landfill vicinity in 2007-09 is presented in Table 3. Collecting points are divided into 3 areas:
southern side from the fencing – 4 samples,
eastern side – 3 samples,
western side – 9 samples (Fig. 1).

The map "Biomass sample collection points" shows that individual collection points should be compared, e.g. 1-2-3, 4-5-6, 7-8-9, 10-11-12, and 13-14-15 regarding individual years. The average dry weight biomass was calculated from the obtained results for all 16 sample collecting points. Table 4 presents a comparison of average dry biomass for all 16 collection points. And the difference in dry biomass [g/m^2] was calculated, the lowest and the highest differences were calculated for 2007-09. The calculations were expressed in percentage to make statistical analysis easier.

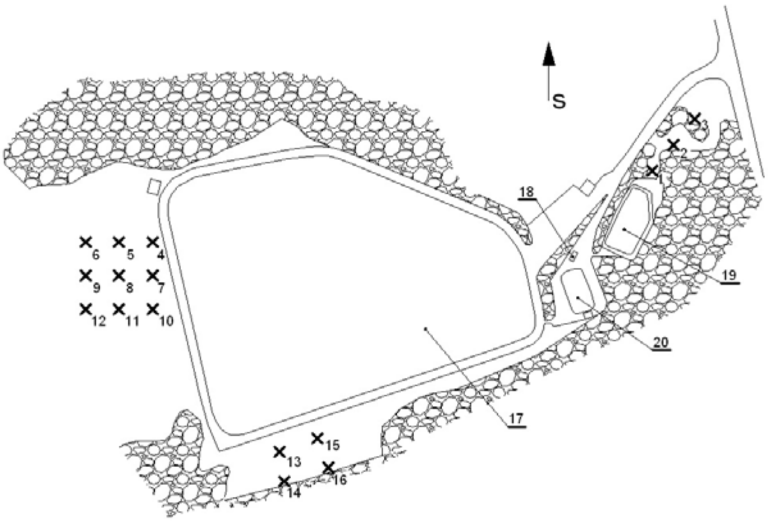

Fig. 1. Biomass sample collection points.
Legend of sample collection points:
1-16 – sample collection points
17 – landfill
18 – entrance gate
19 – rainwater reservoir
20 – drained water tank

The comparison of biomass collected from individual points in individual years shows that there is just a slight difference in their values in individual years. As the differences occur for the majority of collection points, these differences are related to ecological abiotic factor and ecological biotic factors, and not to the mere landfill (gas emissions, dust). Each year is unusual and unrepeatable considering meteorological conditions. Interannual variations, e.g. vegetation period, duration of snow cover, rainfall or temperature distribution, compose the changeability, which is a

Table 3. Dry weight biomass in individual years.

Collecting point	Dry weight biomass 2007 [g/m^2]	Dry weight biomass 2008 [g/m^2]	Dry weight biomass 2009 [g/m^2]	Average dry weight biomass [g/m^2]
1	115.40	116.23	118.56	116.73
2	122.51	140.06	114.95	125.84
3	175.72	160.89	182.56	173.06
4	99.53	87.14	93.93	93.53
5	89.80	82.92	84.68	85.80
6	81.92	76.88	86.92	81.91
7	93.83	93.68	87.98	91.83
8	80.22	90.54	74.35	81.70
9	106.88	107.83	116.93	110.55
10	89.56	97.03	90.09	92.23
11	57.06	89.36	35.60	60.67
12	108.34	103.11	123.28	111.58
13	62.46	75.48	68.63	68.86
14	65.61	86.93	64.28	72.27
15	104.23	99.86	108.33	104.14
16	111.65	117.94	124.56	118.05

Table 4. Comparison of individual collection points.

Collecting point	Average dry weight biomass [g/m^2]	Difference between max. and min. level [abs.] [g/m^2]	Difference between max. and min. level [%]
1	116.73	2.33	2,7
2	125.84	25.11	20.0
3	173.06	21.67	12.5
4	93.53	6.79	13.2
5	85.80	1.76	8.0
6	81.91	10.04	12.3
7	91.83	5.70	6.4
8	81.70	13.54	19.8
9	110.55	20.10	9.1
10	92.23	1.06	8.1
11	60.67	53.76	88.6
12	111.58	29.87	18.1
13	68.86	6.17	18.9
14	72.27	2.65	31.3
15	104.14	8.07	8.1
16	118.05	25.82	5.3

natural phenomenon and has a direct impact on biomass. Field observations, inventory of vascular plant taxa and lichens, and measured and calculated values did not confirm a significant impact of the landfill on the close vicinity.

Conclusions

Nature of the Problem

The main pollution issues associated with landfill sites are the production of potentially explosive gases and liquid leachate. Leachate emissions from landfill sites are of growing concern, primarily due to their toxic impact when released unchecked into the environment, and the potential for landfill sites to generate leachate for many hundreds of years following closure [15].

Landfill Potential Impact on Environment

Landfilled waste is comprised of a wide range of inorganic, natural, and xenobiotic compounds, the mixture of which in turn affects the composition and pollution potential of the landfill [16]. Municipal waste deposition is the relatively least troublesome method of its utilization. However, this method is related to environmental risk issues, among which the most important are as follows: leachate from the landfill, formation of landfill gas, landfill stability, dust, carried small materials, odour, concentrated presence of rodents and birds, and noise due to landfill operation. The potential impact of landfill on the near vicinity, particularly on plants, was evaluated on the basis of analysis of available materials. Just two impacts from the above-mentioned ones were analyzed. These were the formation of landfill gas and dust and carried small materials as they can have a significant impact on plants.

Formation of Landfill Gas

Gas emitted from landfill often contains compounds whose concentrations considerably exceed the concentration of the surrounding environment. Such concentrations may lead to the development of ecosystem with specific organisms. New conditions can be favourable for tolerant species, which can manage the emissions and use them in their metabolic process or, on the contrary, can lead to the elimination of sensitive species [13]. The main components of landfill gas are methane (from 40% to 60%), carbon dioxide (from 35% to 50%), nitrogen (from 0% to 20%), oxygen (from 0% to 1%), and hydrogen sulphide (from 50 to 200 ppm) [17]. Landfill gas can also contain trace compounds such as aliphatic and aromatic hydrocarbons, halogenated compounds, and silicon-containing compounds up to a total concentration of 2,000 mg/m^3 [18]. Hypothetically, plants (plant communities) in the ecosystem can be assumed to induce emissions and occurrence of polluted areas under the influence of landfill gas. The pollution may be indicated by:

- the development of specific species content and/or external reactions of organisms
- accumulation of contamination in plants.

The most common reason for disturbing vegetation in the vicinity of landfills is the presence of landfill gas in the root zone. The main reason for some damages is the deficiency of oxygen required to maintain root respiration. The emissions of landfill gas can diminish oxygen levels in soil to the amount required by the majority of plants, e.g. 5-10%. And the increased concentration of CO_2 is toxic even at sufficient oxygen levels. The usual CO_2 concentration in soil equals 2%, and typical plant growth is provided at 5%. Concentrations exceeding 20% are regarded as the phytotoxic level [13]. Plants present in the vicinity of landfills constantly affected by local conditions can be very interesting due to their diversity. The specified type of plants can be competitive and can grow when other species occur quite rarely. As some species are tolerant toward specific environmental conditions, it can be hypothetically assumed that plants (plant communes) can be used to evaluate the pollution/landfill impact [13].

Dust, Carried Small Materials

Regarding constant emissions (dust) from the landfill, this will probably have a negative impact on the aboveground plant parts, especially due to shading, mechanical clogging or covering of stomata, which can result in slowing down the photosynthesis, overheating of leaves, adsorption changes, and the reflection of heat radiation or mechanical damage of leaf surface. Thus it can directly affect biomass.

On the basis of conducted tests, it was found that waste management at Štěpánovice landfill complies with valid provisions of law. Landfill location and optimization of the transport route significantly minimizes the effect of landfill exploitation and used technique on natural environment [8]. Landfill location and adjusted configuration of the area in the vicinity of waste landfill do not have a negative impact on inhabitants from nearby Štěpánovice village [19]. The influence of noise and dust on the environment and daily life of inhabitants from the nearby area is minimal. Obedience to technological processes at the landfill prevents small materials carriage (they are regularly covered with a layer of neutral material and compacted with the use of a compactor). The protection of surface and ground water against leachate from the landfill is provided by means of a special system of bottom isolation (geomembranes made from high-density polyethylene HDPE) and drainage [8]. The landfill is monitored and inspected on a regular basis. In addition to a daily inspection of the landfill, there is also an independent inspection of negative effects on the environment (at least twice a year), especially the monitoring of ground water and leachate from the landfill, as well as the analysis of landfill gas formation. The deterioration of measured indicators has not been observed so far [8]. After completing the exploitation of individual parts of the landfill, they will be gradually reclaimed (the landfill surface will be covered to prevent the penetration of rainwater, landfill gas will be caught and removed, etc.). In other words, the negative effect of exploiting the open landfill on the environment will be eliminated. Due to the above and considering relatively little traffic of vehicles through the landfill area, its exploitation (operation) is not a significant negative factor that influences the environment [19]. The performed studies did not confirm the negative impact of landfill on the nearby area. This landfill is constructed and operated in compliance with the most modern and strictest requirements and standards.

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