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Chapter 1

Characteristics of leachate from landfills and dumpsites in Asia, Africa and Latin America: a review update

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ABSTRACT

Using published data, this chapter updated a previous review to examine differences in pollutant levels in the leachate between landfills and dumpsites in Africa, Asia, and Latin America. A total of 3584 scientific articles published between 2018 and 2022 were initially identified in Scopus. After reviewing the abstracts, only 434 studies were selected, and the full text was examined. Finally, 38 studies were included in the review. However, some studies assessed more than one waste disposal site. Thus, 58 landfills and dumpsites were included. The most significant difference in the leachate between dumpsites and landfills generally occurred in climatic zone A. Indeed, significantly higher values in dumpsites were found for Cr, Ni, and Zn. Comparing the findings with the previous review confirms the differences in the levels of Cd and Pb between landfills and dumpsites. To mitigate these risks, it is vital for there to be investments in improving the waste management infrastructure and systems in Global South countries. In addition, there should be improved governance structures to enhance the enforcement of the existing policies.

Keywords: Leachate, dumpsites, landfills, climatic conditions.

1.1 INTRODUCTION

In recent decades, global solid waste generation rates have increased at a rapid pace (Chen *et al.*, 2020). Due largely to urbanization and rapidly increasing populations, global generation of waste is predicted to rise by 73% between 2020 and 2050 to approximately 3.88 billion tonnes (World Bank, 2022). However, landfilling and open dumping, along with uncontrolled burning of waste, still represent the world's most common solid waste management (SWM) practices (Gómez-Sanabria *et al.*, 2022; Kaza *et al.*, 2018). Indeed, in the Global South, approximately 90% of the waste is either disposed of in dumpsites or openly burnt (World Bank, 2022).

Dumpsites and poorly maintained landfills pose a high risk to human health and the environment (e.g., in terms of greenhouse gas (GHG) emissions, which can also impact on the health of individuals) (Gómez-Sanabria *et al.*, 2022; Pujara *et al.*, 2019; Vinti *et al.*, 2021). The risk posed by dumpsites is higher, as unlike landfills, these structures are not engineered, therefore, leading to higher pollutant flows (Vaccari *et al.*, 2019a).

Despite the existence of global frameworks (e.g., the Basel Convention) and national legislation, countries in the Global South, which are primarily located in equatorial and warmer climates are particularly at risk. For example, waste pickers living on dumpsites are at risk due to direct exposure from hazardous materials, which are often imported into Global South countries (Ferronato & Torretta, 2019).

Thus, understanding the risks posed by different waste disposal sites and the key factors influencing these risks (particularly leachate contaminant levels) is crucial to developing measures to mitigate them (Tesseme *et al.*, 2022). With this in mind, Vaccari *et al.* (2019a) conducted a review of the characterization of leachate from landfills and dumpsites in Asia, Africa, and Latin America. Using these findings as a basis, this study presents an updated analysis.

1.2 MATERIALS AND METHODS

The previous review (Vaccari *et al.*, 2019a) included studies published up to 2017. Thus, this review focused on work from 2018 to 2022. Only peer-reviewed articles were selected. Scopus was used as the search engine. The following search words were adopted: landfill leachate; dumpsite leachate; open dump leachate. As in Vaccari *et al.* (2019a), only the general distinction between landfills and dumpsites was considered, and only sites from Asia, Africa, and Latin America were selected. In particular, dumpsites were defined as open and not regulated areas in the ground with no environmental protection, used for the disposal of waste. Landfills were defined as waste disposal sites characterized by the registration of waste inflow, and typically using daily cover material, surface and groundwater monitoring, infrastructure, and a waterproof liner at the bottom. When it was not possible to establish the nature of the disposal site, the study was discarded. Furthermore, waste disposal sites that had already closed were not included. This approach was utilized because some authors have found a lower leachate contamination level in closed landfills (Wdowczyk & Szymańska-Pulikowska, 2021). Thus, including closed sites could have biased the results.

As in Vaccari *et al.* (2019a, 2019b), the following leachate parameters were selected: chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), NH_3-N, Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn. Thus, if the study did not include any of them, it was not included. For each parameter, the mean (μ), standard deviation (σ), median (M_e), and coefficient of variation (CV) were calculated to determine the spread of the factors and the impact of each at the site. As in Vaccari *et al.* (2019a), the significance level (α) was evaluated by using Welch's test. Thus, once t and ν were computed, they were used with the t-distribution to test the null hypothesis that the two population means were equal (p-value).

When more than one measure of a chemical parameter from the same disposal site was reported, the average value was considered. In any paper, when the value assigned to a parameter was given as 'less than…', this value was used.

The site's age was also indicated whenever possible, trying at least to distinguish between more, and less than 10 years old.

Furthermore, as temperature and precipitation can impact the leachate generation and characteristics (Ma *et al.*, 2022), the data were also categorized according to climatic conditions by using the Köppen–Geiger climate classification map. The updated open source version available online (Rubel *et al.*, 2017) was used. Thus, the following climatic zones were included in the classification: A (equatorial), B (arid), C (warm temperate), D (snow) and E (polar).

1.3 RESULTS AND DISCUSSION

1.3.1 Study selection

A total of 3584 studies published between 2018 and 2022 were initially identified in Scopus. After reviewing the abstracts, only 434 studies were selected because they concerned leachate from landfills or dumpsites in Asia, Africa and Latin America; thus, the full text of these studies was examined. Finally, 38 studies were included in this review. This number of sites was based on the fact that most studies did not have enough information, the nature of the site (i.e., dumpsite or landfill) was unclear, the data were inadequate for the purpose of this review, the same study was collected more than once by using different keywords, or the waste disposal site was closed. However, some studies assessed more than one waste disposal site. Thus, 58 landfills and dumpsites were included.

General information about landfills and dumpsites that were selected are available in Tables 1.1 and 1.2. In particular, the reference of each study, the country, the waste disposal site and its age are provided. If the age was not available, the cell was left empty.

1.3.2 Key types of sites and climatic zones

As shown in Figure 1.1, the majority of the sites (46 out of 58) were identified in the most populated continent, that is, Asia. All of the disposal sites identified in Latin America were landfills. However, in Africa, most (55%) came from dumpsites, and in Asia, the same number of dumpsites and landfills was identified.

Furthermore, as shown in Figure 1.2, considering the climatic zone, more than half of the sites (both landfills and dumpsites) were from zone A (equatorial). The remaining sites were from zone B (arid), and zone C (warm temperate).

Table 1.1 General information about the landfills analyzed.

Country	Site	Age of the Site (years)	Source
China	XinFeng landfill, Guangzhou	12	Deng *et al.* (2018)
Malaysia	Rimba Mas Sanitary landfill, Kaki Bukit	n.a.	Kow *et al.* (2022)
Thailand	• Tha Rae landfill, Sakon Nakorn • Sakon Nakhon landfill, Sakon Nakhon • Phang Khon landfill, Sakon Nakhon	n.a.	Ruengruehan *et al.* (2021)
Bangladesh	Matuail sanitary landfill, Dhaka	n.a.	Saeed *et al.* (2022)
China	Sanitary landfill in Xiamen city	≈12	Mao *et al.* (2022)
Pakistan	Lakhodair landfill site, Lahore	12	Ashraf *et al.* (2022)
Oman	• Multaqa landfill, Muscat • Barka landfill, Muscat	n.a.	Siddiqi *et al.* (2022)
Morocco	Sanitary landfill of Fez city	n.a.	El Mrabet *et al.* (2022)
China	Sanitary landfill site in Weifang	n.a.	Deng *et al.* (2021)
Vietnam	Nam Som landfill, Hanoi	>10	Hoai *et al.* (2021)
Malaysia	• Sungai Udang sanitary landfill, Melaka • Ladang Tanah Merah sanitary landfill, Negeri Sembilan	2 2	Hussein *et al.* (2021)
Brazil	Sanitary landfill of Sabará	n.a.	Reis *et al.* (2020)
Turkey	Sanitary landfill of Aksaray	n.a.	Tulun (2020)
India	Turmuri sanitary landfill, Belgaum	n.a.	Desai *et al.* (2020)
Malaysia	Pulau Burung sanitary landfill, Nibong Tebal	>10	Shadi *et al.* (2020)
Ghana	Tema landfill site, Tema	<10	Sackey *et al.* (2020)
China	Landfill in Qingdao	n.a.	Li *et al.* (2019)
Colombia	Landfill in Riohacha	<1	Galindo Montero *et al.* (2019)
China	Sanitary landfill in Wuhan	n.a.	Wang *et al.* (2019)
Colombia	Sanitary landfill in Tubarà city	n.a.	Rebolledo *et al.* (2019)
Malaysia	Jeram Sanitary Landfill, Kuala Lumpur	n.a.	Aziz *et al.* (2018)
Malaysia	Tanjung Langsat Landfill Site, Pasir Gudang	n.a.	Ismail *et al.* (2018)
Ghana	Otil landfill site, Kumasi	13	Boateng *et al.* (2018)
Malaysia	Jeram Sanitary Landfill, Kuala Lumpur	n.a.	Erabee *et al.* (2018)
Egypt	El-hammam sanitary landfill, Alexandria	n.a.	Al-Wasify *et al.* (2018)
India	Hyderabad landfil, Hyderabad	17	Somani *et al.* (2019)

Table 1.2 General information about the dumpsites analyzed.

Country	Site	Age of the Site (years)	Source
Ethiopia	• Arba Minch illegal dumpsite 1 • Arba Minch illegal dumpsite 2 • Arba Minch illegal dumpsite 3 • Arba Minch illegal dumpsite 4	n.a.	Tesseme *et al.* (2022)
India	• Okhla landfill, Delhi • Ghazipur landfill, Delhi • Gurgaon landfil, Gurgaon	24 34 <10	Somani *et al.* (2019)
Thailand	• Dong Mafai controlled dump • Nong Lat controlled dump • Sawang Daen Din controlled dump • Wanon Niwat controlled dump • Bong Tai open dump • Nong Luang open dump • Song Dao open dump • Ban Phon open dump • Kut Bak open dump	n.a.	Ruengruehan *et al.* (2021)
Sri Lanka	Waste dumping site A, Kesbewa	≈20	Koliyabandara *et al.* (2022)
India	Perungudi dumpsite (LS1), Chennai	20	Kuchelar *et al.* (2022)
India	Urali-Devachi landfill, Pune	n.a.	Ingle (2022)
Malaysia	Alor Pongsu landfill site, Perak	>10	Aziz *et al.* (2021)
Lebanon	Naameh municipal solid waste landfill, Naameh village	>10	Sawaya *et al.* (2021)
Iran	Saravan landfill, Rasht	>10	Farhangi *et al.* (2021)
Malaysia	• Ulu Maasop landfill, Senaling • Kampung Keru landfill, Tampin	>10 >10	Hussein *et al.* (2019)
Ethiopia	Landfill site in Mekelle	n.a.	Alemayehu *et al.* (2019)
India	Ramna MSW landfill, Varanasi city	<10	Mishra *et al.* (2019)
India	Dapha landfill, Kolkata	n.a.	De *et al.* (2019)
Sri Lanka	Dumping site in Karadiyana	n.a.	Nayanthika *et al.* (2018)

1.3.3 Leachate quality by site

High levels of Fe and Cr, as well as BOD_5 and COD were found in both the landfills (Figure 20.3), and the dumpsites (Figure 20.4). Relatively high concentrations of Ni and Zn were also found in the landfills. Aluminum (Al) was not included in Figures 1.3 and 1.4 because of the paucity of available data. In particular, studies about it were not found for dumpsites. In both figures, values are expressed in milligram/liter.

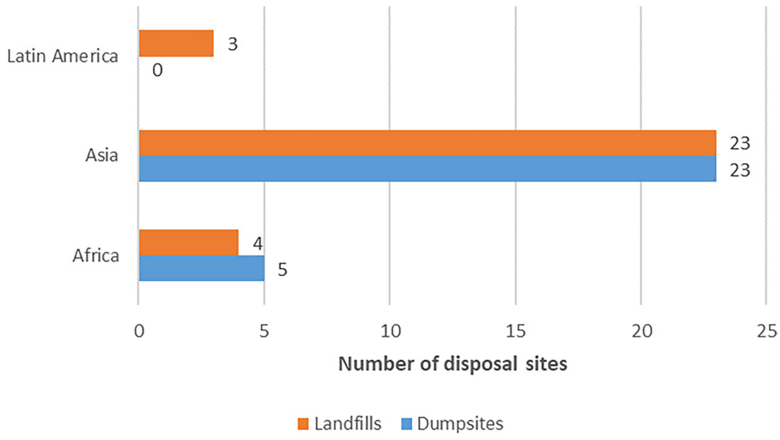

Figure 1.1 Number of waste disposal sites analyzed according to their typology and continent.

1.3.4 Leachate quality by region

Figure 1.5 illustrates that landfills in Africa had higher Fe concentrations, but lower COD levels compared to the other two regions.

Figure 1.6 shows that COD, BOD_5, NH_3-N, Fe, and Zn concentrations were higher in Asian dumpsites compared to African dumpsites. As in Figure 20.1, no studies about Latin America were found. Al does not appear in the figure for the same reasons discussed in Figure 1.3.

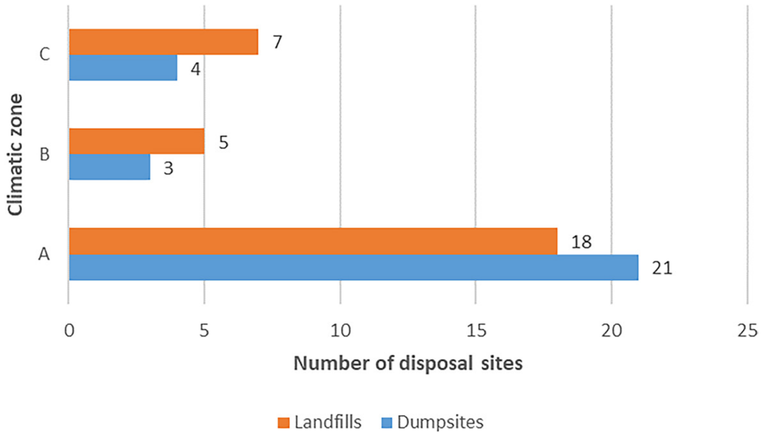

Figure 1.2 Number of waste disposal sites analyzed according to their typology and climatic zone.

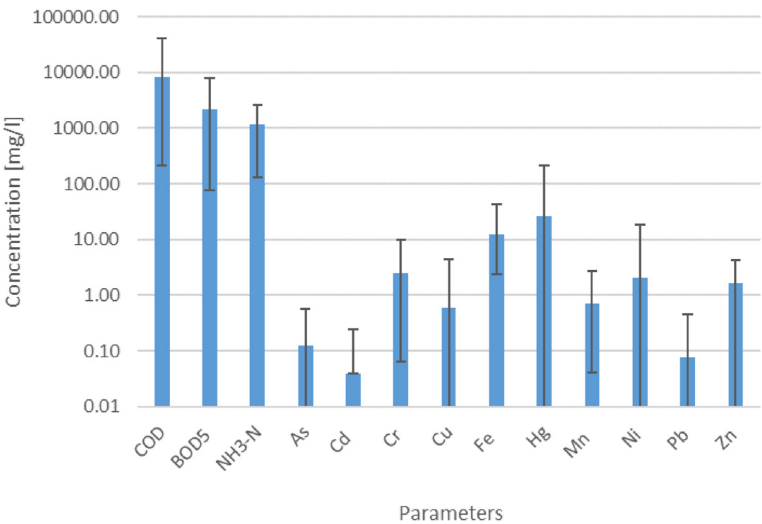

Figure 1.3 Biochemical parameters in all landfills.

1.3.5 Pollutant levels by site type

In the previous study (Vaccari *et al.*, 2019a), almost all pollutant levels were higher in dumpsites than landfills. In this study, the values were higher in dumpsites for some parameters (see Table 1.3). In particular, for COD, BOD_5, As, Cd, Fe, Mn, and Pb. However, there was a significant difference between landfills and dumpsites ($p < 0.05$) only for Cd and Pb.

In dumpsites, only the average concentrations of BOD_5 and COD were higher compared to the values obtained in the previous review. All of the other

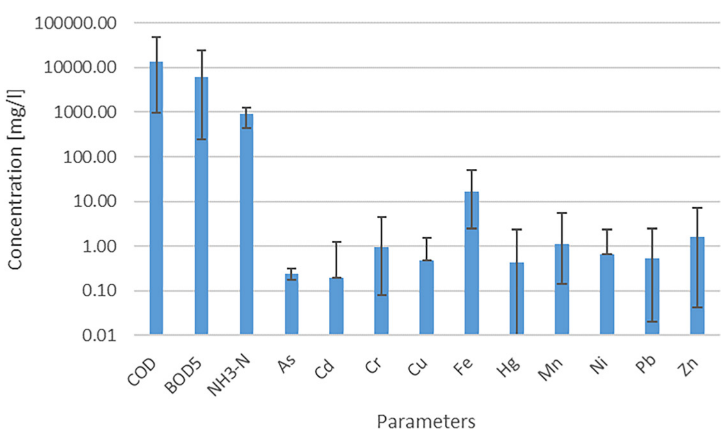

Figure 1.4 Biochemical parameters in all dumpsites.

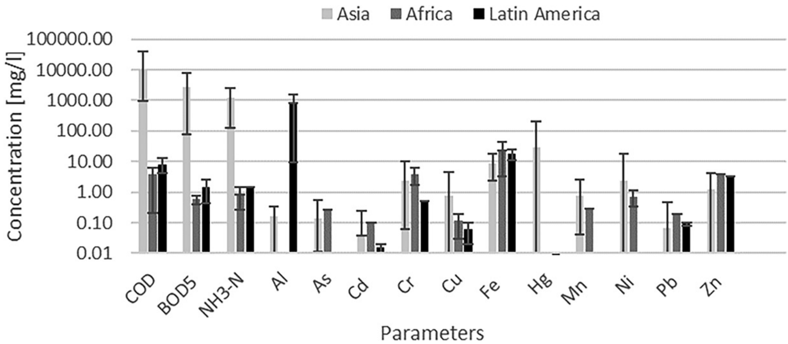

Figure 1.5 Biochemical parameters in landfills from Asia, Africa, and Latin America.

parameters investigated were higher in the study published in 2019. Focusing on landfills, most of the parameters (COD, As, Cd, Cr, Cu, Ni, Zn) were higher in this review than in the previous one. Further investigations would be necessary. Indeed, heavy metals and metalloids such as As, Cd, and Cr may pose significant risks for human health and the environment (Vaccari *et al.*, 2019b). However, the previous review (Vaccari *et al.*, 2019a) gathered more data, with studies covering about two decades (from 1998). In this review, the influence of hot spots, such as the study of Siddiqi *et al.* (2022), could have influenced the results.

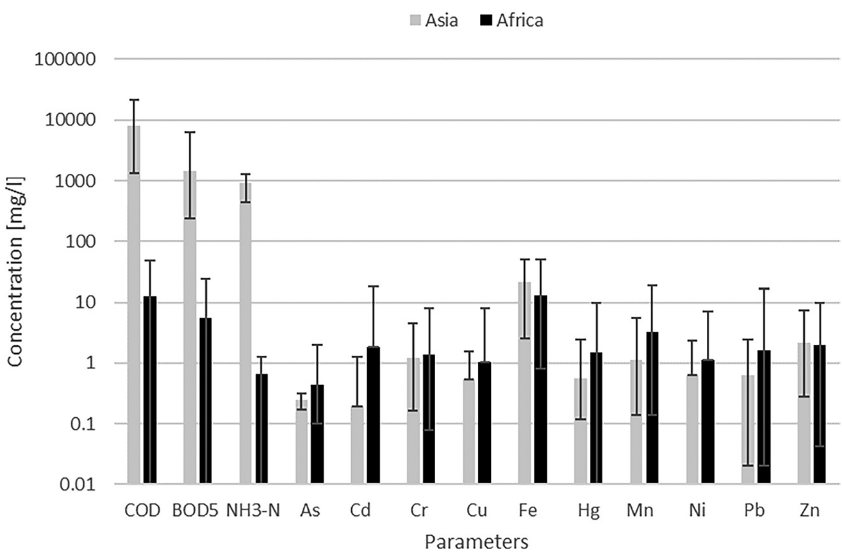

Figure 1.6 Biochemical parameters in dumpsites from Asia and Africa.

Table 1.3 Comparison of the biochemical parameters in the landfills and dumpsites (values are expressed in mg/l).

	Mean		Standard Deviation		Coefficient of Variation		Median	
	Landfills	Dumpsites	Landfills	Dumpsites	Landfills	Dumpsites	Landfills	Dumpsites
COD	8,416.01	13,813.57	9,161.58	13,493.01	1.09	0.98	5,198.00	10,700.00
BOD_5	2,202.07	6,057.57	2,651.93	7,969.41	1.20	1.32	1,177.00	1,335.00
NH_3-N	1,156.54	921.55	978.65	394.18	0.85	0.43	986.95	986.50
Al	0.71	–	0.76	–	1.06	–	0.48	–
As	12.10	0.24	11.38	0.10	0.94	0.41	9.43	0.24
Cd	0.04	0.19	0.07	0.30	1.81	1.54	0.01	0.11
Cr	0.60	0.96	1.20	1.28	1.99	1.34	0.10	0.37
Cu	0.08	0.48	0.12	0.48	1.54	1.01	0.02	0.33
Fe	401.27	17.00	795.83	15.93	1.98	0.94	5.04	11.08
Hg	2.05	0.43	5.35	0.65	2.61	1.50	0.36	0.20
Mn	2.42	1.12	3.56	1.26	1.47	1.13	0.51	0.52
Ni	1.63	0.65	1.80	0.69	1.11	1.05	0.50	0.55
Pb	0.13	0.54	0.19	0.62	1.48	1.15	0.06	0.29
Zn	26.40	1.60	74.59	1.99	2.83	1.24	0.01	0.75

Furthermore, both here and in the previous review, few studies investigated Al concentration in leachate from landfills and dumpsites.

Comparing the findings with the previous review (Vaccari *et al.*, 2019a) confirms the differences previously found in the levels of Cd and Pb between landfills and dumpsites. Evidently, Cd and Pb are heavy metals that seem to be often found in the leachate from dumpsites. The presence of these two heavy metals maybe as a result of the dumping of components of electrical and electronic goods and batteries. The breakdown of these metals in the dumpsites would be exacerbated by the climatic conditions. In turn, higher heavy metal concentrations would also lead to greater public and environmental health concerns within the urban poor populations who live on and near to the dumpsites and poorly maintained landfills.

1.3.6 Pollutant levels by region

In climatic zone A, the pollutants concentration was higher in dumpsites than landfills, except for Cr, Fe, Ni, Zn. However, a significant difference was found for BOD_5, and Pb. In climatic zone B, the pollutants concentration was higher in dumpsites, except for Cr, Cu, Ni. Though, a significant difference was found in climatic zone B in Pb concentration from landfills and dumpsites. The most likely reason for the differences in these two regions was most probably due to the influence of climatic conditions (i.e., higher temperatures) on leachate characteristics (Ma *et al.*, 2022). In climatic zone C, given the paucity of data, the analysis was only conducted for COD, BOD_5, Cr and Fe. There were no statistically significant differences found.

1.4 CONCLUSIONS

The presence of heavy metals in dumpsites and landfills, particularly Cd and Pb, poses a significant risk to the environment and to public health, especially of the urban poor. Evidently, the risks are particularly high in Global South countries in Asia, Africa, and Latin America. To mitigate these risks, it is vital for there to be investments in improving the waste management infrastructure and systems in these countries. In addition, there should be improved governance structures to enhance the enforcement of the existing policies. Finally, there should also be attention paid to facilitating stakeholder engagement and co-design with those in the communities who are most at risk from the landfills and dumpsites, as a means of enabling the development of more effective initiatives on the ground. Future research should include case studies from all over the world. Thus, North America, Oceania, and Europe should also be investigated and data could also be aggregated according to the income of the country.

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