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Assessment of Heavy Metals in Landfill Leachate: A Case Study of Thohoyandou Landfill, Limpopo Province, South Africa

Joshua N. Edokpayi, Olatunde S. Durowoju and John O. Odiyo

Additional information is available at the end of the chapter

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Abstract

Landfilling of solid wastes has gained increasing acceptance due to the ease of disposal. However, such activity has consequences if the landfill site is not designed according to specification or does not have a leachate liner and collection system. Leachate possesses potential risk to surface and groundwater aquifer within the area surrounding the landfill site. The aim of this chapter is to assess the physicochemical parameters and heavy metal levels in leachate generated from a periurban landfill site situated in Thohoyandou, Limpopo Province, South Africa. Physicochemical parameters were measured onsite using standard methods, while heavy metals were analyzed with flame atomic absorption spectrometer (FAAS) after nitric acid digestion. pH, conductivity and turbidity values ranged from 6.97 to 7.68, 426 to 2288 $\mu\text{S}/\text{cm}$ and 12.78 to 295.5 NTU, respectively. Most levels of the determined heavy metals exceeded the effluent discharge guideline limit of South African Department of Water Affairs. This could potentially spike their levels in surface and groundwater. Adequate measures should be put in place to manage the leachate generated from landfill sites.

Keywords: groundwater, heavy metals, landfill, leachate, potential risk, surface water

1. Introduction

1.1. General background

Solid waste management is of global concern in both developing and developed countries. Despite much awareness aimed at reducing the waste generated due to anthropogenic activities,

there has been an increase in solid waste generation throughout the world [1–3]. This could partly be due to increase in population, industrialization and urbanization. Different efforts geared toward effective management of solid waste due to the perceived adverse health and environmental impacts have been reported [4–6].

Landfilling remains one of the most commonly used methods for solid waste management in most parts of the world. Its efficiency and safety coupled with cost make it the preferred method [7–9]. Several advances in landfill technology have been reported to enhance its suitability for solid waste management. Leachate is often generated from landfill processes due to the increasing presence of soil moisture and other favorable environmental factors [1, 5].

In most developing countries, the facility for leachate collection and treatment is often not part of the design of landfill sites. One of the adverse effects caused by solid waste disposal onto landfills is the contamination of surface and groundwater by leachate. The extent of such contamination depends on the quality of leachate generated from the landfill [4, 7]. The composition of a landfill waste varies from place to place and depends on a number of factors. Some of them include the location of the site, the socioeconomic status of the people the landfill is serving, the technology used in the landfill and the age of the waste generated including prevailing environmental factors such as weather conditions of the landfill site, all of which influences the composition of leachate [1, 4, 7].

Blight and Fourie [10] reported the variation of the solid waste component disposed in landfill sites (**Table 1**). This ranges from simple organic and inorganic materials to complex ones.

Traditionally, in most developing countries, the segregation of hazardous waste from non-hazardous waste before disposal into a landfill site is uncommon. Edokpayi et al. [11] reported the disposal of several household hazardous waste into sanitary landfill sites. When both kinds of wastes are thus disposed of, the leachate quality will be poorer than if the hazardous waste was pretreated before landfilling or treated using other available methods.

| Components | % Composition by undried mass | | | | | | | |
|-----------------------------------|-------------------------------|----|-----------|--------------|----------|------|-------|-----------|
| | USA | UK | Cape Town | Johannesburg | Gaborone | Lima | Delhi | Abu Dhabi |
| Ash, soil, building rubble, other | 8–14 | 18 | 39* | 1** | 3 | 16 | 41 | 16 |
| Paper and cardboard | 34–44 | 29 | 19 | 23 | 12 | 14 | 9 | 6 |
| Plastic | 8–10 | 7 | 7* | 13 | 5 | 7 | 1+ | 12 |
| Metals | 11–13 | 8 | 2+ | 10 | 6 | 4 | 1+ | 8 |
| Glass | 4–9 | 10 | 1+ | 8 | 6 | 3 | 1+ | 9 |
| Organic, putrescible | 12–22 | 25 | 32 | 45 | 68 | 56 | 47 | 49 |

*Building rubble landfilled, in which sand cover is included.

**Building rubble not landfilled, in which cover soil is not included.

+Scavenged before landfilling.

Table 1. Percentage of solid waste composition from different parts of the world [10].

1.2. Principles of leachate formation

Leachate is formed due to the interaction between the waste in the landfill and water from soil moisture, precipitation, snow and other liquid waste disposed of in the landfill site. Leachate can also be formed as a result of chemical and biochemical processes within the landfill. There is nonuniform and intermittent percolation of moisture through the solid waste in a landfill as a result of leachate generation [5, 12, 13]. This consequently leads to the removal of soluble fractions from the waste into the leachate. A wide variety of contaminants such as heavy metals, some other persistent organic pollutants like flame retardants, polycyclic aromatic hydrocarbons (PAHs), phenols, polychlorinated biphenyls (PCBs), chlorinated alkyl phosphate, polyfluoroalkyl and other fluorinated chemicals, pharmaceuticals and personal care products, polybrominated diphenyl ethers (PBDEs), polychlorinated dibenzofurans (PCDFs), polychlorinated dibenzodioxins (PCDDs) and polychlorinated diphenyl ethers (PCDEs) are also collected into the leachate as it drains through the pile of waste in the landfill [14–20]. This makes leachate a wastewater of high strength because of the high levels of various classes of contaminants it contains.

Leachate control should, therefore, be included in the design of solid waste management systems. The volume and flow rate of the leachates are dependent upon the percolation of water through the waste layers [5]. The transfer of contaminants into the leachate and biodegradation processes are affected by the flow patterns and velocity of the leachate. The general pattern of the generation of leachate in landfills was reported by Farquhar [21] as presented in **Figure 1**.

Percolation from the unsaturated zone into the saturated zone is thus possible, and this gives a pathway for groundwater contamination. Surface runoff through the landfill also provides a possible route to surface water contamination majorly during precipitation events. The generation of leachate from landfills if not properly managed can lead to several adverse environmental and health impacts.

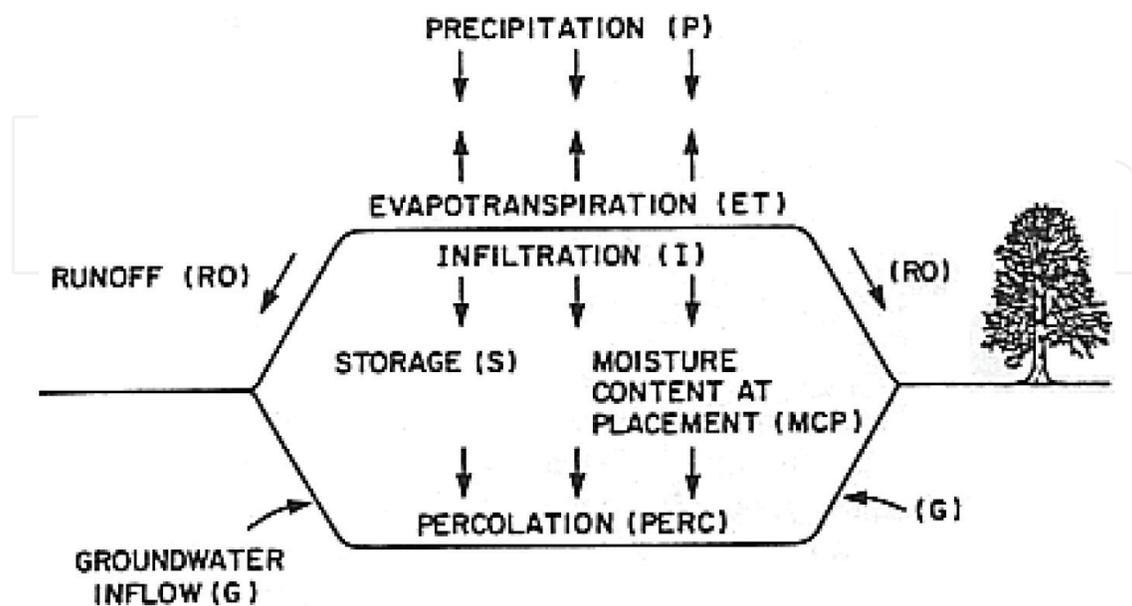


Figure 1. Generalized pattern of leachate generation [21].

1.3. Management and treatment of leachates

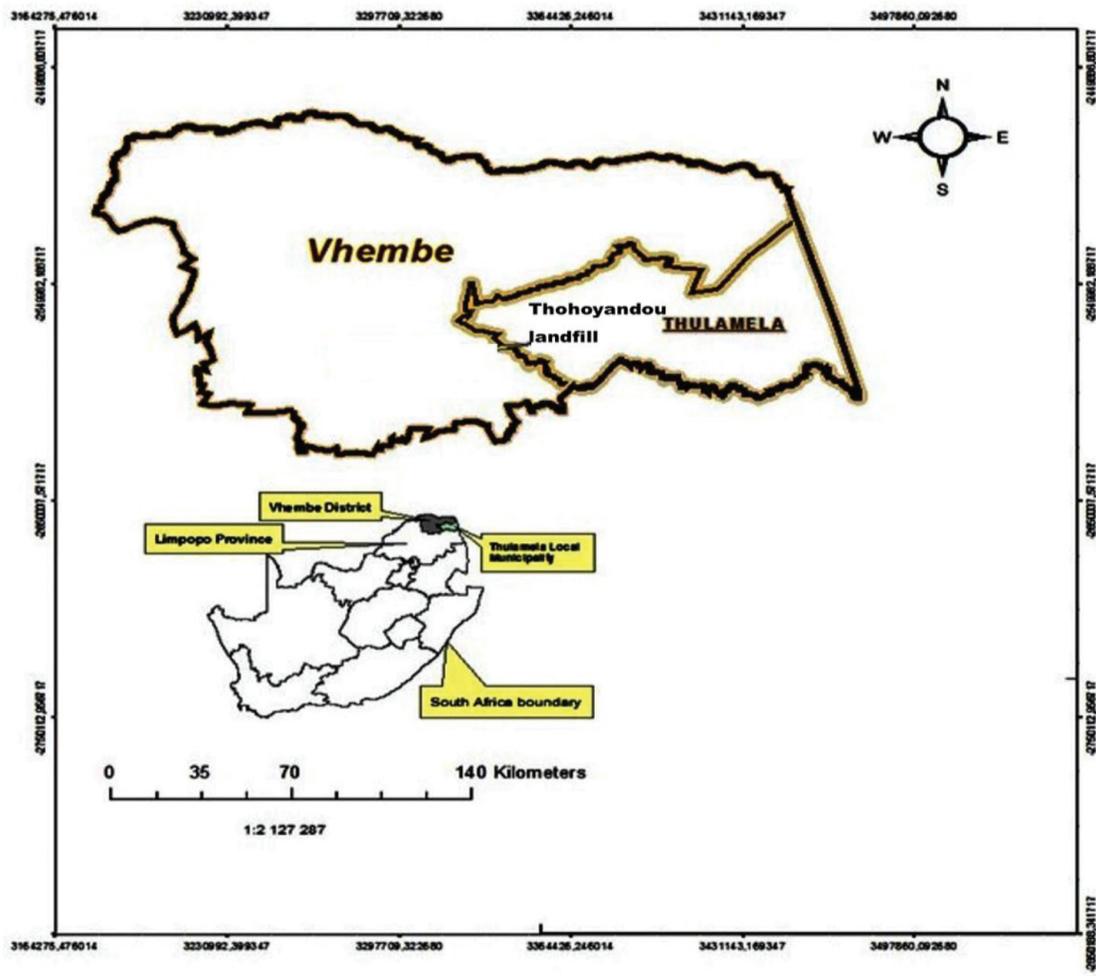
Leachate management is possible if the design of the landfill permits adequate lining, collection and storage systems. Landfill liners should be a part of the initial design of the landfill site. These liners are crucial as they act as a barrier preventing the leachate generated from the landfill to drain into the environment or groundwater aquifer [13, 22]. Various materials used as leachate liners include natural clays, geomembranes (constructed from various plastic materials such as polyvinyl chloride (PVC) and high-density polyethene (HDPE)), geotextiles, geonet and geosynthetic clay liners [13, 22–25]. The lining system can be made from a single material such as clay or a combination of clay and other materials. Basically, there are three types of lining systems which are single, composite or double lining systems. Various factors should be considered when selecting a lining system for a landfill as some lining materials can be easily degraded by chemicals in the leachate.

In developing countries, the lining of landfills and systems for collection and treatment of leachate are often found in some major cities, while some facilities in other cities, periurban or rural areas do not have a provision for leachate management. Collection of leachate in landfills is important to prevent it from accumulating up to the quantity that it can spill over, causing pollution in waterways and water courses [5, 12]. Poverty, lack of required expertise, corruption and misappropriation of funds could be some of the reasons that have limited adequate leachate management in the developing world.

Different methods have been reported for the management of leachate in the different parts of the world. The simpler method is to incorporate the leachate as an influent in a wastewater treatment facility [26]. This method is cheap since there will be no need for the construction of a new facility for the treatment. Conveyance pipe from the landfill to the wastewater treatment plant is sufficient, provided that the distance between both facilities is in close proximity. Depending on the leachate quality, pretreatment may be required before combining it with the influent of the municipal wastewater treatment works. However, in some cases, when a large quantity of leachate is generated on a daily basis, or the distance between both facilities is far apart, then onsite treatment of leachate will be the preferred option or the reticulation of the leachate back into the landfill. Several physical (evaporation, floatation, air stripping, filtration and membrane processes), chemical (coagulation and precipitation, adsorption, ion exchange, chemical oxidation) and biological methods (the use of ponds in various aerobic and anaerobic modes) have been reported for leachate treatment [26–30]. Cost, expertise, the age of the landfill, estimated volume of leachate generated, climatic condition and efficiency of the method often determine the treatment method of choice. Treatment of leachate using biological methods is more common in South Africa [26].

1.4. Study area

The landfill site with geographical coordinates $23^{\circ}0'12.3''$ S and $30^{\circ}28'0.16''$ E is located in Thulamela Municipality of Limpopo Province, South Africa (**Figure 2a**).



b

Figure 2. (a) Map of the study area. (b) Some pictures from Thohoyandou landfill site.

The site is located 180 km from the provincial city of Polokwane. In 2014, the facility received 210,000 tons of waste. Thohoyandou is a semiarid region with variations in temperature between 12 and 22°C in the dry season (winter) and between 20 and 40°C in the wet season (summer) [31]. Precipitation also varies between 340 and 2000 mm with an average rainfall of 800 mm. The region is classified as a humid subtropical dry forest biozone [32]. The landfill site is very close to the municipal wastewater treatment plant. Common surface water sources in the region include the Dzindi, Luvuvhu and Mvudi Rivers. Thohoyandou landfill currently receives all kinds of sanitary wastes from the periurban center, which is Thohoyandou and other villages in the suburb. At the time of this study, there was no leachate collection and treatment system on the site. Residential areas are located around the landfill. Some other major land use around the landfill includes subsistence agriculture, schools and wastewater treatment plant. Some pictures taken from the landfill are presented in **Figure 2b**.

2. Materials and methods

2.1. Sampling

Six leachate samples were collected during the wet season of 2014 from various places within the premises of the landfill site. The samples were collected in a precleaned 1-L polyethylene sample container. The containers were washed with liquid detergent and soaked with 1% nitric acid. Subsequently, the sample containers were rinsed with deionized water. Physicochemical parameters such as pH, conductivity and turbidity were measured in situ, while samples for the determination of heavy metals were preserved using concentrated nitric acid. The samples were transported on ice to Hydrology and Water Resources Department of the University of Venda. Four major metals (Calcium (Ca), Potassium (K), Magnesium (Mg) and Sodium (Na)) and 10 heavy metals (Aluminum (Al), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni) and Zinc (Zn)) were selected and analyzed due to their availability in landfill leachate. The samples were preserved at -4°C until further analysis.

2.2. Instrumentation

pH and conductivity multimeter supplied by Fischer Thermoscientific was used for field measurements of pH and conductivity, respectively, while a turbidimeter supplied by HANA was employed to determine the turbidity of the samples. The measuring devices were calibrated following the protocol approved by the manufacturer. Flame atomic absorption spectrometer (FAAS) supplied by Perkin Elmer was used for the analysis of major and heavy metal content in the leachate samples. Calibration standards were prepared from AAS grade reagent for all the metals of interest.

3. Results and discussion

The pHs of the leachate from all sites of sampling (**Table 2**) were found within the acceptable range of wastewater discharge onto the water resource by the South African Department of Water Affairs [33]. An average leachate pH of 7.39 was determined in this study which is suitable for methanogenic bacteria [34]. Various average pH values below and above this value have been reported for leachate in different parts of the developing world (**Table 3**). pH usually affects the speciation of metals in solutions with most metals easily speciated to their toxic forms in acidic pH below the value of 4, while some precipitate out of the solution at alkaline pH values.

| Samples | pH | Conductivity (µS/m) | Turbidity (NTU) |
|---------|------|---------------------|-----------------|
| L1 | 7.60 | 486 | 22.56 |
| L2 | 7.47 | 485 | 28.83 |
| L3 | 7.68 | 2288 | 295.5 |
| L4 | 7.42 | 604 | 25.43 |
| L5 | 7.20 | 721 | 33.15 |
| L6 | 6.97 | 426 | 12.78 |

Table 2. Physicochemical parameters of leachate samples.

| Parameters | Thohoyandou landfill (South Africa) | Alexandria landfill (Egypt) [34] | Semur landfill (Indian) [35] | El-Jadida landfill (Morocco) [36] |
|----------------------|-------------------------------------|----------------------------------|------------------------------|-----------------------------------|
| pH | 7.39 | 8.9 | 6.9 | 8.8 |
| Conductivity (µS/cm) | 835 | 30,725 | NR | 26,000 |
| Turbidity (NTU) | 69.71 | NR | NR | NR |
| Na (mg/L) | 33.88 | 364 | 462 | NR |
| K(mg/L) | 22.94 | 5400 | 1241 | NR |
| Ca (mg/L) | 46.27 | 8.4 | NR | 190 |
| Mg (mg/L) | 16.58 | 302.5 | NR | 235 |

NR indicates values that were not reported.

Table 3. Comparison of the average physicochemical leachate characteristics in some developing countries.

Generally, the presence of inorganic charged particles such as carbonates, chlorides, sulfates and bicarbonate ions in water is often estimated in terms of the conductivity of the water. Conductivity oftentimes is also used as a surrogate for total dissolved solids [37]. **Table 2** shows the levels of conductivity determined from all the sampling sites. This level complied

with the DWA wastewater discharge limit [33] and was much lower than the levels reported in Alexandria landfill leachate in Egypt (**Table 3**), Columbia (22,000 $\mu\text{S}/\text{cm}$) and Morocco (26,000 $\mu\text{S}/\text{cm}$) [34, 36, 38]. However, Rahim et al. [39] reported a lower conductivity level of 31.68 $\mu\text{S}/\text{cm}$ for landfill leachate in Malaysia.

The turbidity of the leachate samples obtained was very high. Liquids with high turbidity often indicate the likelihood of silt, clay, fine organic matter and microscopic organisms that are suspended in the water. Site three recorded a very high turbidity level, much higher than the levels from other sites in the landfill.

Figure 3 shows the levels of major metals (Na, K, Mg and Ca) in the leachate of Thohoyandou landfill. The levels found are not higher than what can be disposed of into water bodies. The only concern is the continuous migration of salt-rich leachate into surface and groundwater sources which could increase their levels in the river and groundwater aquifers. Various sequences of major metals' occurrence in leachate varied greatly from one location to the other. The sequence for major metals determined in this study follows the trend: $\text{Ca} > \text{Na} > \text{K} > \text{Mg}$ (**Table 3**), while at Alexandria landfill in Egypt, the sequence is $\text{K} > \text{Na} > \text{Mg} > \text{Ca}$ [34]. Level of Mg is higher than Ca in the leachate of all the landfills reported except Thohoyandou landfill. Although rock type in groundwater aquifers contributes significantly to its salinity level, continuous percolation of metal-rich leachate may also contribute to increased groundwater salinity.

The levels of heavy metals determined in this study are presented in **Figures 4** and **5**. Variable levels of heavy metals were determined in the landfill site. On average, Fe, Mn and Al are present in higher concentrations than the other metals. A possible reason for the high level of these metals could be due to their relative abundance on Earth. Previous studies have shown that Fe and Al are present in higher concentrations in river water, soils and sediments around Thohoyandou when compared to other metals [32, 37, 40]. The relatively low levels of the

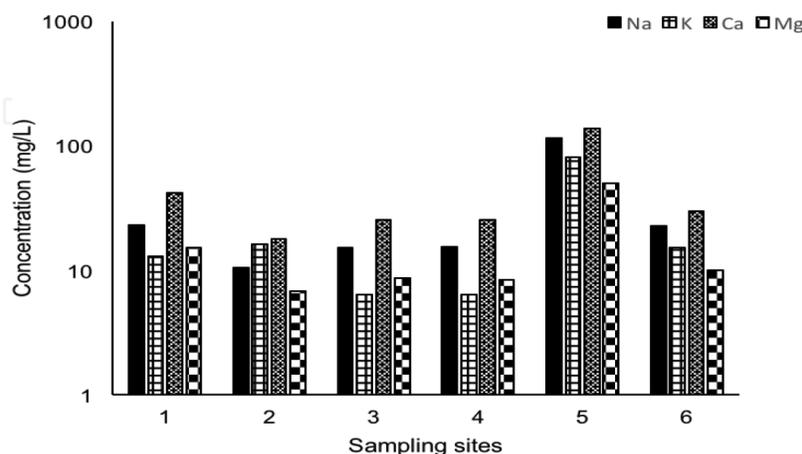


Figure 3. Concentrations of major metals in leachate samples.

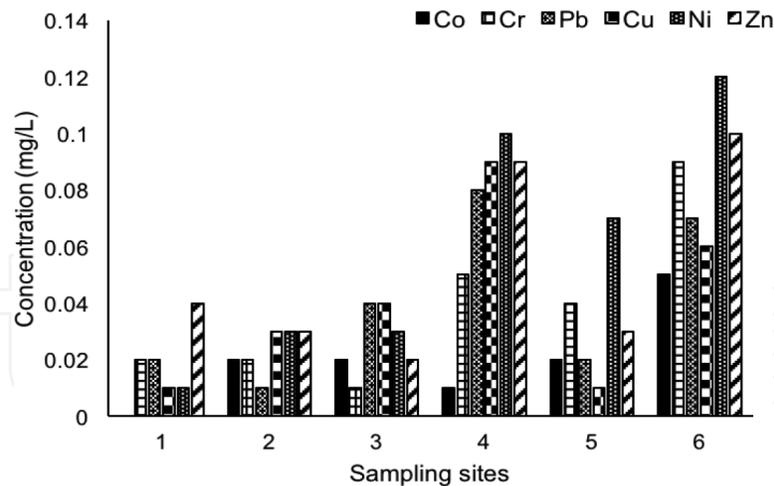


Figure 4. Levels of Co, Cr, Pb, Cu, Ni and Zn in different sampling sites of Thohoyandou landfill.

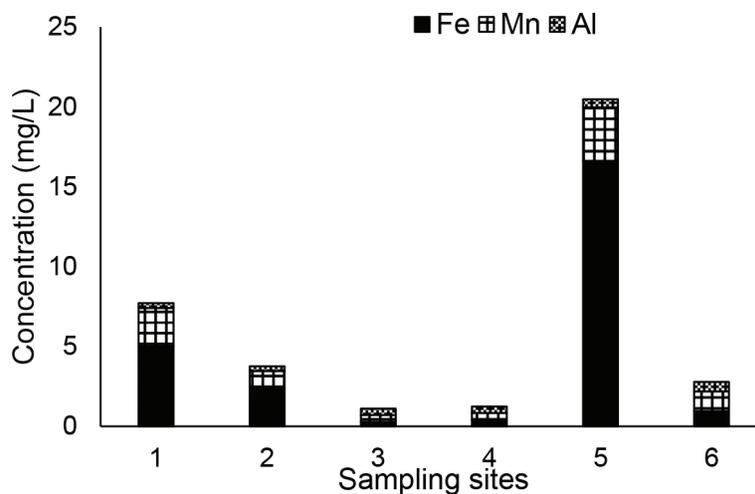


Figure 5. Levels of Fe, Mn and Al in different sampling sites of Thohoyandou landfill.

more hazardous heavy metals could suggest that the waste generated from this region is not largely from a highly industrialized area. It is, however, noteworthy to mention that most of the heavy metals were present in concentrations higher than the normal wastewater discharge guideline values except for Zn and Cr. Ni, Al and Co does not have guideline values for their discharge. **Table 4** shows the comparison of average heavy metal concentration in leachate from landfills in some developing countries. Fe recorded the highest level from all the countries except in Jebel Chakir, Landfill of Tunisia, where Fe was not part of the metals determined [34, 36, 37, 41, 42]. Mn and Zn were also part of the metals that generally existed in high concentration.

| Heavy metals (mg/L) | Thohoyandou landfill (South Africa) | Alexandria landfill (Egypt) [34] | Semur landfill (Indian) [35] | El-Jadida landfill (Morocco) [36] | Alger landfill (Algeria) [41] | Jebel Chakir landfill (Tunisia) [42] | DWA wastewater discharge limit [33] |
|---------------------|-------------------------------------|----------------------------------|------------------------------|-----------------------------------|-------------------------------|--------------------------------------|-------------------------------------|
| Al | 0.42 | NR | NR | NR | NR | NR | NR |
| Cd | 0.02 | 0.10 | 0.02 | 0.03 | NR | 0.04 | 0.005 |
| Cr | 0.02 | 0.06 | 0.28 | 0.16 | 0.50 | 1.17 | 0.05 |
| Co | 0.02 | NR | NR | 0.21 | NR | NR | NR |
| Cu | 0.07 | 0.07 | 0.71 | 0.16 | 0.45 | 0.80 | 0.01 |
| Fe | 4.26 | 6.31 | 58.91 | 24 | 12.30 | NR | 0.3 |
| Pb | 0.03 | 0.02 | 1.20 | NR | NR | 0.35 | 0.01 |
| Mn | 1.50 | 0.84 | NR | 1.25 | 0.40 | 0.05 | 0.1 |
| Ni | 0.03 | 0.10 | 0.31 | 0.13 | 0.25 | 0.23 | NR |
| Zn | 0.08 | 0.75 | 1.29 | 0.75 | 0.70 | 0.75 | 0.1 |

NR indicates values that were not reported.

Table 4. Comparison of the average heavy metal characteristics in some developing countries.

4. Conclusion

This chapter has provided the much-needed baseline data of leachate for Thohoyandou landfill. The levels of Fe and Mn determined in the leachate of this study were very high as they exceeded the guideline value for wastewater discharge. Al concentration was also high. The most interesting result indicated that leachate from Thohoyandou landfill is of comparable quality to leachate from other developing countries.

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Author details

Joshua N. Edokpayi*, Olatunde S. Durowoju and John O. Odiyo

*Address all correspondence to: joshua.edokpayi@univen.ac.za

Department of Hydrology and Water Resources, University of Venda, South Africa

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