



Development of a pragmatic methodology for the environmental assessment of uncontrolled dumpsites in developing countries

May A. Massoud¹ · Ricardo Khoury² · Rachad Ghanem² · Rana Ghousseiny² · Farouk Merhbi³

Received: 19 August 2021 / Accepted: 16 April 2022 / Published online: 12 May 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract

The management of solid waste is a major determinant for sustainable development due to the social, economic, and environmental implications that the sector can have on public health and the environment. Generally, the practice of solid waste disposal by means of landfilling in developing countries is below par resulting in numerous open dumps/uncontrolled landfills that lack the necessary remedial and control measures. Several models and approaches have been applied for the environmental assessment of uncontrolled landfills that depend on complex physical models and probabilistic concepts that are normally difficult to use, involve large amount of data and thus are time consuming and costly. This research aimed to formulate a pragmatic methodology that can be utilized in low- and middle-income countries where comprehensive environmental assessment studies are scarce. The proposed methodological framework can guide decision makers in prioritizing sites for remediation according to their potential for contamination of surface and groundwater as well as air. A pilot basin and dumpsite were selected to test the methodology. Application of the methodology provided plausible results on the significance of the impacts on water resources and air quality and provided a systematic approach to guide the decision-making process on the need to rehabilitate the dumpsite.

Keywords Uncontrolled dumps · Developing countries · Environmental assessment · Methodological framework

Introduction

Globally, solid waste generation has been increasing at an alarming rate owing to population growth, urbanization, increasing living standards, and changes in consumption patterns. Improper management of solid waste has been correlated to human and phytotoxicity, resource depletion and degradation, and climate change (Çetinkaya et al. 2018). The solid waste sector is one of the leading anthropogenic sources of greenhouse gas (GHG) emissions, ranking the third largest human-induced source of GHGs (Singh et al. 2018; Pujara et al. 2019). The problem is further exacerbated

in developing countries, as the dearth of financial resources and competing priorities have heaped more pressure on the already fragile solid waste systems in place and contributed to degrading existing infrastructure. Such factors have hindered the establishment and implementation of effective and proper solid waste management systems as environmental issues tend to be pushed down the order of priority, leading to the adoption of inferior methods for waste disposal such as open dumping and burning. The open dumping of wastes is highly prevalent in developing countries with the majority of generated wastes being indiscriminately disposed of in an unsanitary manner (Epstein 2015; Kaza et al. 2018; Ferronato and Torreta 2019). This has led to a salient lack of progress on the solid waste with waste management systems continuing to be predominantly characterized by having low rates of resource recovery, being financially unsustainable, and having large ecological footprints (El-Sherbiny et al. 2011). With practices such as open dumping and burning of waste being commonly relied upon for the disposal of accumulated refuse, pollutants are constantly being dispersed into the environment by means of leaching into soil and water resources and into the air.

✉ May A. Massoud
may.massoud@aub.edu.lb

¹ Department of Environmental Health, Faculty of Health Sciences, American University of Beirut, Riad el Solh, P.O. Box 11-0236, Beirut 1107 2020, Lebanon

² Earth Link and Advanced Resources Development (ELARD), Matn, Lebanon

³ Environmental Health, Safety, and Risk Management Department, American University of Beirut, Beirut, Lebanon

Evidently, improper collection and inadequate disposal of waste can lead to serious air, soil and water contamination, which in turn can have major impacts on the health and wellbeing of the population (Zwijnenburg and Te Pas 2015; De Cassia Silva Bacha et al. 2021). Inevitable byproducts of the open dumping of solid waste are leachate and gas generation. In uncontrolled open dumps, which lack any form of basal isolation or liner, leachate can seep and percolate into the surrounding soil. Thus, contaminating soil, surface water, and groundwater resources (Rajoo et al. 2020). Given the link between soil quality and water quality, such pollution can eventually reach down-gradient receptors including springs and wells used for domestic and agricultural purposes (Cetin 2013). Soil and groundwater resources provide vital ecological functions and services to support human health and existence. Groundwater serves as the primary source of fresh drinking water to most communities in developing countries. The leachate comprises concentrations of organic carbons and heavy metals in addition to high concentrations of fluoride, chloride, ammonium–nitrogen, biological oxygen demand (BOD) and chemical oxygen demand (COD) (Karak et al. 2013; Torretta et al. 2017). Heavy metals, such as mercury, lead, nickel, and cadmium could leach into soil and water bodies (Vongdala et al. 2018), which can cause people to come directly into contact with these metals should the contaminated water be used for bathing or drinking, or indirectly should these metals infiltrate surface and underground water sources or be used for irrigation purposes. These metals can also enter the food chain, as certain metals have the potential to buildup in plants and animals. Their ingestion can cause neurological diseases, organ failure, and several types of cancers (Baalbaki et al. 2016).

Several studies (Kanmani and Gandhimathi 2013; Oluseyi et al. 2020; Morita et al. 2021) have highlighted the impacts of open dumpsites through the collection and analysis of soil and water samples from areas surrounding the disposal sites, with samples often being considerably contaminated. Moreover, improperly disposed wastes can also negatively affect human health since wastes tend to attract rodents and insects, which can act as vectors for many diseases.

Furthermore, uncontrolled open dumps contribute to air pollution due to the release of gases that have the potential to carry air pollutants to the atmosphere. These gases are mainly methane (CH₄) and carbon dioxide (CO₂) along with small amount of volatile organic compounds (VOCs) and other trace gases (Ferronato and Torretta 2019). They are formed because of waste degradation and/or because of burning of waste. Burning leads to the formation of additional pollutants that threaten human health and the environment. Figure 1 depicts the major environmental, health and economic impacts of the open dumping of solid waste. The implications of such treatment and disposal methods in developing countries are amplified by the fact that hazardous wastes, including medical and industrial wastes, are often commingled with the municipal waste stream (SWEEP-NET 2014). This may increase the potency of the generated emissions and leachate, and could in turn increase the costs associated with remediating and rehabilitating the polluted dumpsites (El-Sherbiny et al. 2011). To complicate matters further, the threats and implications posed by dumpsites is heightened by the fact that they tend to be situated near residential areas, primarily in small countries where limited amount of land is available (Zafar 2018).

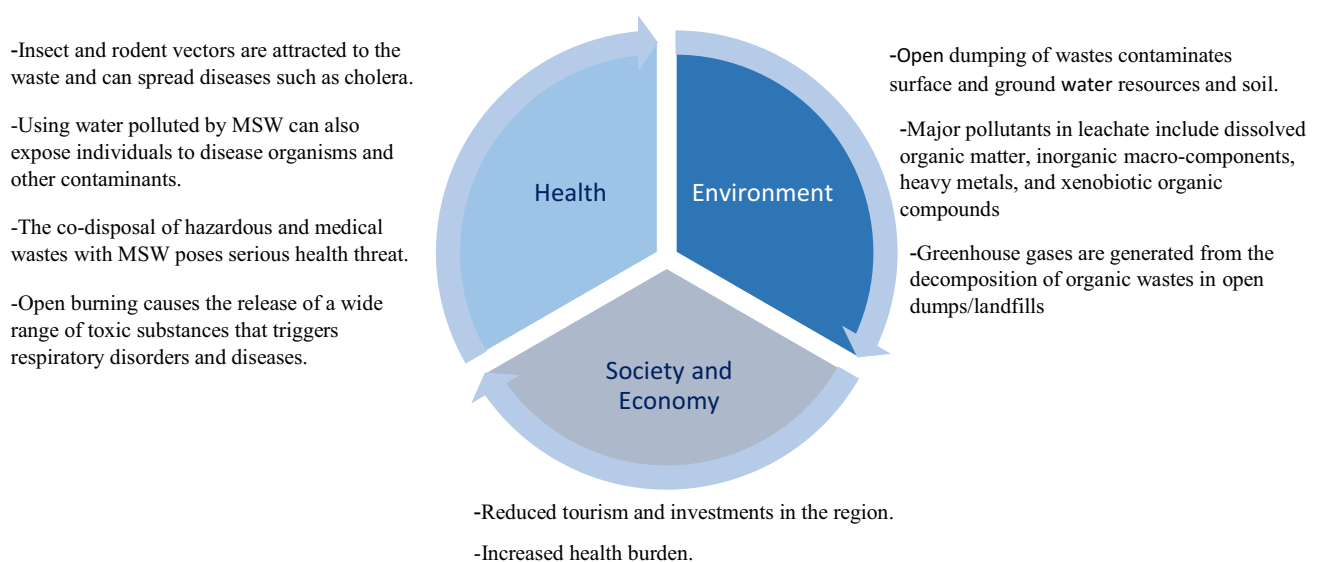


Fig. 1 Major environmental, health and economic impacts of solid waste open dumping

Increasing municipal solid waste generation along with the high fraction of organic waste primarily food waste and a common disposal method of open dumping is the present waste management structure in most areas in Lebanon. The lack of contingency plans and the consistent reliance on ad hoc strategies for handling the solid waste sector culminated into a nationwide garbage crisis when the country's largest landfill was brought to a close. Despite the unsustainability of Lebanon's solid waste management structure becoming more publicly apparent during the crisis in 2015, practices such as open dumping and burning have always been common in the country, especially in rural areas. Generally, the problem does not lie with service delivery considering that an upwards of around 90% of generated wastes are collected. The issue lies in what occurs after the wastes had been collected, with about 77% of generated wastes being landfilled or openly dumped (SWEEP-NET 2014). The pressure placed on Lebanon's solid waste management infrastructure was further inflated by the Syrian crisis, which caused the influx of approximately 1.5 million refugees; resulting in a 15% increase in waste volume, half of which were reportedly being openly dumped or burnt. The increase in the amount of wastes being openly dumped has caused the number of open dumpsites to increase from 670 in 2010 to 904 at present (MOE/UNDP 2017). Accordingly, this research aims to develop a pragmatic methodology for the assessment of the impacts of open dumps on the environment and to test the methodology in a pilot basin. Various methodological frameworks have been utilized to assess environmental and public health risks of open dumpsites including but are not limited to stochastic failure simulations, water balance analysis, numerical scoring and categorical ranking (Kumar et al. 2016) that are generally difficult to use, involve large amount of data and thus are time consuming and costly. Given the large number of uncontrolled dumpsites in developing countries, prioritization of sites requiring remediation or closure is a major challenge. This research could help prioritize dumpsites that require rehabilitation based on the relative risks and the approach could be followed in other developing countries.

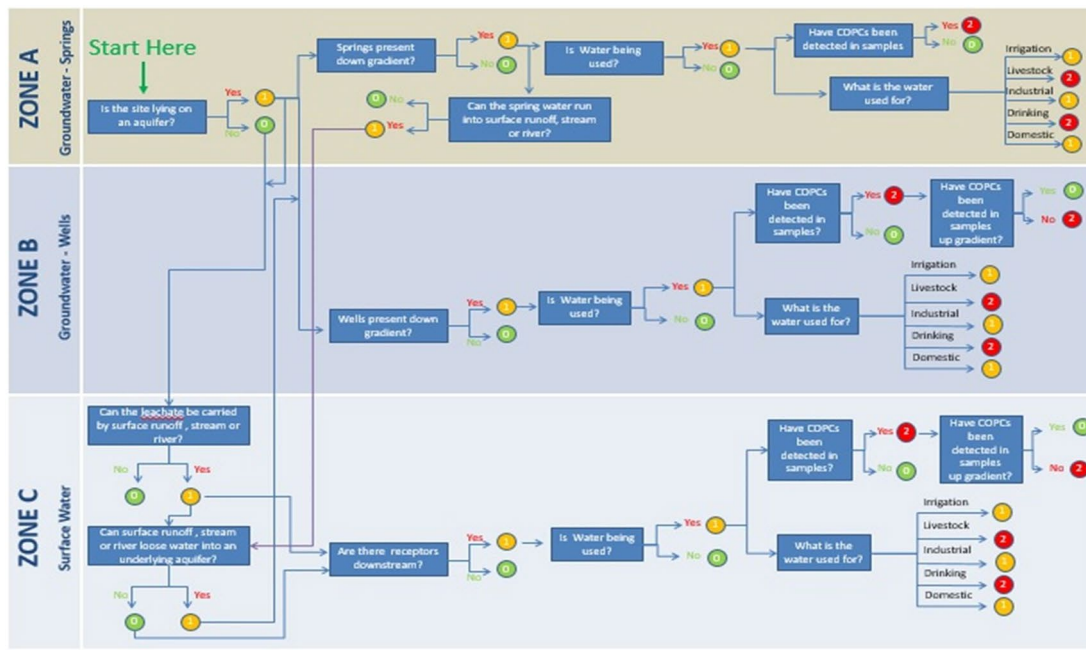
Methodological framework

Design and techniques

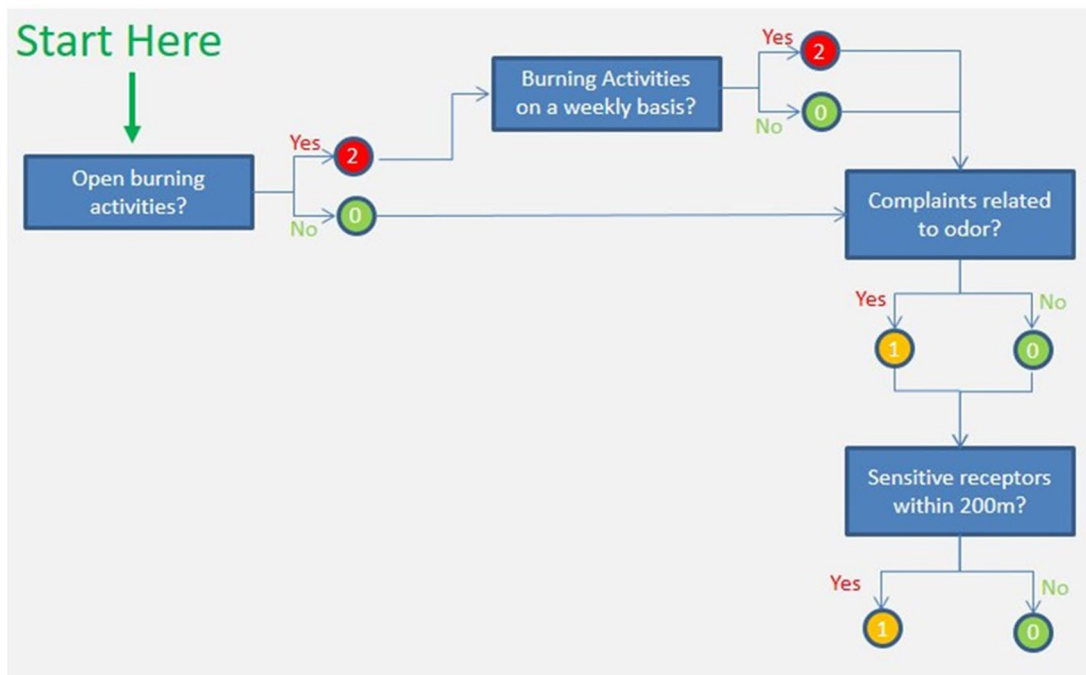
The methodology to assess the impacts of open dumps focused on two major impacts mainly impacts on water resources and impacts on air quality. The significance of the impacts on water resources is based on characterizing the hydrogeological setting of the site, existing receptors and groundwater quality. Accordingly baseline conditions for (1) topography and surface drainage; (2) hydrogeology mainly

groundwater basins, wells, and springs; (3) land use; and (4) water quality were assessed. The main effect of topography will be on surface runoff and drainage. Pollution from the surface can thus be carried via surface runoff into nearby drainages and into streams and rivers. The identification of the presence of an aquifer, semi-aquifer or aquiclude directly underlying a dump will help assess the impact of the dumpsite on groundwater. Groundwater flow direction determines the most likely spread of contamination in case it occurs. The wells located within the same groundwater basin as the dump and down-gradient from it are considered sensitive receptors that can be affected by groundwater pollution from the dump. Springs are also one of the main potential down-gradient receptors. They drain the groundwater from the productive groundwater basins; therefore, any surface pollution potentially affecting groundwater up-gradient, such as a dump, may reach the spring. The classification of the land use surrounding the dumpsite will help identify the potential sources of pollution on water resources and potential receptors affected by it. Analyzing up-gradient and down-gradient water bodies for pollutants that may be correlated to open dumpsites is one approach to distinguish impacts from dumpsites from other land uses such as industrial or agricultural. The model accounts for the following three potentially affected zones that form an interlinked hydrogeological system at the dumpsite: (1) Zone A for groundwater—springs, (2) Zone B for groundwater—wells, and (3) Zone C for surface water. However, for impact assessment rating purposes, each zone is evaluated separately.

The significance of the impacts on air quality is assessed based on the following criteria: (1) open burning practiced at the site, (2) frequency of burning, (3) complaints related to odor in nearby communities and (4) sensitive receptors within 200 m of the site. It is necessary to analyze the dumpsite setting primarily prevalent wind direction to assess the likely dispersion of air pollutants and land use. Impacts from air pollution are largely dependent on weather conditions in the area, particularly wind speed and direction. Moreover, land use around the dumpsite, particularly within a 500-m radius, needs to be documented to identify sensitive receptors. A flowchart approach was proposed (Fig. 2) whereby each answer would generate a predefined score. This score is set to reflect the degree of the impact. A score of 0 means there is no impact while a score of 1 or 2 implies that there is a potential negative impact on the environment that is more severe for the higher value. The total score of each zone is obtained by summing up individual criteria scores with score between 0 and 2 indicating low impact, 3–5 moderate impact, and 6 and above high impact. The priority basin to run the pilot test was selected since it ranks among the top priority dumps and it has relatively limited presence of other sources of pollution to better establish the linkage between pollution levels and the presence of the dumpsite(s).



(a)



(b)

Fig. 2 Water resources (a) and air quality (b) impacts' assessment flow chart

As mentioned earlier, one of the ways to differentiate impacts from dumpsites from other land uses is to analyze up-gradient and down-gradient water bodies for pollutants

that can be attributed to the presence of dumpsites. Very few pollutants can be strictly attributed solely to the presence of dumpsites; however, the presence of heavy metals,

volatile organic compounds (VOCs) and semi-VOCs, polychlorinated biphenyls (PCBs), petroleum hydrocarbons, dioxins and pathogens could be a strong indicator of pollution from wastes. Accordingly, three water samples were taken from different locations chosen: one up-gradient (S1) and two down-gradient (S2 and S3). The sampling locations are relatively far from the dump but these were the only ones accessible for sampling. It is important to notice that by the time the samples were taken, considerable precipitation had already occurred and accordingly groundwater flow was significant in the karstic limestone aquifer in question. This has implications on the concentrations of pollutants that might be encountered in the water samples. Results must, however, be viewed as an additional source of information indicative of the presence of pollution but not refuting it. Not exceeding standards or recommended guidelines cannot be interpreted as lack of pollution because of the dominant hydrogeological nature of the country leading to preferential groundwater flow in the dominant karstic aquifers and fast interaction between surface and groundwater and considerable dilution during winter and spring, which is the most important pollution buffer in karstic aquifers.

Physicochemical analyses were conducted following standard and recommended methods (APHA-AWWA-WEF, 1998). Water samples were analyzed for total and fecal coliform bacteria, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrate–nitrogen ($NO_3^-_N$), ammonia–nitrogen (NH_3_N), orthophosphate ($O-PO_4^{3-}$), sulfates (SO_4^{2-}), and heavy metals. A spectrophotometer was used for NH_3_N (Direct Nesslerization, Standard Methods 4500 NH_3 C), $NO_3^-_N$ (Cadmium reduction; Standard Methods 4500- NO_3 -E), SO_4^{2-} (Turbidimetry; Standard Methods 4500- SO_4^{2-} -E) and $O-PO_4^{3-}$ (Ascorbic acid; Standard Methods 4500-P E). The BOD was based on 5 days incubation at 20 °C using manometer technology and the COD was determined by Closed Reflux/Colorimetry (Standard Methods 5220 D). The bacteriological analyses were determined by the membrane filtration technique (Millipore). Inductively coupled plasma–mass spectrophotometer was utilized for the measurement of metals and gas chromatography–mass spectrophotometer was used to determine the concentrations of volatile organic compounds (VOCs) and semi-VOCs. The results obtained were compared to the World Health Organization (WHO) guidelines, the United States Environmental Protection Agency (USEPA) standards and the Lebanese standards for drinking water.

Research setting

The pilot dumpsite lies on a private land owned by the municipality and located in a valley, below which seasonal water channels run (Fig. 3). Generally, the risk of floods at

the dumpsite is low given that the water channels are small streams that are used for irrigation and the area receives low rainfall. Several springs and wells are present down-gradient from the dump (Fig. 4). In 1970, when the dump first became operational, an average of one truck of waste was dumped every 4 days. However, when the solid waste crisis started in 2015, the municipality allowed other municipalities to dump their waste there for a fee. Today, a total of 2 t/day of construction and demolition waste, municipal solid waste and vegetation are dumped in that site. No open burning takes place at the dump, no leachate or biogas generation were visible during field visits, although scavengers were spotted. The dump covers a 30,000 m² area and has a 2.5 m height and a 75,000 m³ volume. Currently, there are no plans or funds to rehabilitate or close the dump.

Results and discussion: model application

Water resources impact assessment

Environmental baseline conditions

The pilot tested dump is located within the Beirut River watershed on the valley side of one of the two main tributaries of the Beirut River. The valley side in question is sloping towards the southeast. Surface drainages all join in a dendritic pattern the main Beirut River. Streams and rivers eventually discharge in the sea except in the northern and southern most interior parts of the country, which flow toward the outside of Lebanon. The groundwater basin underlying the dump is the Jurassic Basin, which is one of the major productive aquifers of Lebanon due to its karstified nature. The Jurassic limestone is characterized by high infiltration rates and limited soil cover, which makes this aquifer highly vulnerable to pollution (Doerfliger et al. 1999). Groundwater flow in the proximity of the dump is towards the west and the Mediterranean Sea. Down-gradient groundwater receptors are located to the west of the dump. Around twelve (12) public wells are located down-gradient from the dumpsite and are tapping the Jurassic Basin underlying the dump. Surface pollution is likely to reach and contaminate these wells. These public water supply wells are reportedly operational and used for domestic purposes. There is one main down-gradient spring from the dumpsite which is one of the main springs draining the Jurassic. This spring is at risk from any pollution occurring up-gradient from the spring. Moreover, the spring is a main source of water supply for the Capital City Beirut. The land use around the dump is a mix of residential (the nearest home is 1 km away), industrial, recreational areas and open spaces. Public complaints regarding the dump have been recorded at the municipality. Other dumps for municipal and construction/demolition waste as



Fig. 3 Google Earth image showing the location of the dump

well as industries exist up-gradient from the dumpsite within the catchment area of the Beirut River. One of the main challenges in assessing the impacts of uncontrolled dumps on water resources is how to single out the impacts from the dump relative to other impacts.

Water quality assessment

The down-gradient well (S2) exhibited relatively higher concentrations for certain pollutants which were not present in the up-gradient well (S1) and also not in the down-gradient spring (S3). This includes a slight Benzene exceedance at S2 compared to Lebanese standards, as well as some noticeable concentrations (yet below standards) for certain heavy metals (cobalt, copper, nickel, vanadium and zinc). The relatively alkaline pH may have affected the low concentration of some heavy metals as their availability in groundwater is mostly at low pH (Kicińska et al. 2021). Results are not particularly indicative of definitive contamination associated with the presence of the dump however do indicate potential contamination. The fact that the dump is located along the same surface stream reaching S2 Spring within the rocks forming the same aquifer basin leave little room for doubting a pollution potential. The distance between sampled points and the dump has likely enhanced dilution of contaminants down-gradient during the wet season, which potentially

explains that pollutant values remain within standards. This is in agreement with Mor et al., who stated that the quality of groundwater improves with the increase in distance of the well from the pollution source. The fecal and total coliform bacteria count did not comply with the water quality standards and may be associated with the leachate that is generated from the dump and thus, rendering the water unsuitable for human consumption and representing a significant threat to public health (see Table 1).

Impact rating

Based on the significance rating methodology, an assessment of the impact of the uncontrolled dump on water resources was carried out (Table 2). Zone A (Springs) obtained a total score of 8 and Zone B (Wells) obtained a total score of 9, indicating that the dumpsite has a high impact on aquifers and groundwater. Zone C (Surface water) has a total score equal to 3, inferring a moderate impact from the dump on surface water. Obviously, the uncontrolled dump has adversely influenced water bodies in the study area, which in turn can have major impacts on the health and wellbeing of the community. Generally, areas surrounding open dumpsites or poorly designed landfills are at higher risk of groundwater contamination resulting from the degradation of the waste and the percolation of leachate into groundwater

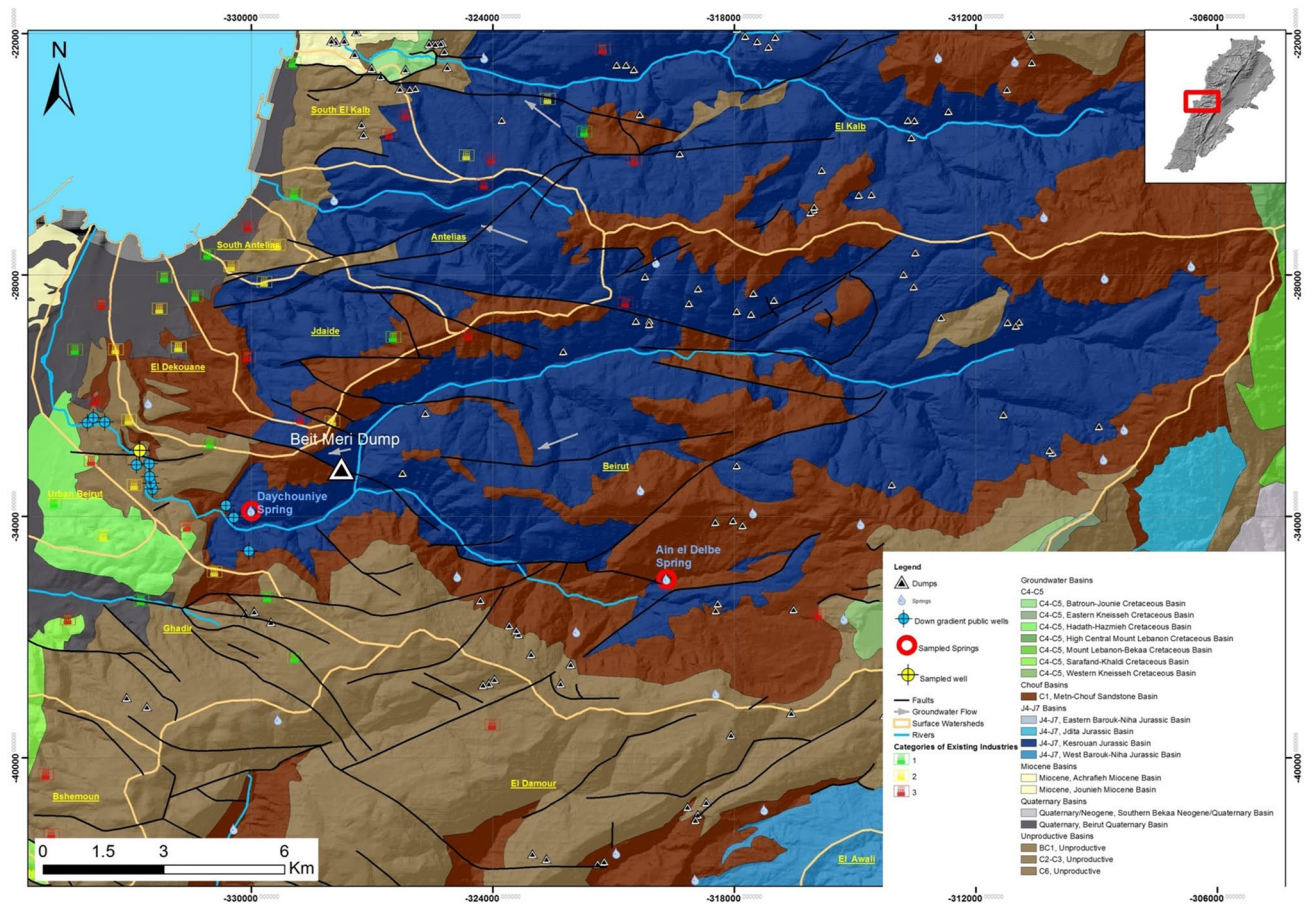


Fig. 4 Geological map of the area surrounding the dump (MOE/EU/UNDP 2014 adopted from Dubertret 1955)

aquifers (Mor et al. 2006; Rajoo et al. 2020; Olaoye et al. 2021).

Air quality impact assessment

Open dumping can lead to the production of foul odor and harmful gases. Moreover, improperly disposed wastes can negatively affect human health since wastes tend to attract rodents and insects, which can act as vectors for many diseases. Impacts from air pollution are largely dependent on weather conditions in the area, particularly wind speed and direction. The predominant wind direction originates from the South and South-West. This will cause receptors to the North of the dump to be more at risk than other receptors. Based on the methodology described in “Methodological framework”, an analysis of the dumpsite setting and its surroundings was carried out to assess the impact of the dump on air quality (Table 3). The total score obtained was 0, meaning that the dump has a low impact on air quality. This is mainly attributed to the fact that no open burning activities were reported when the site was surveyed and that sensitive receptors are located beyond 200 m from the dumpsite.

While sampling of air quality could significantly improve the assessment of the impacts on air quality, this would require careful and detailed analysis of the locations, parameters, and duration of sampling to obtain representative results, and which would be very costly to undertake. The proposed qualitative analysis supports decision-making in a cost-effective manner.

Conclusions

Several models and approaches have been applied for the environmental assessment of uncontrolled dumps that depend on complex physical models and probabilistic concepts that are generally difficult to use, involve large amount of data and thus are time consuming and costly. In this research, a practical methodology that can be easily utilized in low- and middle-income countries where comprehensive environmental assessment studies are scarce was developed. A pilot basin and dumpsite were selected to test the methodology. Application of the methodology provided plausible results on the significance of the impacts on water

Table 1 Water analysis results for the most indicative parameters of leachate

Parameter	Unit	WHO Guidelines ^a	EPA Standards ^b	Lebanese Standards ^c	S1	S2	S3
General (physico-chemical analyses)							
Salinity	ppm	–	–	–	259	334	326
pH	-	NA		6.5 – 8.5	7.6	7.6	7.5
Electrical conductivity	µS/cm	–		1,500	460	590	570
Total suspended solids (TSS)	mg/L	–		–	<2.0	22	11
Total dissolved solids (TDS)	mg/L	NA		500	324	418	406
Ammonia-nitrogen	mg N/L	NA		0	<0.010	<0.010	<0.010
Nitrates-nitrogen	mg/L	50		45	5.8	7.4	7.0
Total organic carbon (TOC)	mg/L	–		–	2.0	<2.0	<2.0
Biochemical oxygen demand (BOD-5)	mg O ₂ /L	–		–	<1.0	3.4	<1.0
Chemical oxygen demand (COD)	mg/L	–		–	13	<5.0	89
Total alkalinity (as CaCO ₃)	mg/L	–		200	<5.0	<5.0	<5.0
Sulfates	mg/L	NA		250	28	49	41
Chloride	mg/L	NA		200	12	24	22
Heavy metals							
Antimony	µg/L	20	6	–	<5.0	<5.0	<5.0
Arsenic	µg/L	10	10	50	<3.0	<3.0	<3.0
Barium	µg/L	700	2,000	500	5.1	9.9	7.8
Cadmium	µg/L	3	5	5	<0.40	<0.40	<0.40
Chromium	µg/L	50	100	50	<2.0	<2.0	<2.0
Cobalt	µg/L	–		–	<1.0	2.2	<1.0
Copper	µg/L	2,000	1,300 ^d	1,000	<3.0	6.1	<3.0
Lead	µg/L	10 P	15 ^d	10	<3.0	<3.0	<3.0
Mercury	µg/L	6 ^e	2	1	<0.040	<0.040	<0.040
Nickel	µg/L	70		20	<2.0	4.8	<2.0
Selenium	µg/L	40 P	50	10	<5.0	<5.0	<5.0
Silver	µg/L	NA		10	<20	<20	<20
Thallium	µg/L	–	2	–	<7.0	<7.0	<7.0
Vanadium	µg/L	–		–	<2.0	5.7	<2.0
Zinc	µg/L	NA		5,000	<5.0	29	<5.0
VOCs and semi-VOCs							
Benzene	µg/L	10	5	0	<0.10	1.1	0.88
1,1-Dichloroethane ethylidene chloride	µg/L	NA		–	<0.10	<0.10	<0.10
Ethylbenzene	µg/L	300 C		–	0.11	<0.10	<0.10
Xylene (total)	µg/L	500 C	10,000	–	<0.20	<0.20	<0.20
Coliforms							
Fecal coliforms	CFU/250 mL	0	5.0%	0	190	21	200
Total coliforms	CFU/100 mL	0	5.0%	0	240	15	190

C concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odor of the water, leading to consumer complaints, NA not available, P provisional guideline

^aWHO (2011)

^bUSEPA (2017)

^cDecree No. 1039/1999

^dLead and copper are regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L

^eInorganic mercury

Results in bold are in exceedance to one or more of the three standards.

Table 2 Water quality assessment

Zone	Question	Answer	Score	
A	Is the site lying on an aquifer?	Yes	1	
	Springs present down-gradient?	Yes	1	
	Is water being used?	Yes	1	
	Have chemicals of potential concerns (COPCs) been detected in samples?	Yes	1	
	What is the water used for?	Drinking	2	
		Domestic	1	
	Can the spring water run into surface runoff, stream or river?	Yes	1	
		Total A	8	
	B	Wells present down-gradient?	Yes	1
		Is water being used?	Yes	1
Have COPCs been detected in samples?		Yes	2	
Have COPCs been detected in samples up-gradient?		No	2	
What is the water used for?		Drinking	2	
		Domestic	1	
	Total B	9		
C	Can surface runoff, stream or river lose water into an underlying aquifer?	Yes	1	
	Can the leachate be carried by surface runoff, stream or river?	Yes	1	
	Are there receptors downstream?	Yes	1	
	Is water being used?	No	0	
	Have COPCs been detected in samples?	NA	NA	
	Have OPCs been detected in samples up-gradient?	NA	NA	
	What is the water used for?	NA	NA	
	Total C	3		

Table 3 Air quality assessment methodology

Question	Answer	Score
Open burning activities?	No	0
Burning activities on a weekly basis?	NA	NA
Complaints related to odor?	No	0
Sensitive receptors within 200 m?	No	0
	Total	0

resources and air quality. It provided a systematic approach that can be adopted to aid decision-making at a local level on the need to rehabilitate the dumpsite. The methodology developed defines the significance criteria and baseline conditions that need to be known in the assessment, as well as a procedure to determine significance rating. Baseline conditions considered for impacts on water resources include topography and surface drainage, hydrogeology (groundwater basins, wells and springs), land use and water quality. Baseline conditions considered for impacts on air quality comprised prevalent wind direction, land use and presence of nearby sensitive receptors. For dumps with high impact significance on water resources, it is recommended to eliminate the source of the pollution, primarily through closure and rehabilitation of the dump. For dumpsites with a high impact on air quality, mitigation measures can be applied

to reduce impacts resulting from open burning activities of waste. For the studied dumpsite, the recommended option for rehabilitation is sort, crush and recycle, and the cost of rehabilitation has been estimated at 939,750 USD. Growing concerns about environmental and public health risks of uncontrolled dumpsites call for taking appropriate mitigation measures and remedial actions. Given the large number of uncontrolled dumpsites in developing countries, it is inevitable to ascertain the conditions of the dumpsites and assess possible environmental impacts. The proposed pragmatic methodology provides a practical approach for assessing risk of uncontrolled dumpsites and can significantly improve decision-making regarding the prioritization of uncontrolled dumpsites for implementing control measures and taking remedial action.

Acknowledgements This work was financed by the Government of Lebanon, implemented through the United Nations Development Programme (UNDP) Country Office in Lebanon and executed by the Lebanese Ministry of Environment (MoE). The authors extend their appreciation to all those who supported this work in particular to Mr. Bassam Sabbagh from MoE and Ms. Jihan Seoud and Dr. Manal Mousallem from UNDP.

Funding This work was financed by the Government of Lebanon, implemented through the United Nations Development Programme (UNDP) Country Office in Lebanon and executed by the Lebanese Ministry of Environment (MoE). The authors extend their appreciation

to all those who supported this work in particular to Mr. Bassam Sabbagh from MoE and Ms. Jihan Seoud and Dr. Manal Moussallem from UNDP.

Availability of data and materials Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest No conflict of interest.

Ethics approval Not applicable.

References

- Baalbaki R, El Hage R, Nassar J, Shihadeh A, Saliba N, Gerard K et al (2016) Exposure to Atmospheric PMS, PAHS, PCDD/FS and Metals near an Open Air Waste Burning site in Beirut. *Leban Sci J* 17(2):91–103
- Cetin M (2013) Landscape engineering, protecting soil, and runoff storm water. In: Ozyavuz M (ed) *Advances in landscape architecture*. IntechOpen. <https://doi.org/10.5772/51738>
- Çetinkaya AY, Bilgili L, Kuzu SL (2018) Life cycle assessment and greenhouse gas emission evaluation from Aksaray solid waste disposal facility. *Air Qual Atmos Health* 11(5):549–558
- De Cassia Silva Bacha D, Santos S, de Alcantara Mendes R et al (2021) Evaluation of the contamination of the soil and water of an open dump in the Amazon Region. *Brazil Environ Earth Sci*. <https://doi.org/10.1007/s12665-021-09401-3>
- Doerfliger N, Jeannin PY, Zwahlen F (1999) Water vulnerability assessment in karst environments: A new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method). *Environ Geol* 39:165–176
- Dubertret L (1955) Geological map of Lebanon at 150000. Republic of Lebanon, Minister of public affairs, Beirut
- El-Sherbiny R, Gaber A, Riad M (2011) Waste management. In: Abaza H, Saab N, Zeitoun B (eds) *Green economy: sustainable transition in a changing Arab world*. AFED, Lebanon
- Epstein E (2015) *Disposal and management of solid waste. pathogens and diseases*. CRC Press, USA
- Ferronato N, Torretta V (2019) Waste mismanagement in developing countries: a review of global issues. *Int J Environ Res Public Health* 16(6):1060–1103
- Kanmani S, Gandhimathi R (2013) Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. *Appl Water Sci* 3:193–205. <https://doi.org/10.1007/s13201-012-0072-z>
- Karak T, Bhattacharyya P, Das T, Paul RK, Bezbaruah R (2013) Non-segregated municipal solid waste in an open dumping ground: a potential contaminant in relation to environmental health. *Int J Environ Sci Technol* 10:503–518. <https://doi.org/10.1007/s13762-013-0184-5>
- Kaza S, Yao LC, Bhada-Tata P, Van Woerden F (2018) *What a waste 2.0: a global snapshot of solid waste management to 2050*. Urban development. World Bank, Washington, DC
- Kicińska A, Pomykała R, Izquierdo-Diaz M (2021) Changes in soil pH and mobility of heavy metals in contaminated soils. *Eur J Soil Sci* 3(1):e13203. <https://doi.org/10.1111/ejss.13203>
- Kumar A, Datta M, Nema A, Singh RK (2016) An improved rating system for assessing surface water contamination potential from MSW landfills. *Environ Model Assess* 21:489–505
- MOE/EU/UNDP (2014) Lebanon Environmental Assessment of the Syrian Conflict & Priority Interventions. EU
- MOE/UNDP (2017) Updated master plan for the closure and rehabilitation of uncontrolled dumpsites throughout the Country of Lebanon. MOE/UNDP
- Mor S, Ravindra K, Dahiya RP, Chandra A (2006) Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environ Monit Assess* 118:435–456
- Morita A, Ibelli-bianco C, Anache J, Coutinho J, Pelinson N, Nobrega J, Rosalem L, Leite C, Niviadonski L, Manastella C, Wendland E (2021) Pollution threat to water and soil quality by dumpsites and non-sanitary landfills in Brazil: a review. *Waste Manag* 131(15):163–176
- Olaoye R, Afolayan O, Adewale R, Ogundairo T (2021) Vulnerability assessment of groundwater contamination from an open dumpsite: Labete dumpsite as a case study. *IOP Conf Ser Mater Sci Eng* 1036:012013. <https://doi.org/10.1088/1757-899X/1036/1/012013>
- Oluseyi T, Fatunsin O, Amadi E (2020) Impact assessment of dumpsites on quality of near-by soil and underground water: a case study of an abandoned and a functional dumpsite in Lagos, Nigeria. *Intern J Environ Sci Technol* 3(3):1004–1015
- Pujara Y, Pathak P, sharma A, Govan J, (2019) Review on Indian Municipal Solid Waste Management practices for reduction of environmental impacts to achieve sustainable development goals. *J Environ Manag* 248(109238):1–14
- Rajoo KS, Karam DS, Ismail A, Arifin A (2020) Evaluating the leachate contamination impact of landfills and open dumpsites from developing countries using the proposed Leachate Pollution Index for Developing Countries (LPIDC). *Environ Nanotechnol Monit Manag* 14:100372. <https://doi.org/10.1016/j.enmm.2020.100372>
- Singh CK, Kumar A, Roy SS (2018) Quantitative analysis of the methane gas emissions from municipal solid waste in India. *Sci Rep*. <https://doi.org/10.1038/s41598-018-21326-9>
- SWEEP-NET (2014) Challenges and opportunities for solid waste management in the Mashreq and Maghreb region. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Berlin
- Torretta V, Ferronato N, Katsoyiannis IA, Tolkou AK, Airoidi M (2017) Novel and conventional technologies for landfill leachates treatment: A review. *Sustainability* 9:9. <https://doi.org/10.3390/su9010009>
- United States Environmental Protection Agency (USEPA) (2017) Table of Regulated Drinking Water Contaminants. Retrieved from: <https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants>. Accessed 16 Feb 2019
- Vongdala N, Tran HD, Xuan TD, Teschke R, Khanh TD (2018) Heavy metal accumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos. *Int J Environ Res Public Health* 16(1):22
- World Health Organization (WHO) (2011) *Guidelines for drinking-water quality*, 4th edn. World Health Organization
- Zafar S (2018) *Waste Management Outlook for the Middle East*. In: Brinkmann R, Garren SJ (eds) *The Palgrave handbook of sustainability: case studies and practical solutions*. Springer International Publishing, Cham, pp 159–181
- Zwijenburg W, Te Pas K (2015) *Amidst the debris... A desktop study on the environmental and public health impact of Syria's conflict*. Colophon

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.