SEASONAL CHANGES AND TOXIC POTENCY OF LANDFILL LEACHATE FOR WHITE MUSTARD (SINAPIS ALBA L.)

Jan Zloch¹, Magdalena Daria Vaverková¹, Dana Adamcová¹, Maja Radziemska², Tomáš Vyhnánek¹, Václav Trojan¹, Biljana Đorđević¹, Martin Brtnický³

¹Department of Applied and Landscape Ecology, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
²Department of Environmental Improvement, Faculty of Civil and Environmental Engineering, Warsaw University of Life Sciences – SGGW, Nowoursynowska 159, Warsaw, Poland
³Department of Geology and Pedology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 1, 613 00 Brno 13, Czech Republic

Abstract


Landfills are the most broadly used methods for the disposal of municipal solid waste (MSW). Leachate can be contaminated with pollutants that may pose a threat to the landfill surrounding namely soil, groundwater and surface waters. Examination of leachate composition is determinative in long-term impact of landfills on the environment and human health. Moreover, it is essential to assess such prior knowledge for prevention of negative outcomes. The evaluation of the seasonal changes of landfill leachate and rainwater composition is presented in this paper. Research samples of leachate and rainwater were collected from February till June of 2017 (still ongoing) and analyzed for pH, electrical conductivity, dissolved oxygen, series of trace elements. Subsequently the test of leachate toxicity for higher plants (Sinapis alba L.) was carried out. Up to now, the results do not indicate significant seasonal difference in landfill leachate composition, however the toxicity tests provided on Sinapis alba L. demonstrate that landfill leachates can present a significant source of contamination. This research can serve practical tools for evaluating quality and risk assessment for landfill leachate.

Keywords: waste, landfill, toxicity tests, pollution, Sinapis alba L.

INTRODUCTION

The oldest form of the removal and disposal of waste is landfilling (Vaverková et al., 2013; Vaverková and Adamcová 2014; Koda et al., 2015; Adamcová et al., 2016a; Ghosh et al., 2017) and landfills are broadly used methods for the disposal of MSW (Baderna et al., 2011; Tsarpali et al., 2012). Moreover, in the future, landfill will continue to be a major disposal option for MSW. This method of waste disposal are known source of environmental pollution (Hu et al., 2017), and waste buried in landfill is subjected to a series of physico-chemical and biological transformations, generating potentially polluted water–leachate (Ghosh et al., 2017). Leachate may contaminate the groundwater as well as the surface waters (Gworek et al., 2015; Li et al., 2017). The composition of leachate is affected significantly by the type of landfill, the waste disposed, the degree of compaction, and water content (Koda et al., 2015; Zhao et al., 2017). It is defined by high concentrations of organic and inorganic compounds, derived mainly from the disposal of non-hazardous MSW, as well as toxic chemicals (Tsarpali et al., 2012). If a waste has a high content of organic fraction, leachate is characterized by a higher oxygen content and higher
concentration of ammonium and organic nitrogen (Koda et al., 2015). Generally, leachate from MSW landfill sites has the same composition: Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), volatile fatty, inorganic macro components like Ca\(^{2+}\), Mg\(^{2+}\), Na\(^{+}\), K\(^{+}\), NH\(_4\)\(^{+}\), Cl\(^{-}\), SO\(_4\)\(^{2-}\), HCO\(_3\)\(^{-}\), trace elements and xenobiotic organic compounds (Ghosh et al., 2017). But trace elements are the most toxic and/or problematic pollutants in leachate. Authors (Baun and Christensen 2004; Oman and Junestedt 2008; Renou et al., 2008), suggested that typical trace elements concentrations in leachate are: Cd (0.0001-0.13 mg/L), Cr (0.0005-1.6 mg/L), Fe (0.08-2,100 mg/L), Mn (0.01-65 mg/L), Ni (0.03-3.2 mg/L), Pb (0.0005-1.5 mg/L), and Zn (0.00005-120 mg/L). The trace elements concentrations in young (acetogenic) leachate are usually higher than those in old (methanogenic) leachate (Kjeldsen et al., 2002; Oman and Junestedt 2008; Oka et al., 2017).

Commonly, assessment of leachate is based on identification of pollutants through chemical analyses (Ghosh et al., 2017), however, evaluation of leachate can be based also on the interactions with biota (Kjeldsen et al., 2002, Tsarpali et al., 2012). Actually, chemical analysis gives results about landfill leachate composition/pollution, while the toxicological tests, integrates the effect of all contaminants, providing information on their bioavailable fraction (Pandard et al., 2006; Kalcikova et al., 2011; Tsarpali et al., 2012).

From the literature view it can be concluded that papers usually contain only random leachate characterization (Wu et al., 2004; Bila et al., 2005; Kurniawan et al., 2006; Laitinen et al., 2006, Gworek et al., 2015), however, toxicological evaluation of leachate to examine the impact of leachate discharged into the environment is rather rare. Only some authors have tried to characterize leachate composition during the landfill exploitation. Therefore, the purpose of this study was to characterize the major components of leachate from MSW landfill, namely the landfill site in Zdounky-Kuchynky (Czech Republic). To authors best knowledge, the seasonally variety of leachate is not well studied yet.

An experimental investigation was conducted to explore: (a) the trace elements concentrations in leachate, (b) the phytotoxicity of the leachate, (c) the effects of leachate on root growth inhibition of Sinapis alba L. and, (d) the seasonal alterations of leachate toxicity. Additionally, rainwater characterization was also defined. Moreover, this study is a part of the long-term research of landfill Zdounky-Kuchynky and its influence on the environment.

**MATERIALS AND METHODS**

**Landfill site description**

The Zdounky-Kuchynky landfill (49.2490778 N, 17.3121181 E) (Fig. 1) is an active and sanitary (with leachate protective layer) landfill site located in the Czech Republic (CR). The landfill activity started in 1995. It is situated in a triangular space delimited by main roads connecting the villages of Zdounky, Nětěice and Troubky-Zdislavice (Vaverková et al., 2012). The designed area of the landfill is 70,700 m\(^2\) with a total volume of 907,000 m\(^3\), i.e. ca. 1,000,000 10\(^3\) kg of waste. 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 annually deposited amount of waste is around 40,000·10\(^3\) kg (50 % is from the communal sphere, non-hazardous waste including MSW). The surrounding is bordered by agricultural fields. The leachate is collected via a draining system and stored in leachate pond (receiving system) (Vaverková et al., 2012).
Leachate sampling

Leachate and rainwater samples were collected from February till June of 2017 (still ongoing). The sample of the leachate and rainwater were not collected in January (2017) because the ponds were frozen. The frequency of leachate and rainwater sampling from leachate pond and rainwater pond was one time per month. Two samples (0.5 L/sample) of leachate (leachate pond) and rainwater (rainwater pond) (Fig. 2) were collected in sterile collection containers. Samples were stored at 4 °C and transported to the analytical laboratory at the Department of Chemistry and Biochemistry, Faculty of AgriSciences, Mendel University in Brno for analysis within 72 h. Leachate and rainwater samples were analyzed for pH, electrical conductivity (EC), chemical oxygen demand (COD) in situ using a Multi-Parameter Meter HQ30d Portable and series of analyses of trace elements (Cd, Cr, Ni, Pb, Zn, Hg) ex situ.

Phytotoxicity test

White mustard (Sinapis alba L.) was used as a test organism to assess toxicity of leachate and rainwater samples. Sinapis alba L. is ideal for studying toxicity because it is sensitive to board range of chemicals. The effect of toxicity was assessed based on physiological (germination energy and germination) and morphological traits (root length) of white mustard (Sinapis alba L.). The treatments consisted of different concentrations of 25 %, 50 %, 75 % and 90 % (three replicate samples). Concentrations of leachate and rainwater has been chosen on the basis of authors previous experiments and studies (Vaverková et al., 2017). The test organisms were germinated in petri dishes and exposed to the leachate and rainwater solutions for a total of 72 h. The hydroponic solution (distilled water with the following chemical ingredients (mg/L): Ca(NO$_3$)$_2$ 0.8, KH$_2$PO$_4$ 0.2, KNO$_3$ 0.2, MgSO$_4$.7H$_2$O 0.2, KCl 0.2, FeSO$_4$.01, pH = 5.2) with tested liquid was added into each dish, and 15 healthy looking seeds of similar size were evenly spread onto the surface of the filter paper. The petri dishes were covered by a glass cap to prevent loss due to evaporation and were located in the EcoCell thermostat (t = 24 °C, air humidity 80%, dark environment). The root length were recorded at the end of the 3rd day (Fargašová 2004; Adamcová et al., 2016b; Vaverková et al., 2017).

Calculations and Data analysis

The analyses and the length measurements were performed using the Image Tool 3.0 for Windows (UTHSCSA, San Antonio, USA). The percent of root growth inhibition (RI) were calculated with the formula (Eq. 1):

$$RI = \frac{A - B}{A} \times 100$$

Where: A means root length in the control; B means root length in the test (Adamcová et al., 2016b).

RESULTS AND DISCUSSION

Chemical characteristics of landfill leachate and rainwater

Chemical characteristics of leachate are summarized in Tab. I and Tab. II. Investigated landfill leachates showed similar characteristics to the leachates sampled in other MSW landfills (Kulikowska and Klimiuk 2008; Guo et al., 2010; Kalčíková et al., 2014). The pH of leachate was 8.03 and demonstrated that the leachate was alkaline and that the landfill is already in methanogenic phase of life cycle. It can be concluded that most of the chemical substance in the leachate is basic.
## I: Trace elements concentrations in leachate

<table>
<thead>
<tr>
<th>Month</th>
<th>Trace element</th>
<th>Cd</th>
<th>Pb</th>
<th>As</th>
<th>Cr</th>
<th>Ni</th>
<th>Zn</th>
<th>Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
</tr>
<tr>
<td>February</td>
<td>Concentration</td>
<td>0.179</td>
<td>11.32</td>
<td>12.54</td>
<td>74.33</td>
<td>34.84</td>
<td>0.0652</td>
<td>0.00306</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>33.5</td>
<td>0.6</td>
<td>0.7</td>
<td>1.3</td>
<td>2.8</td>
<td>4.1</td>
<td>0.164</td>
</tr>
<tr>
<td>March</td>
<td>Concentration</td>
<td>0.373</td>
<td>3.299</td>
<td>11.55</td>
<td>59.3</td>
<td>70.29</td>
<td>0.0251</td>
<td>0.00045</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>24.7</td>
<td>6.448</td>
<td>17.56</td>
<td>442.68</td>
<td>135</td>
<td>0.0787</td>
<td>0.0023</td>
</tr>
<tr>
<td>April</td>
<td>Concentration</td>
<td>0.237</td>
<td>24.5</td>
<td>1.1</td>
<td>27.8</td>
<td>13.9</td>
<td>8.3</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>26.1</td>
<td>6.3</td>
<td>14.2</td>
<td>30.7</td>
<td>11.6</td>
<td>1.3</td>
<td>0.048</td>
</tr>
<tr>
<td>May</td>
<td>Concentration</td>
<td>0.518</td>
<td>15.262</td>
<td>4.5</td>
<td>108.19</td>
<td>155</td>
<td>0.4723</td>
<td>0.00393</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>33.1</td>
<td>5.4</td>
<td>28.2</td>
<td>20.6</td>
<td>5.7</td>
<td>0.7</td>
<td>0.005</td>
</tr>
<tr>
<td>June</td>
<td>Concentration</td>
<td>&lt;LOD</td>
<td>5.282</td>
<td>35.91</td>
<td>325.72</td>
<td>139.22</td>
<td>52.6</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>14</td>
<td>5.6</td>
<td>0.9</td>
<td>0.2</td>
<td>1.2</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

*Standard deviation (SD)
**Limit of detections (LOD)

## II: Main chemical properties of the leachate

<table>
<thead>
<tr>
<th>Parameters</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>2.38</td>
<td>0.99</td>
<td>1.69</td>
<td>0.13</td>
<td>2.92</td>
</tr>
<tr>
<td>pH</td>
<td>7.35</td>
<td>7.6</td>
<td>7.92</td>
<td>8.7</td>
<td>8.61</td>
</tr>
<tr>
<td>EC (µS/cm)</td>
<td>2.65</td>
<td>6.12</td>
<td>12.79</td>
<td>10.87</td>
<td>11.69</td>
</tr>
</tbody>
</table>

*Chemical oxygen demand (COD)
**Electrical conductivity (EC)

## III: Trace elements concentrations in rainwater

<table>
<thead>
<tr>
<th>Rainwater</th>
<th>Trace element</th>
<th>Cd</th>
<th>Pb</th>
<th>As</th>
<th>Cr</th>
<th>Ni</th>
<th>Zn</th>
<th>Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
<td>µg/L</td>
</tr>
<tr>
<td>February</td>
<td>Concentration</td>
<td>&lt;LOD</td>
<td>6.57</td>
<td>&lt;LOD</td>
<td>8.48</td>
<td>2.18</td>
<td>0.033</td>
<td>0.00056</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>0.7</td>
<td>5.9</td>
<td>6.1</td>
<td>7</td>
<td>0.018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>Concentration</td>
<td>&lt;LOD</td>
<td>1.766</td>
<td>&lt;LOD</td>
<td>5.45</td>
<td>9.88</td>
<td>0.011</td>
<td>0.00057</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>27.9</td>
<td>3.9</td>
<td>6.1</td>
<td>7</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>Concentration</td>
<td>&lt;LOD</td>
<td>2.591</td>
<td>&lt;LOD</td>
<td>1.16</td>
<td>&lt;LOD</td>
<td>2.7</td>
<td>0.0165</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>18.7</td>
<td>1.3</td>
<td>31.1</td>
<td>4</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>Concentration</td>
<td>&lt;LOD</td>
<td>2.091</td>
<td>0.74</td>
<td>1.06</td>
<td>5.73</td>
<td>0.0091</td>
<td>0.00203</td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>0.8</td>
<td>21.4</td>
<td>22.9</td>
<td>25.8</td>
<td>5.9</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>Concentration</td>
<td>&lt;LOD</td>
<td>1.18</td>
<td>9.75</td>
<td>4.37</td>
<td>10.7</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD %</td>
<td>4.8</td>
<td>4.8</td>
<td>8.3</td>
<td>3.9</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Standard deviation (SD)
**Limit of detection (LOD)

## IV: Main chemical properties of the landfill rainwater

<table>
<thead>
<tr>
<th>Parameters</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>10.16</td>
<td>9.37</td>
<td>10.02</td>
<td>8.56</td>
<td>9.18</td>
</tr>
<tr>
<td>pH</td>
<td>8.65</td>
<td>7.71</td>
<td>7.99</td>
<td>7.9</td>
<td>7.9</td>
</tr>
<tr>
<td>EC (µS/cm)</td>
<td>1281</td>
<td>1244</td>
<td>1217</td>
<td>1181</td>
<td>1209</td>
</tr>
</tbody>
</table>

*Chemical oxygen demand (COD)
**Electrical conductivity (EC)
in nature. The pH of Zdounky-Kuchyňky leachate was in agreement with other sanitary landfills for example in with Jeram’s landfill Malaysia; Ampar Tenang, Malaysia; Rio de Janeiro, Brazil and Casone, Italy in which the pH fell within the range of 7.36-8.80 (Isidori et al., 2003; Silva et al., 2004; Alkassasbeh et al., 2009; Budi et al., 2016).

Relatively low trace elements concentrations are suggesting that Zdounky-Kuchyňky leachate does not represent a significant trace elements hazard. These low values of trace elements in leachate were in agreement with sanitary landfills in Sweden and Brazil (Silva et al., 2004; Öman and Junestedt 2008).

The concentration of Hg and Pb over a given period of leachate samples was stable, with an increase in concentrations of trace elements As, Cr, Ni, Zn and Hg. The highest concentrations were recorded for trace elements: Cr, Ni and Zn. The lowest concentrations were recorded for Cd, Pb and As.

It can bee concluded that with the passage of time and with seasonal changes values of various parameters (trace elements) in leachate increased, the main reason is that the solid waste material degraded with time and the waste constituents percolated down along with rainwater. Moreover, the age and seasonal changes (like precipitation) has an important effect on leachate composition. However, it was observed that trace elements concentration in rainwater in time decreased. Chemical characteristics of Zdounky-Kuchyňky rainwater are summarized in Tab. III and Tab. IV.

The concentration of Cd, Pb, As, Cr, Ni, and Hg over a given period for rainwater samples was constant, with a significant decrease in the concentration of Zn. However, the concentration of Zn was the highest.

**Plant growth inhibition**

The germination of crop plants was tested using the hydroponics medium supplemented with leachate and rainwater 25%, 50%, 75%, 90% and 100%. The number of germinated seeds was compared with the control. Results are expressed as
mean ± standard deviation (SD). The average rainfall for the given period was 89.72 mm (February–June).

The image of the growth inhibitions of Sinapis alba L. leachate samples for months February, March, April, May, June (concentration 25%, 50%, 75%, 90% and 100%) are shown on Fig. 3. Leachate samples for those months were toxic. The growth inhibition values for sample February ranged from -24.49% to 57.32%, which is the lowest growth inhibition of all tested samples. The results reveal that the growth inhibition for sample March, April, May, June (concentration 25%, 50%, 75%, 90% and 100%) were toxic likewise (average value 89.72%). With increasing leachate concentrations, the examined samples showed higher values of growth inhibition. These results provide reference data for risk assessment and the management of leachate.

Leachate may contain a wide range of inorganic, natural and xenobiotic compounds, the mixture of which can affects the plant growth (Zhang et al., 2013). It was found that leachate at higher levels (concentrations) can severely inhibit plant growth, whereas leachate at lower levels (concentration 25%) can stimulate growth. It is reported that leachate at high levels could lead to a yield reduction and poor survival rate (Menser, 1981; Menser et al., 1983); however, the leachate at low levels (concentrations) enhanced the growth, survival and stomatal conductance of plants (Liang et al., 1999; Sang and Li 2004; Sang et al., 2006; Li et al., 2008; Zhang et al., 2013).

The image of the growth inhibitions of Sinapis alba L. rainwater samples for months February, March, April, May, June (concentration 25%, 50%, 75%, 90% and 100%) are show on Fig. 4. The results show that the growth inhibition (%) for rainwater samples–February, April, May, June (concentration 25%, 50%, 75%, 90% and 100%) compared to leachate were not toxic. The growth inhibition values for sample March ranged from 16.87% to 43.15%, which is the highest growth inhibition of all tested samples. The growth inhibition values for sample February ranged from -14.65% to -45.2%, which is the lowest growth inhibition of all tested samples.

It is worth to mention that previous studies have confirmed that bioassays eliminate the limitations of classical chemical analyses (Ghosh et al., 2017) and that higher plants might be helpful for screening and monitoring of environmental contaminants.

Experimental studies on the phytotoxicity of leachate have reported both positive and detrimental effects on plants (Zhang et al., 2013). The toxicity of leachate was investigated by a numerical study. Bortolotto et al. (2009) evaluated Southern Brazil landfill leachate toxicity using A. repa as an indicator species. In this study the untreated leachate resulted in a significant inhibition of root growth, whereas the treated leachate did not show a significant toxicity. Authors concluded that the leachate treatment caused the reduction in toxicity observed in Artemia sp. toxicity assays (Bortolotto et al., 2009).

Results of the present toxicological assessment of leachates showed that their quality are inconsequential during the study period (February–June 2017). However, interestingly, this is contrary to a study conducted by Sang and Li (2004). They reported that leachate toxicity varies seasonally while working with Vicia faba as a model test organism. In this study authors observed severe genetic damages in V. faba in case of leachate depending on the season (cold and dry season compared to the the hot and rainy season) owing to seasonal changes in the concentrations of contaminants in the leachates (Sang and Li 2004).

CONCLUSION

The current study contributes to our knowledge about chemical parameters, toxicity and/or pollution of leachate during various seasons of the year to achieve an appropriate assessment of its environmental impact. It can be concluded that with the passage of time values of trace elements in landfill leachate increased. However, trace elements concentration in rainwater in time decreased. Furthermore, results of the present toxicological assessment of leachate showed no significant changes in leachate toxicity during the study period (February–June 2017). The second major finding was that leachate at higher levels (concentrations) can heavily inhibit plant growth, whereas leachate at lower levels (concentrations) can stimulate growth. Based on the results it is recommended that further research be undertaken in the evaluation in leachate toxicity.

Acknowledgments

The research was financially supported by the IGA FA MENDELU No. TP 5/2017.

REFERENCES


Contact information
Magdalena Daria Váverková: magda.vaverkova@uake.cz
Jan Zloch: xzloch@mendelu.cz
Dana Adamcová: dana.adamicova@mendelu.cz
Maja Radziemska: maja.radziemska@sggw.pl
Tomáš Vyhnanek: tomas.vyhnanek@mendelu.cz
Václav Trojan: vaclav.trojan@mendelu.cz
Biljana Đorđević: biljana.dordevic@mendelu.cz
Martin Brtnický: martin.brtnicky@mendelu.cz