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ENVIRONMENTAL AND HEALTH RISKS OF OPEN DUMPSITES: THE CASE OF IKLIM EL TEFFAH, SOUTHERN LEBANON

by
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AN ABSTRACT OF THE THESIS OF

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Municipal solid waste management remains an obstacle facing many developing countries. This is primarily due to the lack of proper planning, insufficient funding and lack of legislation for proper implementation and monitoring systems. Thus, open dumping was viewed as a last resort for various countries. The present study aims to (1) investigate the environmental and health risks that open dumpsites have by polluting the groundwater, surface water and soil in Iklim El Teffah, southern Lebanon, (2) identify the dumpsites having the highest risk based on a developed risk sensitivity index, and (3) develop a rehabilitation plan to manage the open dumpsites. Samples were collected from 7 villages, where dumpsites are located. A total of 9 water samples and 21 soil samples were collected twice, once during the wet season and once during the dry season. Samples were examined for total and fecal coliforms and other physio-chemical parameters. Several environmental indices were then calculated to assess the environmental impacts of the present dumpsites. Our findings indicated that several soil parameters including TN, pH, DO, COD, salinity and sulfate levels, were altered due to the dumpsites. The trend of heavy metals concentration varied between dumpsites. Fe, Cr, Zn, Cu & Mn were most prevalent across all dumps but were found to exceed the permissible limits in some of them. Soil samples were found to be moderately contaminated with dumpsite 6 having the highest total ecological risk. The altered parameters have a direct effect on soil fertility and, if biomagnified, they could disrupt crop yield. Physiochemical properties and heavy metal concentrations in water samples weren't significantly altered and were found to be within permissible limits. Soil and water samples were found to have high levels of total coliforms. The use of water having high counts of fecal coliforms and *E.coli* is considered to be critical as they are associated with various gastrointestinal diseases, typhoid, fever and urinary tract infections. For the population exposed to the present dumpsites, incident cases of liver and lung cancer & congenital anomalies that would be merely attributed to the exposure to dumpsites were found to be 39 %, 13% & 2%, respectively. Applying the analytical hierarchy process (AHP), landfill mining was found to be the remediation plan with the highest priority value. The latter is supposed to be followed up with phytoremediation, a bioremediation process for contaminated dumpsite soils.

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ABBREVIATIONS

AC Attributable cases

AHP Analytic Hierarchy Process

CF Contamination factor

COD chemical oxygen demand

CI Consistency index

CR Consistency ratio

DO Dissolved oxygen

EC Electric conductivity

ER Ecological risk

FAO Food and Agriculture Organization of the United Nations

IC Incident cases

Igeo index Geoaccumulation Index

ICP Inductively Coupled Plasma-Mass Spectrometer

MSW Municipal solid wastes

PLI Pollution load index

SWM Solid waste management

TN Total nitrogen

TDS Total dissolved solids

USEPA United States Environmental Protection Agency

WHO World health organization

WQI Water quality index

CHAPTER I

INTRODUCTION

Globally, solid wastes generation has significantly increased due to many factors mainly related to increasing population, exploitation of natural resources, economic development, and urbanization. Solid waste management (SWM) has been an obstacle confronting many countries especially developing ones primarily due to the lack of proper planning, insufficient funding and lack of legislation needed for the proper implementation and monitoring of this sector (Naeem et al., 2010). In 2015, it was estimated that 7 to 10 billion tons of urban wastes were produced each year and the volumes of wastes were expected to double in lower-income African and Asian cities by 2030 (David et al., 2015).

The management of solid wastes faces obstacles at every functional element in the system starting from the generation stage up until final disposal. Around 2 billion people worldwide suffer from improper waste collection methods; yet even a larger number, reaching 3 billion people, lack access to controlled disposal services for the municipal solid wastes (Wilson, 2016). Low-income and upper middle-income countries resort to open dumping as the dominant method for disposal, whereby it was estimated that 40% of the total waste generated was openly dumped (Mavropoulos, 2015). The situation is expected to worsen with forecasts showing that 5.6 billion people will have no access to waste management services by 2050 (Waste Atlas, 2018). This, in turn, calls for a global alliance to face this growing crisis.

Several studies addressed the impacts of open dumpsites and have highlighted their detrimental effects on the environment and health (Mavropoulos, 2015). Soil and ground water samples collected from disposal sites were shown to have high pollution levels when compared to control sites. Various heavy metal concentrations were also found to exceed approved levels for Lead (Pb), Copper (Cu), Nickel (Ni), Chromium (Cr) and Zinc (Zn) concentrations. This was accompanied by a decline in plant growth and vegetation whereby plants' diversity dropped due to the damaged nutrient cycles and altered soil chemistry by the percolation of concentrated toxic leachates. Additionally, water samples around these sites were found to be microbiologically contaminated by total and fecal coliforms (Chandra et al., 2006; Yasmin et al., 2013; Rao & Praveena, 2016; Priyanka et al., 2017). A cross sectional study conducted among residents living around a large active dumpsite in Nigeria showed that 34.5% of residents had severe health impacts and were victims of cholera, malaria, diarrhea, respiratory diseases, and skin infections; thus, the association between increased morbidity rates and exposure to open dumpsites has been established and it is vital to adopt management plans that would reduce the posed health risks (Kabir & Shomoye, 2016).

The plans for SWM have shifted from open dumping to controlled dumping and eventually into sanitary landfilling. Moreover, emphasis has been placed on the closure of open dumpsites in an environmentally sound manner (UNEP, 2005). Like other developing countries, Lebanon is also facing this global threat whereby open dumpsites are widespread around the country. In 2016, the total count of dumpsites reached 941 out of which 658 were municipal solid waste dumpsites (MOE-UNDP, 2017). With current poor management circumstances, these dumpsites are expected to increase especially that municipal solid waste projections reflect a steady increase in the total waste generation. In 2009 the amount of wastes generated had increased to 1.57 million tons, and is further expected to increase by an estimated 1.65% per year to reach 1.92 million tons by 2020 (Ahlback, 2011).

This research proposal aims at assessing the environmental and health impacts of open dumpsites in Iklim El Teffah area and designing a remediation management plan. It is part of a wider project that aims to build a model 'Circular Economy' approach that aims at fostering economic growth, by redesigning resource flows in the target area (Iklim El Teffah) to maximize prevention and recycling of waste in addition to remediating existing open dumps having the highest adverse impacts on the Sainiq River, in southern Lebanon.

CHAPTER II

LITERATURE REVIEW

A. Solid waste management challenges

The management of solid waste has become an issue of increasing global concern as the world hurtles towards urban development and industrialization. SWM is associated with the control of the generation, storage, collection, transfer, transport, processing and disposal of solid waste in a manner that is in accordance with environmental considerations, the principles of public health, and responsive to public attitudes (Tchonglo et al., 1993). Although SWM have been theoretically planned, yet different complexities are being evident upon implementation. Worldwide, waste generation is topping the list of challenges facing a successful management approach as it's directly linked to the economic growth and population size and is increasing proportionally. People are producing vastly more waste than our planet can sustain. Today 3.6 million tons of municipal solid wastes are being generated each day; this figure is expected to double by 2025 reaching approximately 6.1 million metric tons per day (SYNOVA, 2018). Despite the relatively low per capita generation rate in low and middle income countries compared to high income countries, their population size is increasing at a very rapid pace which directly increases the amount of waste generated. As for high-income countries, waste generation rates are already very high and are still increasing with economic growth. Although many industrialized countries have mitigated the amount of waste generated and maximized diversion, there persist others that still rely on unconventional methods for disposal. As for developing countries, there are critical needs that aren't resolved yet. These include lack of political will and commitment, lack of a national policy related to SWM, absence of rules and regulations, insufficient funds dedicated to solve the problem, a severe absence of educational programs, and last, but not least, no attempts to shift into a 'circular economy' (Diaz, 2016).

Accompanied with the high waste generation rate issue, is the challenge of dominating a linear system of resource consumption instead of moving towards a circular one where materials are recovered and fed again into the production systems. Various resources are transformed into different products, distributed to consumers on the global market and then fed back into the SWM system. Tremendous amounts of wastes are entering into the waste streams despite increasing recycling of materials, such as paper, metals..etc. Thus, even countries with a relatively developed infrastructure for SWM face challenges in sustainability, primarily, because of products that are not suited for recycling and the improper sorting at source phase (Frostell et al., 2014). Increasing complexity of product composition, in parallel with consumption systems' demand, came at the expense of recycling phase. Diluted resources are difficult to recover as they are energy-intensive which is sometimes not economically or technologically feasible. Thus, it is hard to foster efficient cycles of reuse with minimal maintenance of resource quality throughout the product chain (Frostell et al., 2014).

Improving waste management requires raising additional investments that are long-term, independent of any political interference and, aim at improving infrastructure regardless of any potential emergency. It is vital to have a clear, well described, and pertinent national policy, for municipalities to determine the most appropriate options to deal with their wastes (Diaz, 2016). It is always ideal to develop a SWM system instead of individual initiatives; however, SWM is being obstructed with informal initiatives that hinder the management process instead of facilitating it (Frostell et al., 2014). Informal sectors are highly active in waste collection phase, especially in low- and middle-income countries, making it more difficult to regulate and implement a new efficient and waste management system (Wilson et al., 2012). Indeed, recycling and reuse approach has been greatly impacted especially because of the scarcity of high quality recyclables. It is true that municipalities' costs for waste collection is being reduced, but it is more likely that the expenditures on waste treatment would increase as waste materials that may be capitalized are recovered by the informal collectors and cost saving for municipalities aren't collected (Burcea, 2015). This reveals the gap found in management strategies followed where informal sectors aren't being integrated in formal waste management planning nor guided by policies and regulations (Wilson et al., 2012).

Moreover, challenges arise from the principle of adopting external solutions rather than adapting any strategy to every country's context. High-income countries have allocated resources to collecting and analyzing the waste related information, for example waste quantity and composition, by using advanced technical support (computer-based simulation programs, data bases...). Accordingly, developed countries formulated the most applicable disposal method to implement whether a landfill or incineration. However, information on solid waste is scarce and inaccessible in low- and middle income owing it to the lack of financial resources. Thus, reaching out to strategies implemented by high income countries as the best solution would only add burden to these countries as the inadequate planning and prioritizing solid waste incineration over other waste disposal methods would only be more expensive (Frostell et al., 2014).

Environmental awareness is pivotal when it comes to SWM. In many developing countries public and environmental health are taken for granted during implementation of SWM system with improvements now shifted towards creative and efficient management of resources to mitigate waste generation rates (Wilson, 2007). However, some countries still lack the proper environmental awareness. Minimal emphasis is shed towards this aspect reflecting on the ability of people to get incorporated in management strategies especially affecting the efficiency of sorting at source and the ability to fade away from primitive disposal techniques. Sorting at source directly limits the recycling activities as recyclables mixed with other kinds of wastes would result in economically and environmentally inefficient recycling operations (Mbeng et al., 2009). At source sorting is a crucial step prior recycling processes. Proper sorting would spare land biodegradation because of the mixed waste dumped, reduce land space consumed by the volume of dumped waste and would allow a better quality of compost and recyclable material that are intended to sold and used later on (Azzi, 2017).

B. Solid waste open dumping

Collection, transportation, and disposal of MSW demonstrate a huge expense for developing cities whereby management of wastes generally accounts 30 to 50 percent of municipal operational budgets (Ghani & Zohoori, 2017). Despite these high expenditures, some cities find it difficult to collect more than 80 percent of the refuse produced. For instance, in India about 50 percent of refuse produced is collected. Eventually, areas that lack or have minimal refuse collection, generally low-income communities, will end up with stacks of waste that they tend either to dump at the closest empty lots, public space, or river, or simply burn it in their backyards. Additionally, dumps in some cities are intentionally and periodically set on fire as a methodology to decrease the volume of the waste; thus, allowing extra tonnages of wastes to be disposed and hence ensuring a prolonged life for the dumps (Ghani & Zohoori,2017). Ignorance in implementing a proper collection system reaching every doorstep or transport area would directly impact the quality of disposal strategies. Additionally, disposal receives even less attention whereby approximately 90 percent of the MSW collected in low-income developing countries ends up in open dumps or is openly burned (World Bank, 2018).

Disposal phase in SWM is more of an issue in developing countries rather than developed ones, as they've reached a consensus that it is significantly more expensive to mitigate impacts of improper disposal than disposing waste in an environmentally sound manner in the first place (Newman & Strainer, 2015). Uncontrolled disposal illustrated by open dumping and burning of waste, was a very common scene everywhere until the 1960s. In the 1970s, public health and equity were the key drivers for high income countries that allowed them to formulate and implement legislation that phased out uncontrolled dumping and in parallel set standards required for environmentally sound management (ESM) facilities (Newman & Strainer, 2015). On the other hand, according to the World Bank (2018), uncontrolled dumping is only persistent now as the norm in most of the developing countries despite the fact that ever since 2000 the World Bank committed over $4.7 billion for the sake of SWM programs in countries across the globe (World Bank,2018).

Uncontrolled dumpsites receive approximately 40% of the world's waste and serve about 3-4 billion people. Keeping up the same pace in management practices, urbanization and population growth, it is expected that at least several hundreds of millions extra people will be served by dumpsites (ISWA, 2016). Today there are at least 50 dumpsites listed as the biggest in the world, out of which 17 are of municipal sources. Almost all of these dumpsites are located near or even within urban areas and close to natural resources. Additionally, 42 out of the 50 dumpsites are less than 2 km away from settlements, 44 dumpsites are less than 10 km close to natural resources and 38 dumpsites are near water sources (figure 1) (Waste Atlas, 2015).

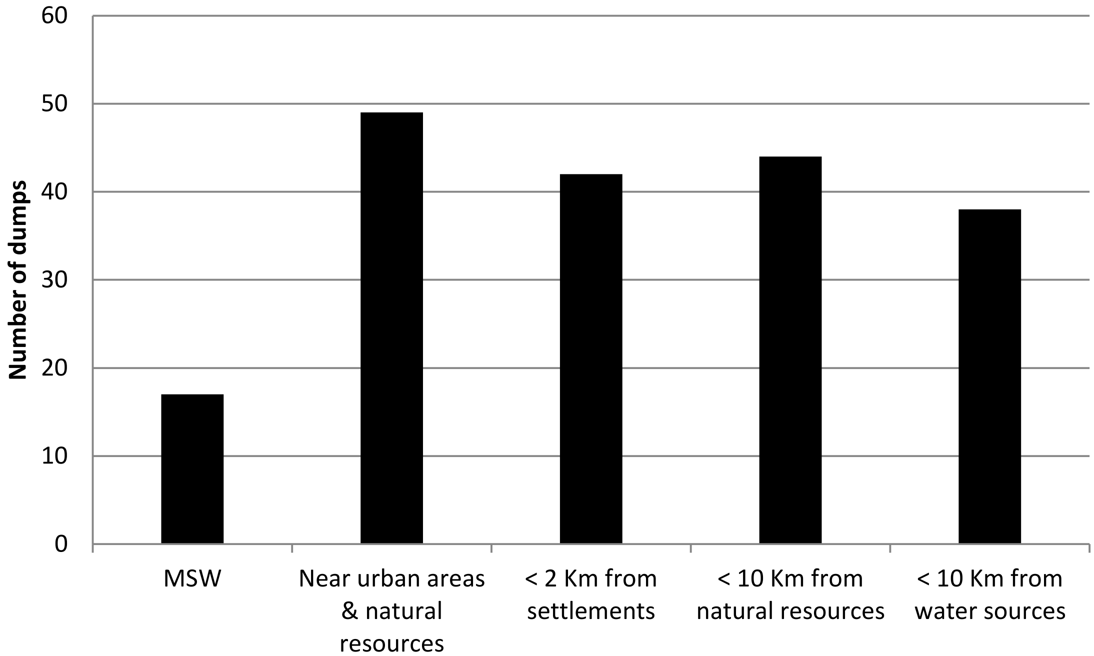


Figure 1: Distribution of world's 50 biggest dumpsites (Waste Atlas, 2015)

C. Impacts of open dumpsites

Dumpsites are considered to be a threat specifically because of leachate percolation that is usually highly concentrated and contaminated. Contaminants can settle on or get digested by plants or animals, get into the air, and eventually enter the food chain and water all depending on the tendency of the contaminants during absorption. Thus, the population is being exposed through the three basic pathways including inhalation, ingestion, and dermal contact. Moreover, the main reason for development of chronic diseases, despite being exposed to traces of contaminants over a long period, is bioaccumulation (Newman et al., 2015).

Leachate isn't the only concern, the decomposition of waste also brings about the generation of gases, particularly methane, and it builds up pressure and then begins to move through the soil. Methane is lighter than air and is highly flammable. It can cause a serious explosion if it reaches a concentration of 15% in air. Aside from being a flammable gas, methane released to the atmosphere greatly contributes to the depletion of the ozone layer and to climate change (EPA,2012). If the situation continues as is, it is expected that dumpsites will account for 8-10 % of the global anthropogenic greenhouse gases (GHG) emissions by 2025 (Newman et al., 2015).

It is important to emphasize that the intensity of the environmental impacts posed by a dumpsite depends on various site-specific factors like location, geological / hydrogeological conditions and proximity to the dumpsite, local flora and fauna, area covered by waste, years of operation, and level of engineered management controls in place. The listed factors would determine not only their environmental but their health impacts. Previous epidemiological studies have found that cancer and having congenital malformations are two main health outcomes being statistically associated with exposure to refuse from open dumpsites (Abiodun et al., 2018). Additionally, soil and water pollution are environmental problems arising from leachate percolation from dumpsites. Many studies show evidence of serious impacts of contaminants like Cd, Cu, Ni, Pb and Zn in altering the soil chemistry, by that, directly effecting organisms and plants depending on the soil for nutrition and ultimately disrupting the plants' life cycles (Newman et al., 2015).

1. *Site accidents*

Due to improper management and lack of any safety measures, site accidents frequently occur at dumpsites, mostly involving scavengers and workers who dump the waste. Severity of accidents that had occurred during the years ranged from simple wounds to fires and explosions.

Waste Atlas 2014 reported that the largest 50 dumpsites worldwide affected the lives of 64 million people and host more than 50,000 informal sector recyclers on-site. The operation of dumpsites damages the health and violates the human rights of the hundreds of millions of people that are living in their surroundings or even inside them. These practices create serious health, safety, and environmental consequences. In 2015, the Wasted Health report highlighted that exposure to open dumpsites has a greater detrimental impact on a population’s life expectancy than malaria and that in addition to human/ environmental impact, the financial cost of open dumpsites runs into the tens of billions of USD. Major incidents have recently occurred that validate the threats posed by dumpsites (Table 1).

Table 1: Major dumpsite accidents

Location	Incident	Reference
Shenzhen, China 2015	• Dumpsite killed 73 people, left four others missing and destroyed 33 buildings • 132 million USD estimated economic losses	(Perlez, 2016)
Zimbabwe, 2015	• Polluted groundwater a result of improper SWM • 502 deaths a result of diarrhea and another 521,573 cases that were treated across the country • Diarrheal diseases are well established as environmental diseases and are directly related to environmental factors, especially with water pollution as a result of improper waste management, which was the case in Zimbabwe	(ISWA, 2016)
Angola end of 2015	• Yellow fever outbreak • Infected 355 people and killed158 • The dumpsites there accelerated the transmission of the disease through the mosquitos they hosted. • Cases of malaria, cholera and chronic diarrhea increased dramatically in other cities especially because of the poor sanitation services and scattered rubbish. • With the beginning of the heavy rainfall and storms, risk attributed to the dumpsites escalated as the refuse got scattered and contaminated drinking and washing sources of water	(WHO, 2016; Winsor, 2016)
Guatemala City 2016	• Massive dumpsite landslide in the largest dump in all of Central America where almost 7,000 people, including children, work as informal recyclers • Four people were killed and at least 24 more people went missing	(Kerry, 2016)
Deonar, Mumbai	• A massive fire started in a 132 hectares dumpsite that receives 4,000 tons of waste per day • Smoke emitted was so thick that it blotted out the sun, the health risks of nearby residents were found to be high and the fire was visible from space on NASA's images	(Hindustantimes, 2016)
New Delhi & Ghazipur dumps, India	• Waste pickers suffered from asthma, tuberculosis, skin diseases, burns and injuries from fires initiated on site • The site threatens surface water quality especially that it is 2.5 Km from Sanjay Lake • Indications that groundwater have been contaminated with heavy metals • Recent fires have caused serious air pollution to India's capital with biogas trapped beneath Ghazipur dump considered to be a ticking bomb	(Nandi, 2014; Hindustantimes, 2016)

West Java Province, in Indonesia 2005	• Leuwigajah dumpsite collapsed, for the third time, after three days of heavy rainfall • A 3-week rescue work wasn't able to find any survivor, after the fatal accident, as works were massively hindered by the fires • Almost 2.7 millon cubic meters of waste went down hitting a settlement close by and covering a distance of 950 meters and an area of 75 ha • At least 69 houses were destroyed and 147 people were killed. • Waste split down Landslide left different environmental problems, such as odors, air pollution from the fires, surface water contamination and Waduk Sagling Dam Lake, used for drinking water and canals utilized in agriculture and industry, was contaminated as leachate found its way to it	(Damanhuri et al., 2005)

2. Environmental and health impacts of dumpsites

Several studies were conducted to establish the association between the registered increase in disease incidents, environmental deterioration and open dumpsites. In Islamabad, a study indicated that the vegetation status is suffering in terms of biodiversity due to the open dumping of wastes. (Yasmin et al., 2014). This is mainly attributed to the release of exchangeable cations during mineralization of organic matter (Anikwe, 2002). Soil pH is always an important parameter to monitor as acidity and alkalinity can alter the bioavailability of metals, their ability to leach into surrounding areas and underlying water sources and by that would affect human exposure and the resulting metal toxicity (Chimuka et al., 2005). The pH and TDS values of dumping sites were relatively higher as compared to control sites. Additionally, the TDS concentrations observed at the disposal site were very high. Elevated levels of TDS in soil indicates an increase in salt concentration and thus reduces water availability for plant uptake. The latter disrupts the osmotic pressure which would hinder the plant growth (Yasmin et al., 2014). A summary of the various environmental and health impact of open dumpsites is presented in Table 2.

Heavy metals are known as Potentially Toxic Elements (PTEs) that are of public health concern especially when exposed to them at concentrations that exceed permissible environmental and human limits. They include chemical elements such as lead, mercury, cadmium, arsenic, zinc, chromium, nickel and copper. PTEs are released into the environment through burning of waste which is a repetitive activity done in open dump sites. PTEs are found in dumpsites receiving E-waste as mercury (Hg), for example, leaches from batteries and fluorescent tubes disposed with MSW. Lead (Pb) is one of the most widely distributed PTEs in dumpsites. It is released by disposal or burning plastics, rubber and lead treated wood (UNEP, 2014). The effects of PTEs were evident in Dandora municipal waste dumping site, located to the East of Nairobi that was considered to be the third world's most polluted areas in 2007. People living near the Dandora dumpsite had elevated concentrations of heavy metals and suffered from different types of diseases. Clinical symptoms were mainly related to respiratory diseases, gastrointestinal problems elevated lead blood levels and abnormalities in red blood cells (RBCs) (Table 2) (Kimani, 2007).

Studies conducted to investigate the health outcomes have confirmed the positive correlation between increased morbidities and exposure to dumpsites. In some areas, open dumpsites contributed in re-emergence of communicable diseases, mainly cholera and malaria, especially because of the spread of different types of mosquitos and parasites. (Pondhe et al., 2015). Other studies showed excess relative risks (ERR, %) in exposed vs unexposed people for all-cause mortality in both sexes, liver cancer, stomach and lung cancer (in men), low birth weight or preterm birth, congenital anomalies of the internal urogenital system and of the central nervous system (Table 2) (Martuzzi et al., 2009; Kass & Gilbearth, 2006).

Table 2: Environmental and health impacts of dumpsites

Location/year	Impact	Reference
Islamabad 2014	• At the control site, vegetation reached 44 different species; however, these species were reduced to 32 in the area in close proximity with the open dumping site. • Organic matter was found to be relatively high at the open dump sites with an average mean value of 1.54 contributing to an increase in pH of the soil • The pH value of dumping sites was relatively higher as compared to control sites with an average pH of 8.3–9.1. • TDS concentration observed at the disposal site was very high and varied between 40 and 450 ppm	(Yasmin et al., 2014)
Dandora MSW dumping site in Nairobi, Kenya 2007	• Soil samples taken from locations adjacent and within the dumpsite showed high levels of heavy metals, particularly, lead, mercury, cadmium, copper and chromium. • Mercury (Hg) in soil samples exceeded the WHO acceptable exposure level of 2 ppm • Cadmium (Cd) adjacent to the site was eight times higher than those prescribed by the Dutch and Taiwanese authorities (5 ppm). • Copper concentrations greatly exceeded the prescribed standard values and the natural range (7 and 80 ppm) • 50% of the examined children who live and attend schools near the dumpsite had respiratory problems and blood lead levels equal to or exceeding internationally accepted toxic levels (10 μg/dl of blood) • 30% had size and staining abnormalities of their red blood cells • Clinical evaluation of information collected on the children and adolescents living within the vicinity of the Dandora waste dumping site indicated highest incidence of respiratory (upper respiratory tract infections (URTIs), chronic bronchitis and asthma), gastrointestinal and dermatological diseases. • Other clinical effects such as headaches, chest pains, gastrointestinal problems and muscular weakness were also reported	(Kimani, 2007)
India, Sangamner city	• The residents perceived malaria and diarrhea to be the most prevalent diseases • Increased morbidities and disrupted environment as a result of birds, odor, aesthetic disturbance, flies, eye irritation, breathing problems, water & soil contamination, and plastic pollution • Findings showed that half of the respondents had changed their source of drinking water and more than the half suffered from an illness which they attributed directly to contamination resulting from waste dumping sites. • Residents perceived malaria and diarrhea to be the most prevalent diseases; cases of eye irritation breathing problems were also reported	(Pondhe et al., 2015)

	• Odor, aesthetic disturbance, flies, water contamination, soil and plastic pollution were found to be a result of the open dumps and contributed in increasing morbidities	
Campania region, Italy	• Results indicated that cancer mortality and congenital anomalies were higher than regional averages, and were positively correlated to waste exposure within the area at the level of municipalities. • Statistically significant excess relative risks (ERR, %) in exposed compared with unexposed municipalities were found for all-cause mortality in both sexes and liver cancer. • Increased risks were also found for all cancer mortality (both sexes), stomach and lung cancer (in men) • Statistically significant ERRs were also found for congenital anomalies of the internal urogenital system and of the central nervous system)	(Martuzzi et al., 2009).
Alaska Native villages	• Adverse pregnancy outcomes associated with open dumpsites were investigated in a retrospective cohort study evaluated in Alaska Native villages. Outcomes included low or very low birth weight, preterm birth, and intrauterine growth retardation • Infants from mothers in villages with intermediate and high hazard exposed villages (odds ratio (OR) : 1.73 and 2.06 respectively) had a higher proportion of low birth weight infants than did infants from mothers in the referent category • More infants born to mothers from intermediate and high hazard exposed villages (OR: 4.38 and 3.98 respectively) suffered from intrauterine growth retardation. On average, infants weighed 36 g less and 55.4 g less when born to highly exposed mothers than did infants in the intermediate and low exposure groups, respectively	(Kass & Gilbearth, 2006)

D. Remediation strategies

As demonstrated earlier, the health and environmental implications associated with SWM are mounting in urgency. This makes managing open dumpsites a priority that requires fast interventions to prevent further dramatic incidents. Thus, closing the world's dumpsites is now becoming a central element for the progress of the sustainable development goals (SDGs) (Mavropolous et al,2016).

Maintaining proper sanitation and SWM, are of equal importance with establishing potable water, shelter, food, and energy. It is important to keep in mind that closing or remediating a dumpsite is not a simple task to plan and implement. It is essential to have an alternative waste management system in the first place. The latter demands the presence of adequate planning, enough financial resources, and the ability to reach political and public consensus. These basic requirements are difficult to meet and are considered main obstacles faced by many countries attempting to manage their open dumpsites (Mavropoulos et al, 2016).

Developing a plan for closure of any open dumpsite necessitates starting with a site assessment. This step is crucial to evaluate the extent of the contamination that has occurred. Site assessment includes the following:

1. Looking at the inventory of natural resources around the site
2. Assessing the geology and hydrology of the area when it comes to the depth of groundwater and the distance of the dump to the nearest water source
3. Keep track of the type and volume of wastes disposed

4. Investigating the incidents that have previously occurred on site
5. Determining the points of leachates and investigating the impact of the dispose solid wastes on water and soil quality

A final cover is always necessary as it serves as a barrier to reduce water percolation and gas migration, prevents the emergence of vector borne diseases, minimizes odors and supports vegetation. The final soil cover is designed to a specific depth that is at least 0.60m (2ft.). It is normally composed of compacted and un-compacted soil layers that are usually a minimum of 0.45m (1.5 ft.) and 0.15m (0.5 ft.), respectively. A definite step in any management technique is implementing drainage control systems. The latter would mitigate erosion, minimize leachate percolation and, as a result, would secure the integrity of the soil cover. Leachate and gas control systems are usually canals that collect the leachate then direct it towards a leachate retention basin down-gradient of the site (UNEP, 2005).

Waste characterization study is first conducted to determine the percent composition of the generated refuse. Wastes are then excavated from the dumpsite and segregated into four categories, which are the soil/clay fraction, combustibles (paper, textiles, rubber, wood, plastic films), recyclable incombustibles (metal, glass, dense plastic other than films) and others. The recovered material is finally transferred to a treatment and recovery facility for further processing. The land is stabilized and rehabilitated. This option showed great advantage in cities in need for the land asset where the revenues collected from mining showed higher dollar values than the cost of landfill mining process (Dubey et al.,2016). Re-using your land is best when wastes are removed or else it should be left intact for 5 years before use. It is advised not to construct residential buildings at the site as methane, can build up under the site cover and migrate into new buildings or surface soil pockets; thus, risking explosions and exposure to toxic chemicals; Ground can subside and erode as wastes deteriorate and settle underneath forming holes and depressions (ADEC, 2001).

Common methodologies have been utilized throughout the history of dumpsites rehabilitation. However, the common feature within all is the post closure management phase and monitoring for optimal results and continual improvement. Post-Closure care is needed to ensure environmental impacts are controlled and public health and safety are adequately maintained, for a specified number of years after closure. This step includes performing continual maintenance of the integrity (settlement, slope instability and vegetation cover, run-off drainage controls) of the cover layer; Monitoring leachate management system and groundwater wells (Figure2) (ISWA,2007).

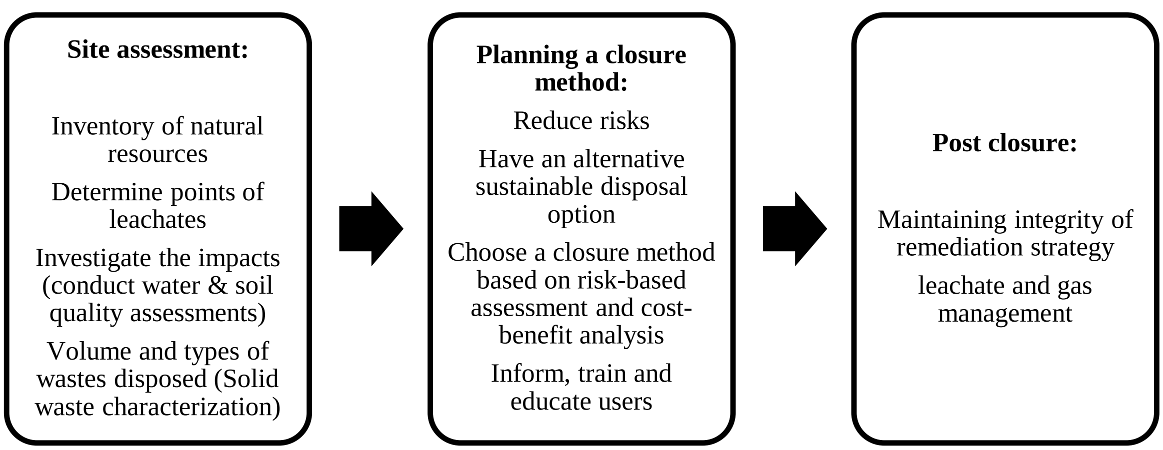


Figure 2: Brief process for closing an open dump

There are in principle 3 main methods available to close or remediate an open dump: Closing by covering the waste (in-place method) or closing by removing the waste from the site (evacuation), landfill mining and closing by upgrading the dump to a controlled dumping site or sanitary landfill (up-grading method).

1. In place and evacuation method

These methods are the most commonly used options. Wastes present on site are removed, temporarily in the case of in-situ closure, critical slopes are stabilized, drainage control systems are installed, soil cover is placed, compacted and graded and leachate and gas management systems are installed (ISWA, 2007). Upon removing the wastes completely, a sanitary landfill, or a waste incineration plant is needed to receive the excavated refuse. Leachate and gas management systems are sometimes not installed which shortens the success of this method, incase dumping persisted, as leachate would continue to form and percolate with minimal mitigation (Table 3).

2. Landfill mining

Technically, dumpsite mining employs sorting out the mixed material according to their size by using a screening machine. The oversized materials are prescreened by another sorting machine which separates the larger objects like tires and rocks from cardboards and other smaller unearthed materials (Joseph et al., 2008).

Landfill mining is a developing technology for waste management. There are several objectives behind dumpsite mining starting with conservation of landfill space, reduction in landfill area and waste volume, elimination of potential contamination source, rehabilitation of dumpsites, energy recovery from recovered wastes, reuse of recovered materials, and reduction in waste management costs. Landfill mining is a mechanical process, involving excavation and screening, to recover soil, recyclable materials and a combustible fraction of the waste. The process starts by using an excavator to dig up the waste and transport it onto floor conveyor belts which move the wastes to a sorting machine, afterwards. Two rotating trommels are then used to separate the refuse by size. Large appliances are first sorted out, then soil fraction pass through the wholes of the small trommel allowing the collection of recyclable materials and non-biodegradable fractions left on the screen. Final step is passing the waste on a second conveyor belt where the left metallic debris is sorted out by an electromagnet. The recovered material can be used differently dependent on the aim of the project. Soil fraction, which usually is the highest percentage of the recovered material, is used as a daily cover cap for the landfill. The remaining material may be recovered to produce energy or processed for recovery of recyclables. However, site specific conditions are key pillars for the success of landfill mining. In addition to the efficiency and effectiveness of the technology implemented for mining, it is important to assess the extent of the waste degradation, the composition of the dumped refuse and the present market ability to accept the recyclables recovered (Rosendal, 2009).

Landfill mining has been proven a successful technique in different countries. In India, for example, the effectiveness of landfill mining was investigated on two dumpsites, Kodungaiyur and Perungudi. Results supported the feasibility of landfill mining as a methodology for lifetime expansion of the dumps, remediation and for use of the recovered fine fraction as compost for non-edible crops or as cover material to future landfills (Table 3) (Selvam et al., 2003).

3. Upgrading method

Upgrading method is a process of conversion from an open dump to a controlled dumpsite then an engineered landfill until reaching a sustainable landfill. Controlled dumping means that disposal will be on a site previously used for open dumping. Thus, preparation of the area will consist of leveling and compacting existing garbage heaps and construction of drainage canals/ ditches. Operational procedures include limiting the working area, application of daily cover and installation of litter barriers. The facility also monitors for incoming waste volumes, water quality, condition of drainage systems and others. This transition would eliminate uncontrolled fires, site accidents, would allow preliminary waste handling techniques and drainage control measures and control will be exercised over scavenging operations which would help material recovery (Table 3) (Joseph et al., 2008).

A further step from controlled dumping is upgrading the site to an engineered landfill, which is a gradual adoption of engineering techniques. An engineered landfill aims at controlling and redirecting surface water entering the deposited wastes by installing surface drainage system, spreading of soil materials to cover wastes, compacting wastes into smaller layers, collecting leachate away from wastes into lagoons, passive venting of landfill gas out of the wastes and isolating of wastes from the surrounding geology (Joseph et al., 2008).

Table 3: A summary of the main dumpsites remediation strategies

Methodology	Process	Advantages	Limitations
In-place Closure (In-situ)	• The disposed material is removed • The ground is lined with composite material • A leachate drainage system is installed, along with a gas control unit • Wastes are not typically recovered or treated, and are generally redeposited in the original site following its remediation • Site is capped with a final soil layer and revegetated	• Flexible, since the wastes can be treated or recovered, if the budget permits such an action • Permits the installation of a leachate drainage system • The site would be transformed into a controlled dump or engineered landfill • The dump site can be rehabilitated to serve commercial purposes following closure • Limits the amount of soil, water, and air pollution emanating from the site	• Waste volume would not be significantly reduced • Forfeits the potential of recovering raw material • A landfill or disposal site would be needed to accept the excavated refuse, temporarily • The land would continue to house the wastes dumped into it

Evacuation method (Ex-Situ)	• The land is stabilized through grading • A cover is applied over the wastes • Gas emissions are regulated • Leachate is collected	• Relatively inexpensive and easily applicable • Mitigates gas emissions • Supports vegetation • Prevents the escape of rodents • Reduces leachate formation	• Limits the opportunity to recover energy or resources • Leachate would continue to percolate into the soil, since the site would not be lined • Could be impacted by heavy rains if a drainage system isn't implemented
Landfill mining	• A waste characterization study is conducted to determine the percent composition of the generated refuse • Wastes are excavated from the dumpsite • The recovered material is then transferred to a treatment and recovery facility for processing • The land is stabilized and rehabilitated	• Generate significant revenues from recovered materials, such as ferrous metals, aluminum, plastic, and glass, that could be sold if markets exist for these materials • Reclaimed soil can be used on site as daily cover material on other landfill cells. Also, a market might or reclaimed soil could be used in other applications, such as compost • Allows for the recovery of raw material and the use of	• Requires significant financial investments • Unlikely to appear economically profitable if when recovered materials are of poor quality • Not always applicable; it must occur after local wastes had been characterized • Recovered materials need to undergo chemical analysis and treatment • A landfill or disposal site would be needed to accept rejects

		Combustible reclaimed waste to produce energy • Reducing the size of the landfill "footprint" through cell reclamation or make land available for other uses	
Upgrading method	• Typically involves the in-situ treatment of wastes, the lining of the dump's bed, capping of wastes, the development of a leachate drainage pipe, and the management of gas emissions.	• Allows for the aggregation of the wastes located in all dumps in a single location • Halts soil and water contamination • Long term solution • Could serve a large area • Could be utilized to generate electricity • The dumpsite can be rehabilitated to serve commercial purposes following closure	• Public opposition • Requires the construction of a wastewater treatment plant for the leachate • Highly technical and expensive to operate and maintain • Consumes significant amount of land • limits the opportunity to recover raw material • Could potential become a permanent solution • Requires financial resources and trained physical resources to ensure sustainability

CHAPTER III

METHODOLGY

A. Description of the studied sector

Few years before the 1975 war began, Beirut upgraded its treatment and disposal infrastructures. A composting plant and an incinerator were built in Karantina and Amrouseih, respectively. The city was also equipped with non-compacting refuse collection trucks. However, after the war era, infrastructure suffered. Two dumpsites were created in the Normandy and Bourj Hammoud as the capital's MSW and destruction waste was transported to the areas. Outside Beirut, the population relied on uncontrolled dumping and burning of wastes. The first waste crisis came up in 1997, the Amrouseih incinerator was destructed as civilians protested against its emissions and the disposal activities happening in Bourj Hammoud. The management of solid wastes was then identified as a priority area for intervention. Accordingly, an emergency plan was designed, meanwhile attempts to develop a sustainable SWM plan were still ongoing. The plan distributed SWM activities between three different private companies (Azzi, 2017). Additionally, in 1997, the government agreed on opening the Naameh landfill, which was supposed to receive 3M tons of waste from Beirut and Mount Lebanon for the following 10 years. However, the landfill reached its full capacity in 2001 for several reasons. Naameh landfill received 600,000 tons per year since its opening. Bsalim landfill was supposed to share the amount of bulky items and inert material wastes received with Naameh, but never opened at the time needed and as intended. Bsalim landfill was delayed until it was constructed as environmental impact assessment showed a high risk of ground water contamination; Bsalim landfill was then only allowed to accept inert material from Naameh landfill (Saadeh & Mikhael, 2015). Additionally, organic material piled up at a fast pace as the composting capacity of Naameh landfill was not enlarged as planned. Recyclable wastes also contributed to exploiting the Naameh capacity as recyclables were supposed to be accepted by Karantina and Aamrousieh, but the latter did not go as planned. Concurrently, the Naameh landfill was long overdue for closure because of the lack of other alternatives (Cesa, 2017).

The second waste crisis happened in 2015, the Naameh landfill was closed by force from the nearby residents. The aftermath of the Naameh's closure was tragic. Dumping and burning became the most adopted solutions for individuals to handle their waste as the government still lacked any planned substitute. Trash piled in the streets and open burning of wastes in unauthorized places started to be a very common activity jeopardizing the health of residents. It has been established that open burning poses serious health risks like heart disease, cancer, skin diseases, asthma, and respiratory illnesses. Especially that its commonly being practiced in poor areas putting the vulnerable population at higher risk as they are the least equipped to mitigate its health impacts (Human Rights Watch, 2017).

According to a 2017 Ministry of Environment and UNDP report, there are more than 941 open dumps across Lebanon, including 617 municipal waste dumps, more than 150 of which are being burned on a weekly basis (Fakih, 2018). A comparative cross-sectional study was done on people in close proximity (100 m radius) with a major open dump, where wastes was also being burnt. It was found that the prevalence of acute health symptoms was greater among the exposed workers than the non-exposed workers. Symptoms included gastrointestinal, respiratory and dermatological cases. Upon controlling for confounding variables, such as age, insurance, family support, residence near dumpsite, work site, and smoking, a minimum odds ratio (OR) for developing acute physical symptoms of 4.30 was obtained when comparing the exposed population to the non-exposed (Chaaya et al., 2017).

It was thought that the solid waste management crisis started in 2015; however, the root of the problem goes back several decades. The crisis gained inertia after the Naameh landfill closure but is actually a result of poor governmental planning and management patterns, inadequate support and oversight of areas outside Beirut and Mount Lebanon and overuse of landfills with the reliance on the private sector to mitigate current situations. Most importantly, the failure to plan an alternative for the proper disposal of solid wastes throughout the years was the keystone that lead to the catastrophic environmental impacts. Historically, waste management in Lebanon has not been based on environmentally sound and public health practices, and important decisions were often made in a reactive manner jumping from one emergency plan to the other (Human Rights Watch,2017).

B. Description of the study area

The scope of this research includes the Iklim El Teffah region, located in the south of Lebanon. It consists of 10 villages governed by 9 municipalities. The population of Iklim El Teffah is approximately 39,000 citizen, generating approximately 33 tons of municipal wastes daily on the basis of a generation rate of 0.85kg/capita /day. Villages resort to open dumping as their main disposal method whereby 7 active dumps are currently being used.

C. Study Design

1. Sampling plan

In order to assess the environmental impacts of open dumpsites, soil and water samples were collected and analyzed. Soil samples were collected once during the wet season (February) and the dry season (June) at each of the seven dumpsites. A total of 22 soil samples were thus collected to capture the spatial, temporal, and inter-dump variability (Table 4). Sampling sites were selected to achieve the best possible compromise between representativeness and operational feasibility in terms of accessibility and topography (Netaji et al., 2017; Saha et al., 2015). Samples were collected using a spade at a depth 0 to 15cm. At every location, several samples were collected in a random pattern. Subsamples were all sifted over a bucket and then mixed thoroughly until an individual composite samples were formed. Approximately 1 Kg of the soil samples were emptied into a polyethylene plastic bag. Only three quarters of the bag was filled and then placed in a cooler with ice packs to be transported to the laboratory. During the wet season, soil samples were spread and left to air dry over three days (Appendix A).

Surface water samples were collected once during the wet and dry season. During the wet season, a total of 9 water samples were collected which included 8 samples from springs and one sample from Sainiq river waters (Table 4). In the dry season, only 5 samples were collected from spring water as the other 4 sites were not flowing. Samples were numbered according to tables 6 &7.

Table 4: Distribution of water and soil samples

Type of Sample	Source		Number of Samples	Total
Water	Wet season	Sainiq River	1	9
		Spring Water	8	
	Dry season	Sainiq River	0	5
		Spring Water	5	
Soil	At each dumpsite (7 Sites)		7	22
	1Km away		7	
	2Km away		7	
	Far from any dumpsite (control)		1	

Table 5: Villages where dumpsites are located

Number	Sample Location
V1	Kfarfila
V2	Kfarmilki
V3	Jbaa
V4	Jarjooa
V5	Arab Salim
V6	Houmine El Fawqa
V7	Ain Kana

Table 6: Soil samples

Number	Sample Location
S1	Kfarfila Dumpsite
S1a	1 Km from Kfarfila
S1b	2 Km from Kfarfila
S2[1]	Kfarmilki Dumpsite
S2a	2 Km away from Kfarmilki
S3	Jbaa Dumpsite
S3a	1 Km away from Jbaa
S3b	2 Km away from Jbaa
S4	Jarjooa Dumpsite
S4a	1 Km from Jarjooa
S4b	2 Km from Jarjooa
S5	Arab Salim Dumpsite
S5a	1 Km from Arab Salim

S5b	2 Km from Arab Salim
S6	Houmine El Fawqa Dumpsite
S6a	1 Km from Houmine El Fawqa
S6b	2 Km from Houmine El Fawqa
S7	Ain Kana Dumpsite
S7a	1 Km from Ain Qana
S7b	2 Km from Ain Qana

[1]: S2b overlaps with S3a as villages and dumps are near to each other

Table 7: Water samples

Number	Sample Location
W1	Spring Ebn Akil in Kfarfila
W2	River near Jbaa
W3	Spring Jlyakha in Jbaa
W4	Spring Akita in Jbaa
W5	Ain El Fawka in Ain Biswar
W6	Spring Houmine El Fawka
W7	Spring Houmine El Fawka downstream
W8	River passing Kfarmilki
W9	End of Sainiq river

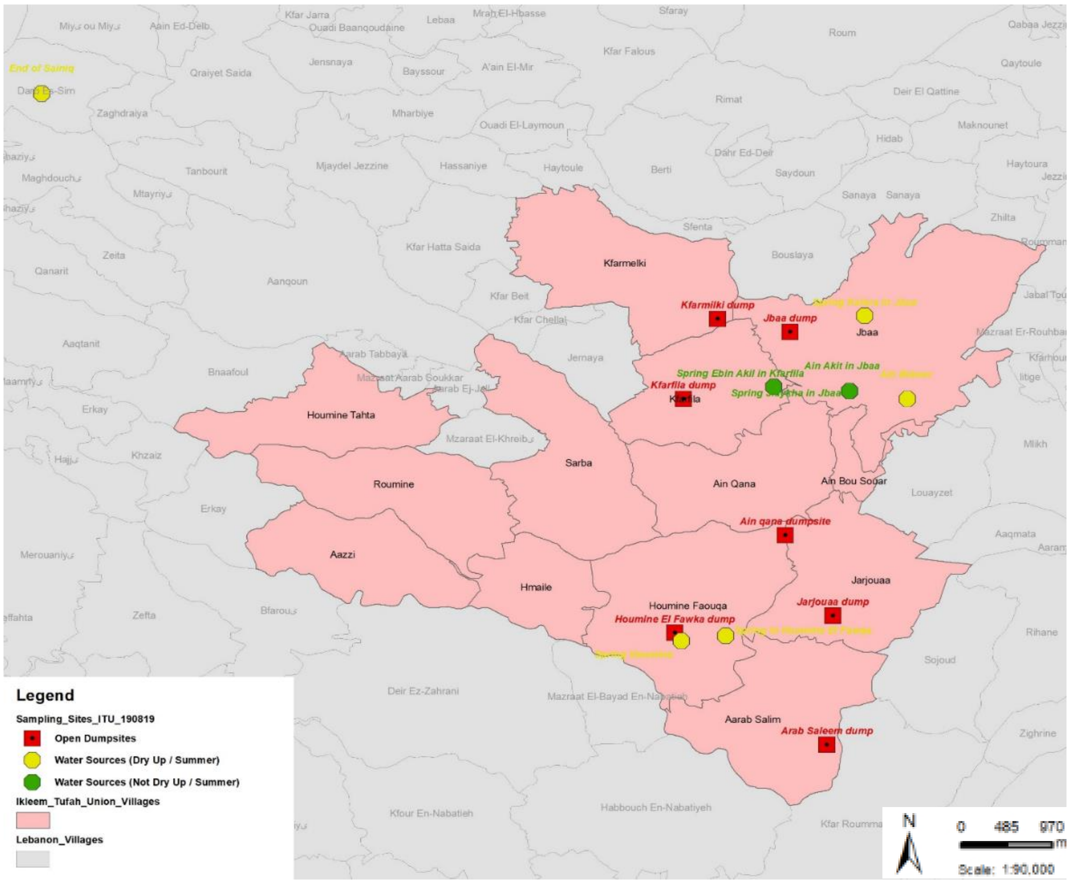


Figure 3: Soil and water sampling sites

2. Analytical Procedures

In preparation for sampling, all equipment is to be thoroughly cleaned. Equipment for trace element analysis and collection bottles were washed in dilute (0.1 percent) low phosphate soap and tap water, then rinsed with dilute (5 percent) nitric acid solution and deionized water (UNEP&WHO, 1996). Samples were transported to the American University of Beirut laboratories for chemical analysis. Various microbiological and physio-chemical parameters were examined for soil and water samples including the parameters presented in Table 8 (Appendix B). Metals were analyzed by an Inductively Coupled Plasma-Mass Spectrometer (ICP). pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured on site by membrane electrode method. Results were compared with the controls samples, as well as the United States Environmental Protection Agency (USEPA) and World Health Organization (WHO) standards (Netaji et al., 2017; Saha et al ., 2015; Chaudhari, 2013).

Table 8. Analysis methods for various indicators (Hach, 2014)

Indicator	*Type of analysis*	*Hach method*	*Reference method*
pH(Water & Soil)	Potentiometry	8156	EPA 420.1
TDS (Water & Soil)	Potentiometry	8277	SM 2540 C
EC (Water & Soil)	Potentiometry	8160	SM 2510 B
COD (Water & Soil)	Closed Reflux/Colorimetry	8000	40 CFR 136.3
DO (Water)	Titration for winter analysis DO meter for summer analysis	8215	SM 4500-O C
Sulfates (Water & Soil)	Colorimetry	8051	ASTM D516-90, 02
Nitrates (Water)	Colorimetry	TNT840	EPA 354.1/SM 4500-NO 2 B
Ammonia (Water)	Colorimetry	8038	SM 4500-NH 3 C
Ortho-phosphates (Water & Soil)	Colorimetry	8480	EPA 365.1/365.2
Metals (Water & Soil)	ICP-MS2	EPA 200-8	
Total Nitrogen (Soil)	Nessler	8075	
Total & fecal coliforms (Water & Soil)	Membrane filtration technique (Millipore)	8001A	SM 9221 E

1 ICP-MS = Inductively Coupled Plasma-Mass Spectrometer

3. Quality control and sample preparation

Upon each analytical procedure done, a blank, standard, sample duplicate and sample spiked were prepared for every ten samples. During the wet season, soil samples were spread and left to dry three days prior analysis. Soil samples were extracted by water for a day before reading the sulfates and phosphates concentrations. Soil samples collected during the wet season, a 1:5 dilution was done before reading on spectrophotometer to reduce any interference. Six microwave digestions were done for soil samples before determining the heavy metal concentrations on the ICP. Water samples were filtered before carrying on with the analysis.

D. Environmental and health risk assessment

Various indices were utilized to evaluate the risks on environment and human health posed by the contaminated soil and water. The extent of heavy metal pollution was quantified using the pollution load index (PLI) as shown in equations 1 & 2. The ecological risk assessment of heavy metals in soil was also be performed using the ecologic risk factor (ER) and the total ecologic risk (RI) as shown in equations 3 & 4 (Hakanson ,1980). The latter is important in identifying the samples having the most impact on the ecosystem because of their high heavy metal contamination levels. Geo-accumulation index (Igeo), that serves to compare the current contamination with background preindustrial geochemical concentrations of heavy metals, was be quantified using equation 5 (Muller, 1969). The Geo-accumulation index serves as an indicator for the presence of anthropogenic contaminant deposition in soil samples that would lead to toxicity because of the bioaccumulation phenomena (Barbieri, 2016). Tables 9 & 10 illustrate the classifications of the indices. Water quality was assessed based on water quality index (WQI) as shown in equation 6. The measurement scale classifies the water quality as "very bad" if the WQI falls in the range of 0 to 25, "bad" if it ranges from 26 to 50, "medium" if it ranges from 51 to 70, "good" if it ranges from 71 to 90 and "excellent" if it falls in the range of 91 to 100 (Pesce and Wunderlin 2000; Jonnalagadda and Mhere 2001). Table 11 indicates the different parameters that were used in the evaluation process, as well as their relative weights (Pi) and the normalization factors (Ci)

(1)	$PLI = (CF1 \times CF2 \times \ldots.CFn)^{1/n}$	Where: *CF* is the contamination factor of a particular heavy metal and n is the count of the multiplied contamination factors
(2)	$CF = \frac{C\ metal}{C\ reference}$	Where: *C metal* is the concentration of a particular heavy metal in the contaminated area and *C reference* is the concentration of a particular heavy metal in an uncontaminated area (control sample S8)
(3)	$ER = Ti \times CF$	Where: T_i is the potential ecologic risk coefficient of a particular heavy metal. Coefficients based on toxicity are 40 for Hg, 30 for CD, 10 for As, 5 for Cu, Pb and Ni, 2 for Cr and 1 for Zn (Hakanson, 1980).
(4)	$RI = \sum ER_n$	Where: ER_n is the ecologic risk of every heavy metal (n is the number of metals)
(5)	$Igeo = log2 \times \frac{Cn}{1.5 \times Bn}$	Where: C_n is the concentration of a particular heavy metal in contaminated area, B_n is th geochemical background value for each heavy metal found by Turekian et al., (1961) for major elements in earth's crust and 1.5 is a coefficient used to amplify very low values during comparison
(6)	$WQI = \frac{\sum Ci\ x\ Pi}{\sum Pi}$	Where: n is the number of parameters Ci is the value assigned to the parameter (i) after normalization Pi is the relative weight assigned to each parameter which ranges from 1 (assigned to the parameter of the smallest impact on the quality of water) to 4 (assigned to the parameter of the most importance)

Below is an example of the indices calculated for cupper in S1.
CF was calculated using equation (2); PLI is the sum of every metal's CF:

$$\mathrm{CF} = \frac{\mathrm{C\ metal}}{\mathrm{C\ reference}} \qquad (2)$$

CF of Cu in S1= (Mean Cu concentration)/ (Mean concentration of control)

$$CF = \frac{40.55}{7.28} = 5.57$$

Ecological risk was calculated according to equation (3) where Ti is the potential ecologic risk coefficient of the particular heavy metal (Hakanson, 1980). Total ecological risk was then calculated as it's the sum of ER of each heavy metal.

$ER = Ti \times CF$ (3)

$$ER = 5.57 * 45 = 27.8$$

Igeo index was calculated using equation (5) where Cn is the concentration of a particular heavy metal in contaminated area, Bn is the geochemical background value for each heavy metal set by Turekian et al (1961)

$Igeo = log2 \times \frac{Cn}{1.5 \times Bn}$ (5)

$$Igeo = Log(2) * (\frac{40.55}{1.5 * 45}) = 0.18$$

Results are then interpreted according to the classifications in tables 9&10

Table 9: Hakanson classification for the potential ecological risk index (RI).

RI value	**Grades of ecological risk**
RI < 110	Low risk
110 ≤ RI < 200	Moderate risk
200 ≤ RI < 400	Considerable risk
400 ≤ RI	Very high risk

Table10: Index classifications

Class	**CF [1] value**	**Quality class**
1	CF < 1	Low
2	1 ≤ CF < 3	Moderate
3	3 ≤ CF < 6	Considerable
4	CF ≥ 6	Very high
Class	**Igeo[2] value**	**Quality class**
0	Igeo ≤ 0	Uncontaminated
1	0 < Igeo < 1	Uncontaminated to moderately contaminated
2	1 < Igeo < 2	Moderately contaminated

3	2 < Igeo < 3	Moderately to heavily contaminated
4	3 < Igeo < 4	Heavily contaminated
5	4 < Igeo < 5	Heavily to extremely contaminated
6	5 < Igeo	Extremely contaminated

[1] Contamination factor (Håkanson, 1980).

2 Geo-accumulation index (Müller, 1969).

Table 11: The variables used in the calculation of the WQI with their relative weights and normalization factors (Kannel et al., 2007)

	Weights (Pi)	Normalization factor (Ci)										
		100	90	80	70	60	50	40	30	20	10	0
pH	1	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	3-12	2-13	1-14
EC (micro S/cm)	1	<750	<1000	<1250	<1500	<2000	<2500	<3000	<5000	<8000	<=12000	>12000
DO (mg/L)	4	>=7.5	>7	>6.5	>6	>5	>4	>3.5	>3	>2	>=1	<1
TDS (mg/L)	2	<100	<500	<750	<1000	<1500	<2000	<3000	<5000	<10000	<=20000	>20000
SO4 (mg/L)	2	<25	<50	<75	<100	<150	<250	<400	<600	<1000	<=1500	>1500
NH3-N (mg/L)	3	<0.01	<0.05	<0.1	<0.2	<0.3	<0.4	<0.5	<0.75	<1	<=1.25	>1.25
N03-N (mg/L)	2	<0.5	<2	<4	<6	<8	<10	<15	<20	<50	<=100	>100

Studies previously done to estimate relative risks show some weaknesses in the observations related to the quality of exposure assessments and the difficulty of accounting for confounders. However, we based our calculation for health impacts on the relative risks reported by Fazzo et al., (2011) and Forastiere et al., (2009). These risks were calculated for different types of cancers and congenital malformations on residents living within 2 km of the landfills or dumpsites.

The population at risk to develop cancerous and noncancerous health effects was calculated using equation (7) that is recommended for the assessment of European dumpsites (WHO, 2015).

$$AC = Rate \times ER \times Popexp \qquad (7)$$

Where AC is the attributable cases that would develop a cancerous or noncancerous health effect, Rate is the background incidence in the general population being unexposed, ER is the excess risk in the exposed population (relative risk - 1) and Popexp is the number of exposed people (WHO, 2015).

E. Management plan

The multi-criteria decision analysis (MCDA), AHP, was the decision-making tool to benchmark the remedial practices to be utilized for the rehabilitation of the selected dump site(s). Its purpose is to compare remediation alternatives against each other to find the best alternative, based on weights and sensitivity grades assigned to the indicators. One plan was then agreed on that would suit all the dumps in the studied area.

AHP method was used to assess the most suitable remediation plan for the dumpsites. The process is divided into two steps. First step is to calculate the performance values and weights of the alternatives and criteria, respectively; Second step is to assess the consistency ratio (CR) of the developed pairwise comparison matrices. The alternatives were assessed based on three criteria. First criteria is the environmental sector whereby long term effect of the alternatives was taken into consideration, their ecological footprint (by products, conservation of natural resources, life span). Second criteria is the economic aspect of the alternative whereby assessment was based on the economic burden in terms of cost and equipment needed for the implementation process; additionally, revenues collected and number of employment opportunities created were taken into consideration. Third criteria is the social aspect taking into consideration the population's acceptance of the suggested alternative, number of workers needed and training and safety measures required. Four alternatives were assessed: In situ closure (A1), Upgrading into a landfill (A2), Landfill mining (A3) and ex situ site closure (A4) (Table 12).

Table 12: The decision matrix

	Economical (C1)		Environmental (C2)			Social (C3)	
Alternatives	Cost of implementation	Revenues	By product (Leachate, gas)	Life span	Conservation of natural resources	Number of workers needed	Acceptance
Closure in situ (A1)							
Upgrading to a landfill (A2)							
Landfill mining (A3)							
Closure ex situ (A4)							

Priorities were calculated based on scale of relative importance set by Saaty (1980) (Table 13).

Table 13: Scale of relative importance (Saaty,1980)

Intensity of importance	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over the other	Experience and judgement slightly favor one activity over the other
5	Essential or strong importance	Experience and judgement strongly favor one activity over the other
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over the other is of the

		highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

CHAPTER IV

RESULTS AND DISCUSSION

A. Soil Analysis

1. Physiochemical parameters

The pH parameter is an indicator of the degree of acidity or alkalinity of soil. It is considered a critical variable that majorly affects the physical chemical and biological properties of the soil. Soil fertility and plant growth are directly affected by manipulation in degree of acidity. The latter affects microbial reactions taking place, plant metal uptake and availability of essential nutrients in soil. The optimal pH for plant growth is considered to be within the neutral range (6.8-7.5) (Obasi et al., 2012). The mean pH values of the collected soil samples were found to be very close ranging between 8.3 and 8.7. In general, samples had pH values similar to the one recorded for the control, having a mean value of 8.4 (Table 14). Samples collected in winter had pH values slightly higher than ones collected during summer. According to Victor et al., (2006), activities of microorganisms are responsible to elevate the pH levels of soil. The latter justifies our pH findings values especially that bacterial colonies in soil were doubled during winter season. Additionally, rainfall plays an important role in increasing leachates percolation over time into the soil. Our results suggest that the dumpsites and the other soil samples, including our control, are mostly alkaline in nature. In this alkaline medium some micronutrients (Ca, Mg, K, Fe ....)

become less available which directly retards plant growth and disrupts plant cycles. Our findings are in line with other results reporting soil properties affected by dumpsites (Uba et al., 2008; Badmos et al.,2017); thus, the present dumpsites could have contributed to the increased soil pH. Due to the mineralization of the high levels of organic matter present, cations are released, which buffers the soil pH levels to prevent excessive changes (Folaranmi et al., 2007). However, the calcareous soil nature present is also another factor that affects soil acidity especially that the control samples came out to be alkaline in nature also.

Salinity is considered a critical factor in agricultural land as it has a vital role in maintaining nutritional balance for plants and altering soil permeability. Salinity is determined by measuring the mass of total dissolved solid and electric conductivity of soil water extracts (Corwin & Yemato , 2019). The mean TDS values ranged between 32 and 192 mg/L in dumpsite soils. Values were, generally, decreasing as we went further away from the dumpsites. The control sample was found to have a mean value of 25 mg/L (Table 14). This elevated level indicates that the waste refuse has increased soil salinity. The primary effect of excess soil salinity is the increased osmotic pressure of the soil. This reduces water availability for absorption and increases the absorption of ions that would hinder plant growth. Samples taken from the dumpsites had EC mean values ranging between 64 and 386 μS/cm while ones collected away from them recorded a relatively lower value ranging between 73 and 190 μS/cm. All EC values came out to be higher than the collected control sample with a mean conductivity value of 50 μS/cm (Table 14) However, the soil is non saline, with EC values below 2000 μS/cm, and thus it is expected to have negligible effects on crops (FAO, 1988). Although our values are considered to be non-saline, they still exceed the control values. TDS & EC values reported during summer had higher values than ones collected in winter. Our findings for EC are less than other results previously reported by Olurin et al., (2014) that ranged between 5030μ S/cm to 6080 μS/cm in Nigeria but higher than the results reported by Tazdait et al., (2018) in Algeria where all samples had soil conductivity less than 4 μS/cm. Although our values are considered to be non-saline, they exceed the control values indicating that the dumped refuse has high levels of organic matter that affected soil quality. As solid wastes dumped are mostly organic, elevated levels of EC are expected. Soil having high percentages of organic matter is prone to having high levels of ions. Upon organic matter decaying, naturally or by the present microorganisms, cations and anions are released plugging the soil pores and by that increasing soil EC (Tazdait et al., 2018). Our results also indicated that summer samples had higher EC values, which is justified by the fact that rainfall and water floods dilute the solute components in the wastes (Saidu, 2016).

Sulfate levels ranged from 117 to 591 mg/Kg and 50 to 195 mg/Kg in the samples collected from and away dumpsites, respectively. Sulfate levels have been altered due to the dumped refuse as all values reported from dumpsites were higher than the control sample with a mean value of <50 mg/kg (Table 14). Sulfate values showed a decrease during winter and in samples collected far from the dumpsite. According to EPA standard limits (2011&2012), our reported sulfate concentrations aren't considered a limiting factor that would restrict soil use, as they are below 3000mg/kg. Our results are in line with sulfate levels reported in Nigeria, Autonagar dumpsite, where levels ranged between 298.81 to 552.9 mg/Kg with a mean value of 377.01 mg/Kg (Hussain et al.,2014). However, in comparison to sulfate levels reported for MSW dumpsites in Nigeria, our values are approximately ten times higher than their recorded mean values that had a maximum of 56 mg/kg (Badmos et al., 2017). As for phosphates, our results suggest that phosphates are deficient in the collected soil samples as approximately most samples came out to be less than the detection limit (<1) (Table 14). Orthophosphates are an indicator of the available phosphorus levels in soil as the latter affects soil fertility (Counties et al., 2010). Our results suggest that phosphate is deficient in the collected soil samples as approximately most samples came out to be less than detection limit (<1) (Table 14).

Total nitrogen is an indication of organic and inorganic forms of nitrogen in soil. The normal total nitrogen percentage is considered to be between 1000 to 1500 mg/kg in a typical agricultural land. Only a slight amount of the present total nitrogen, at most 40000 mg/kg, is absorbed by the plant (Sulivan et al., 2011). The mean total nitrogen was found to be similar between samples collected from and away the dumpsites ranging between 0.07 and 2700 mg/kg. Results were slightly higher than the previously normal set values and our recorded control value (1600 mg/kg) in sites S6, S1b, S6b, S5a & S4a. Samples collected in summer had higher values than ones collected during winter (Table 14). According to Herbert et al., (2008), nitrogen released increases linearly with the incubation period of organic waste in the dumpsites. Thus, it is normal to have higher percentages of nitrogen levels in soil during the second sampling period. Additionally, ash from nearby burnt vegetation or wastes could have contributed to the elevated levels of TN as also samples taken away from the dumpsites had slightly higher percentages than the control samples (Banunalne et al., 2020). Availability of nitrogen for plant absorption and promotion of growth is dependent on mineralization, which is the ability of microorganisms to decompose organic matter and convert organic forms of nitrogen to mineral one available for plant uptake. However, as the dumpsite ages, the rate of mineralization decreases and proportionally reduces the percentage of plant available nitrogen (Herbert et al., 2008). Our findings for percentage of total nitrogen are similar to other reported results where total nitrogen ranged between 400 to 6200 mg/kg and 1100 to 3600 mg/kg in soils collected from waste dumps in Nigeria (Tanee et al., 2017; Obasi et al.,2012). However, this value is expected since the dumped wastes have a high organic composition as they originate from municipal sources.

COD is an indicator of biodegradable and non-biodegradable substances present in soil. In dumpsite samples, COD mean values ranged between 170 and 1995 mg/Kg. Sites S1, S5 and S7 had COD values similar to the control samples (407 mg/Kg), but site S6 and S3 reported mean values approximately four times greater than the control. This indicates that sites S6 and S3 have a different waste composition particularly a higher organic matter concentration than the other dumpsites. However, samples collected 1 & 2 Km away from the dumped refuse showed relatively less COD levels (Table 14). Generally, samples collected in winter had higher values than ones collected during summer. Elevated levels of COD signify an increase in oxidizable organic matter (Schmitz, 2017). In comparison with COD levels reported by Hussain et al (2014), where COD reached a maximum of 4174 mg/Kg, our samples have lower COD values.

The above findings could be justified by the following pattern. Organic matter mineralization would increase the nitrogen content in soil particularly in the form of ammonia which increases soil pH. Sulfur originating from plant remains and degraded wastes, will later be oxidized by autotrophic bacteria into sulfate, which explains the elevated concentrations of sulfate present in our collected samples. High concentrations of iron would tie up the free phosphorus present in the soil leaving phosphate in a deficient state, as reported in our findings. Additionally, the elevated soil pH found in our samples is another factor that justifies the unavailability of phosphate ions, as under alkaline conditions, phosphorus binds to free calcium ions. Although enzyme activity is generally enhanced, thereby increasing the nutrients in soil, most are found in an unavailable form for plant uptake (Osuocha et al., 2016).

Table 14: Physiochemical parameters of the collected soil samples

	COD (mg/kg)			pH			TN(mg/Kg)			Sulfate (mg/kg)			TDS (mg/L)			EC (uS/cm)			Phosphate (mg/kg)		
Sample Label	Winter sample	Summer sample	Mean vale	Winter	Summer	Mean value	Winter	Summer	Mean value	Winter	Summer	Mean value	Winter Sample	Summer Sample	Mean value	Winter	Summer	Mean value	Winter	Summer	Mean value
S1	685	180	432.5	8.89	7.72	8.3	1300	1600	1500	<50	117	117	47.7	146	97	95	293	194	3.7	<1	1.85
S1a	240	400	320	9.08	7.96	8.5	1500	1700	1600	<50	51.5	25.75	28.5	162	95	57	324	190	<1	<1	<1
S1b	745	130	437.5	9.14	8.01	8.6	2300	2200	2300	<50	367	183.5	24.2	125	75	48	250	149	<1	7.1	<1
S2	230	110	170	9.07	8.02	8.5	700	600	700	97.2	506	301.6	20	212	116	209	425	317	<1	<1	<1
S2a	60	190	125	9.13	8.04	8.6	1700	1500	1600	<50	283	141.5	26	104	65	52	207	129	<1	<1	<1
S3	665	2730	1697.5	9.3	7.36	8.3	1100	2600	1900	< 50	535	535	41.5	22	32	83	44	64	1.16	<1	0.58
S3a	705	<62.5	352.5	9.27	8.15	8.7	600	1200	900	<50	<50	<50	21.5	44.2	33	43	88.3	66	<1	<1	<1
S3b	390	190	290	9.17	8.13	8.7	900	400	700	<50	<50	<50	27.1	80.8	54	54	162	108	<1	<1	<1
S4	770	100	435	9.42	7.89	8.7	900	900	900	< 50	537	537	30.4	233	132	61	447	254	1.2	5.42	3.31
S4a	525	180	352.5	9.05	7.7	8.4	2500	2900	2700	<50	<50	<50	21.9	105	63	44	210	127	<1	<1	<1
S4b	155	90	122.5	9.05	7.87	8.5	1700	1600	1700	<50	34.2	34.2	25	81.6	53	50	163	107	1.9	20.6	11.25
S5	275	390	332.5	9	7.99	8.5	1400	1500	1500	132	461	296.5	84.4	264	174	171	529	350	<1	1.54	0.77
S5a	1770	<62.5	885	9.04	7.88	8.5	1900	800	1400	<50	61	30.5	25.4	77.8	52	51	156	103	<1	<1	<1

S5b	535	<62.5	267.5	9.04	7.8	8.4	2400	1300	1900	<50	50.7	25.35	21.3	68.7	45	43	137	90	<1	<1	<1
S6	3040	950	1995	9.21	7.55	8.4	1100	3700	2400	< 50	511	511	40.8	344	192	82	689	386	<1	<1	<1
S6a	100	150	125	8.99	7.8	8.4	2000	1800	1900	<50	<50	<50	26.3	91.3	59	53	183	118	<1	3.45	1.725
S6b	670	<62.5	335	9.1	8.05	8.6	2100	1800	2000	<50	37.6	18.8	23.7	76.3	50	47	153	100	<1	<1	<1
S7	515	590	552.5	9.66	7.49	8.6	300	1900	1100	<50	591	591	22.4	288	155	45	576	310	<1	10.1	5.05
S7a	620	70	345	9.05	8.04	8.5	1700	1300	1500	<50	35.5	17.75	19.9	55.1	38	37	110	73	<1	<1	<1
S7b	385	200	29.5	9.07	8.12	8.6	2100	1400	1800	<50	381	190.5	24.3	96.7	61	49	193	121	<1	<1	<1
S8	725	90	407.5	9.21	7.55	8.4	2100	1000	1600	53.7	<50	<50	25.4	24.9	25	51	50	50	<1	<1	<1
Limits[1]				6.8-7.5			1000 to 1500			<3000						<2000					

[1]: (FAO, 1988; Sullivan et al., 2011; EPA , 2011&2012).

2. *Heavy metals*

Only samples S4 and S6 were above the permissible limit of 45 mg/Kg for lead in soils used for agricultural purpose (EPA, 2012). As expected lead concentrations decreased as we went further from the dumpsites. Lead poses a health risk when it leaches to ground water. Its mobility is affected by many factors like soil pH, organic matter content and the age of the dumpsite. Solubility of lead is most likely to decrease as the age of the dumpsite increases; thus, decreasing the risk of leaching to ground water. This is primarily because of the accumulated organic matter and increased pH of soil that making lead contained in top soil layers (Wright, 2003). Additionally, lead could pose a threat of entering the food chain through plant uptake, only when reaching concentrations above 300 ppm, which isn't the case in our study area (Okiemein et al., 2011). Except for dumpsites S6 and S7, all dumpsite soils along with samples S2a, S1a, S1b & S5b showed arsenic values higher than permissible ones of 11 mg/Kg set for agricultural land use but close to the one set for soils that can be used for residential purposes (18 mg/Kg) (USEPA, 2012). Generally, all arsenic concentrations halved as we went away from the dumpsites reaching 2 Km, except for samples collected far from dumpsite S1. Samples S1a & S1b showed an increase in arsenic mean concentration to reach 2619 mg/Kg which significantly overreaches the permissible limits (Table 15). The latter could be attributed to field observations and might be related to the history of the present locations. Arsenic is more likely to leach to ground waters as its mobility increases proportionally with increased pH. It is known to cause skin damage, increase cancer risk and cause problems in circulatory the system (Okiemien et al., 2011).

Our findings for potassium soil concentrations are relatively higher than the control mean value that had a mean value of 3000 mg/Kg. All samples collected away from the dumpsites showed decreased concentrations of potassium except for the ones collected way from dumpsites S3, S4 & S5. Although no standard limits have been set for potassium levels, it is still an essential nutrient for soil fertility as high levels could cause toxicity and disrupt plant nutrient cycles. Similarly, sodium has no limiting value set. Our dumpsite soil samples had sodium levels higher than the reported control mean value 211 mg/Kg. Sodium and potassium concentrations decreased as we went away 1 & 2 km from the dumpsites but were still found to be above the mean sodium concentration reported in our control sample. Sodium, however, would contribute to the increased EC of soil. Thus, sodium is a factor affecting soil salinity and by that hinders soil fertility. The elevated levels of sodium and potassium in soil are primarily due to the retention abilities of granite and clay soil textures present in our studied areas and the elemental affinity to the soil particles; Thus, reducing elemental leaching to subsurface soil layers (Kubo et al., 2016).

Samples S2, S5 & S6 exceeded the permissible limits set for Cu concentrations in residential and agricultural land use purposes, 92 mg/Kg and 62 mg/Kg, respectively (USEPA, 2012). Copper concentrations decreased in all samples taken far from the dumpsites except for the ones taken away from sample S1 & S4. Copper is considered to have a complex interaction with the environment as is becomes rapidly stable and its solubility in soil increases at acidic pH values which is considered within the ideal range of pH for the plant growth, 6.0–6.5. However, copper strongly adsorbs to clay particle which reduces its mobility and its risk to leach to groundwater (Okiemien et al., 2011). Only sample S6 exceeded the permissible limit of Zn soil concentrations set for agricultural and residential land use (290 mg/Kg) (USEPA, 2012). Samples taken away from the dumpsites showed a decrease in zinc mean concentrations except from ones far from sites S3, S4 & S7. Zinc is an element that could cause toxicity if biomagnified. Plants with darker leaves than normal is considered a symptom for Zn toxicity; however, Zn is considered to be a threat only under acidic soil conditions as mobility increases. Thus, the possibility for Zn leaching to groundwater is minimal as pH is relatively basic in our studied area. On the other hand, high levels of Zn could disrupt the activity of microorganisms and, by that, reducing organic matter breakdown (Okiemien et al., 2011). All reported mean manganese values, except for S8, S7b & S5b, are considered to be within permissible limits for a non-polluted area as they are below 500mg/Kg (USEPA,2012). The mean concentration of Mn was found to increase in samples collected away from dumps S3, S4, S5 & S7. The availability of manganese is influenced primarily by soil pH. Manganese availability increases under extreme acidic soil conditions. Manganese soil toxicity is evidenced by distorted dark leaves and dead edges. Additionally, high values of Mn could cause iron deficiency thus directly affecting the plant cycles and growth (Hussain et al., 2014). Samples S2 & S6 exceeded the permissible limits set for Cr in agricultural and residential land, 70 and 67 mg/Kg respectively (USEPA,2012). Except for samples collected away from sites S2 & S6, chromium concentrations increased as we went further from the dumpsites. Excessive Cr soil concentration could affect seed germination, disrupt photosynthesis and plant uptake of nutrient. The increased pH, presence of manganese and sulfates, as in the case of our studied area, are factors that depress Cr adsorption to soil particles; thus, increasing the risk of it leaching to the groundwater (Wade, 2019). The mean value for selenium in dumpsite soil samples ranged between 0.6 and 2.6 mg/Kg. In comparison to the control sample, which had Se concentration below detection limit, our dumpsite soils showed a slightly higher concentration. A slight increase was found in Se mean concentrations only in samples taken away from dumpsites S3, S5 & S7. (Table 15). Selenium is supposed to be in trace amounts as it isn't an essential nutrient for plant growth. According to Wade (2019), selenium concentrations above 200mg/Kg are considered to be toxic and could stunt plant growth and cause chlorosis. All samples had Cd concentrations within limits for agricultural land use 1mg/Kg, except for site S6 (USEPA. 2012). Cadmium is plant available in acidic soil conditions and low organic matter which isn't the case in our studies area. However, this puts Cd at higher risk of leaching to ground waters (Hussain et al., 2014). Several samples, indicated in table 15, exceeded permissible limits for iron in uncontaminated soils, 15000 mg/Kg (EPA, 2012). Additionally, samples were higher than recorded control value, 1200mg/Kg. Most samples collected away from the dumpsites showed a greater mean concertation than the dump itself except for the ones collected away from sites S2 & S6. This could be attributed to the history of the site. Iron is considered to be an essential micronutrient as it has a vital role in development of chlorophyll, respiration, metabolism and nitrogen fixation. However, elevated concentration of Fe can cause toxicity causing bronzing of the leaves, brown spots and, most importantly, inhibiting the uptake of other nutrients. Organic matter available would increase uptake of iron. However, the high pH present along with the reported concentrations of Mn, Zn, and total nitrogen, Fe uptake would be inhibited (Wade, 2019). Almost all samples collected away from the dumpsites, along with S6, were found to be above permissible limits permissible levels of Ni for agricultural land use, 37 mg/Kg (EPA, 2012). Nickel is considered an essential micronutrient; however, in elevated levels it could cause necrosis, chlorosis especially as it hinders plant uptake of iron (Wade, 2019). Nickel toxicity is highly influenced by soil pH and the present organic matter. under basic soil conditions, as the present MSW in our studied area, Ni mobility decreases. Thus, the risk of it leaching to the nearby water sources isn't a concern. Additionally, the present organic matter percentage will further inhibit Ni mobility as large compounds of Ni adsorb to organic matter and soil particles (Hussain et al., 2014). Seasonal variation didn't show any specific trend while measuring As, K, Zn, Cr Se and Cd concentrations. However, the majority of the collected samples had higher concentrations of Pb, Mn, Fe and Ni during summer season. As for Na and Cu, the majority of samples recorded higher concentrations during winter. Table 15 summarizes heavy metal concentrations in all the collected soil samples.

The trend of heavy metals concentration varied between dumpsites but Fe, Cr, Zn, Cu & Mn were most prevalent in all dumps. The current heavy metal distribution was found similar in previously published reports. Heavy metal concentrations in dumpsites reported in Rajshahi, Bangladesh, Northern Nigeria and Pakistan Zaria Metropolis, Nigeria reported to have Fe, Mn & Zn in highest concentrations (Saha et al., 2015; Folaranmi et al., 2007) Our current reported levels of Pb were found to be less than ones reported in Apollo and OAU dumpsites in Ile-Ife -Nigeria and India; Similarly, for Mn, our reported levels were slightly less than the ones reported in Pakistan. However, the rest of the elements measured were found to be higher than ones reported in Nigeria & Pakistan (Adebiyi and Oloukoi, 2018; Olakunel et al.,2018; Malik et al., 2016; Saidu , 2016; Hussain et al., 2014; Uba et al., 2008; Folaranmi et al., 2007).

As expected, metals were found in high concentrations. Domestic wastes are considered to be a source of chromium originating from household chemicals and cleaners, rubber, candles and matches, plastics, packaging materials, lead-chromium batteries and leather; they are also a source of copper found in cookware, medications, cooking utensils, pipes, fungicides, insecticides, food leftovers, fertilizers & flying ash; cadmium is usually found in cigarette smoke, tobacco, steel cooking pans, metal pipes, rubber, fertilizers, batteries, fungicides, grains, plastics, oil, paint, pesticides, processed foods, soft drinks, pharmaceutical and recreational drugs; Lead is found in dyes, gasoline, lead based paint, old plumbing, pottery, insecticides, tobacco smoke, textiles, scrap metal, food cans, batteries; iron is usually found in textiles and metal appliances; Zn & Mn can originate from electrical glass, pesticides, paint, rubber, batteries & detergents; Ni is present in dumped batteries, electrical appliances and fertilizers; Se and As are found mostly in wood, pesticides detergents and dyes (Guatam et al., 2016). However, another important factor that has caused the elevated concentrations of some types of heavy metals is the redirected wastewater. The latter justification is validated by the high count of E.coli and total coliforms detected in the soil samples.

According to Obasi et al (2012), soils under alkaline conditions similar to our current soil condition, are considered to hold heavy metals in their mobile state with Cu, Cr & Ni being the least mobile. Additionally, excessive concentrations of iron were found to reduce the Mn availability in soil. Thus, not only are some heavy metals exceeding permissible limits and reported values in other dumpsites, but they are highly bioavailable which increases the human risk for toxicity. The latter also applies for samples taken away from the dumps as they also had high pH values and high metal concentrations.

The results reported for the physiochemical parameters of dumpsite soils are expected as they're within the ranges found for leachate characteristics. However, samples taken away from the dumpsites were found to have traces of metals higher than the dumpsites. There stands two reasons behind the latter finding. First, soil samples taken near dumpsites have been affected by contaminated ground and surface water through leachate percolation and/or by water run offs. This is true to a certain extent as water results have been reported to be uncontaminated by heavy metals which discards the risk of leachate affecting ground waters. However, runoffs particularly in winter season, could have caused the high concentrations of heavy metals to in nearby soils. Additionally, as the studied area has poor sewage management system, it is more likely that nearby soils have been contaminated with wastewater. The second reason behind our findings is in-line with results reported by Yao et al (2012) and Lemanowicz et al (2019) that have established a linear relationship between traffic near soil and elevated levels of heavy metals. Thus, anthropogenic activities within our studied area is another reason behind the elevated levels of some heavy metals in soil samples. Especially that unlike dumpsites locations, samples taken 1 and 2 km away from the dumpsites, are near roads and traffic sources.

Table 15: Mean heavy metal concentrations in the dumpsites and soils taken 1 & 2 Km past

	(mg/Kg)	Sodium	Potassium	Chromium	Manganese	Iron	Nickel	Copper	Zinc	Arsenic	Selenium	Cadmium	Lead
S1	Winter	1840	6780	75	425	2540	37.7	52	122	27	2.08	0.816	20.5
	Summer	458	4140	56.4	376	19800	30	29.1	119	11.9	0.876	<0.5	21.1
	Mean value	1149	5460	65.7	400.5	11170	33.85	40.55	120.5	**19.45**	1.478	0.658	20.8
S1a	Winter	290	756	69.5	25	6260	25.3	15.4	25.6	23.1	1.2	0.185	2.03
	Summer	273	784	71.4	25.5	6090	26.2	11	32.8	20.9	0.685	<0.5	2.73
	Mean value	281.5	770	70.45	25.25	6175	25.75	13.2	29.2	22	0.9425	0.0925	2.38
S1b	Winter	168	3470	77.2	380	16700	51.8	18.1	59	5230	0.716	0.257	5.34
	Summer	396	4000	101	473	27100	65.2	21.4	68.4	9.25	0.821	<0.5	9.68
	Mean value	282	3735	89.1	426.5	**21900**	**58.5**	19.75	63.7	2619.625	0.7685	0.1285	7.51
S2	Winter	1310	3750	73.3	295	21400	32.7	184	281	18.1	2.98	1.26	37.4
	Summer	455	4.95	98.8	408	21100	38.6	16.2	73.9	17.8	1.54	<0.5	9.33
	Mean value	882.5	1877.475	86.05	351.5	21250	35.65	100.1	177.45	17.95	2.26	0.63	23.365
S2a	Winter	281	1360	110	122	10600	45.1	37.6	64	14.4	0.8	0.328	7.66
	Summer	353	6530	63.2	658	28700	35.3	11.6	62.7	17	<0.5	<0.5	14.1
	Mean value	317	3945	86.6	390	19650	40.2	24.6	63.35	15.7	0.4	0.164	10.88
S3	Winter	17200	3260	87.9	139	18600	40.3	26.4	106	32.5	1.83	0.536	9.28
	Summer	362	2180	48.7	218	18800	24.2	35.7	142	7.72	<0.5	<0.5	17
	Mean value	8781	2720	68.3	178.5	**18700**	32.25	31.05	124	20.11	0.915	0.268	13.14
S3a	Winter	179	3440	111	560	31700	62.8	20.2	75.5	11.1	1.76	0.346	6.75
	Summer	3660	20400	168	575	38600	91.9	543	1860	10.1	1.63	9.44	10.7
	Mean value	1919.5	11920	139.5	567.5	**35150**	**77.35**	281.6	967.75	10.6	1.695	4.893	8.725
S3b	Winter	226	4930	78.2	651	39700	59.1	13.4	54.9	1.76	1.19	0.187	8.53

	Summer	380	1460	86.7	97.8	9440	30	**26.1**	59.3	9.79	0.845	<0.5	4.89
	Mean value	303	3195	82.45	374.4	**24570**	**44.55**	19.75	57.1	5.775	1.0175	0.0935	6.71
S4	Winter	797	2040	27.8	127	13700	18.4	9.93	30.5	20.2	1.78	0.46	15.7
	Summer	742	1590	30.9	68.6	4410	45.3	10.9	37.6	4.32	<0.5	<0.5	105
	Mean value	769.5	1815	29.35	97.8	9055	31.85	10.415	34.05	**12.26**	0.89	0.23	**60.35**
S4a	Winter	316	3400	75.9	423	19800	58.8	19.5	54.3	4.63	0.77	0.377	6.12
	Summer	14.4	1080	2.98	15.6	850	1.83	0.486	2.87	1.39	<0.05	<0.05	1.41
	Mean value	165.2	2240	39.44	219.3	10325	30.315	9.993	28.585	3.01	0.385	0.1885	3.765
S4b	Winter	271	5900	76.2	429	16700	50.1	13.1	54.7	6.7	0.442	0.401	10.8
	Summer	193	2950	86.9	266	22900	46.2	22.5	77.9	11.8	0.798	0.598	14
	Mean value	232	4425	81.55	347.5	**19800**	**48.15**	**17.8**	66.3	9.25	0.62	0.4995	12.4
S5	Winter	764	2980	82.8	317	26200	54	290	181	21.2	1.37	1.52	34.7
	Summer	88.2	2400	10.4	43.6	2980	8.26	6.49	22.1	9.21	<0.5	0.131	4.11
	Mean value	426.1	2690	46.6	180.3	14590	31.13	**148.245**	101.55	**15.205**	0.685	0.8255	19.405
S5a	Winter	418	9330	164	819	29800	100	37.1	114	13.1	1.04	0.491	11.6
	Summer	35.9	3350	17.1	93	5170	9.05	2.84	11.7	1.48	<0.5	<0.5	1.92
	Mean value	226.95	6340	90.55	456	**17485**	**54.525**	19.97	62.85	7.29	0.52	0.2455	6.76
S5b	Winter	324	6270	136	647	25900	88.4	31.2	93.6	8.43	0.951	0.454	7.77
	Summer	496	9820	139	709	39300	67.7	24.9	131	16.8	2.27	0.485	22.2
	Mean value	410	8045	137.5	**678**	**32600**	**78.05**	28.05	112.3	12.615	1.6105	0.4695	14.985
S6	Winter	813	2780	77.6	300	27500	56	520	1020	6.92	1.42	3.76	134
	Summer	1010	5100	120	363	18600	57.4	70.6	370	14.3	2.08	0.899	64.5
	Mean value	911.5	3940	**98.8**	331.5	**23050**	**56.7**	**295.3**	**695**	10.61	1.75	**2.3295**	**99.25**
S6a	Winter	449	1870	102	135	7210	47	25.4	72.7	16.4	0.807	0.432	7.89
	Summer	55.3	2690	21.9	72.7	4140	14.4	4.35	17.5	3.5	<0.5	<0.5	4.43

	Mean value	252.15	2280	61.95	103.85	5675	30.7	14.875	45.1	9.95	0.4035	0.216	6.16
S6b	Winter	259	2250	122	334	13000	85	30.3	72.4	15.5	0.788	0.506	5.7
	Summer	27.3	833	17.7	48.3	2490	11.1	3.73	12	2	<0.5	<0.5	1.41
	Mean value	143.15	1541.5	69.85	191.15	7745	**48.05**	17.015	42.2	8.75	0.394	0.253	3.555
S7	Winter	163	372	6.8	24.6	1980	3.85	2.04	4.01	2.19	<0.5 BDL	0.097	<0.1 BDL
	Summer	823	1790	28	73.1	3.07	10.8	16.8	87.3	7.64	0.686	<0.5	16.3
	Mean value	493	1081	17.4	48.85	991.535	7.325	**9.42**	45.655	4.915	0.686	0.0485	8.15
S7a	Winter	397	4420	100	567	31900	74.2	23.6	66.9	6.37	0.929	0.251	10.6
	Summer	26.9	1920	10.3	57.4	4260	6.85	1.66	5.99	0.749	<0.5	<0.5	1.62
	Mean value	211.95	3170	55.15	312.2	18080	**40.525**	12.63	36.445	3.5595	0.4645	0.1255	6.11
S7b	Winter	361	5470	132	887	38800	84.3	30	94	8.51	1.68	0.318	16.9
	Summer	273	5560	102	666	44200	76.6	11.9	61.1	12.1	0.94	<0.5	13.5
	Mean value	317	5515	117	**776.5**	**41500**	**80.45**	20.95	77.55	10.305	1.31	0.159	15.2
S8	Winter	211	5200	65.1	409	16000	44.2	14.2	46.3	14.7	1.06	0.284	9.03
	Summer	7.54	0.51	0	0	1.58	6.47	1.9	6.26	BDL	10.25	8.45	0.619
	Mean value	109.27	3041.5	34.13	**214.95**	8605	23.16	7.2805	24.07	7.846	0.53	0.142	4.8245

Table 16: Findings of heavy metals concentrations in dumpsite soil samples previously reported in different countries

	(Adebiyi and Oloukoi, 2018) Nigeria	(Olakunel et al.,2018) Nigeria	(Malik et al., 2016) Pakistan	(Uba et al., 2008) Zaria Metropolis, Nigeria	(Hussain et al., 2014) India	(Saidu , 2016) Kaduna Nigeria	(Folaranmi et al., 2007) Northern Nigeria
Fe	1148.61	8221	2022.8 to 4722.5	5 to 354	437 to 5439	0.01 to 0.06	0 to 1.5
K	1774.57	ND	ND	2.7-16	125 to 1118.5	ND	ND
As	22.34	ND	ND	ND	0.09 to 1.57	ND	ND
Cr	48.76	22.85	0.37 to 2.42	ND	10.31 to 25.64	0.001 to 0.002	ND
Zn	299.41	ND	9 to 34	ND	29.88 to 236.7	2.2 to 3.6	0 to 2.9
Cu	239.44	ND	3.69 to 18.67	ND	29.53 to 113.53	0.0025 to 0.0055	0 to 2.5
Na	4.16	ND	ND	4.16 to 8	ND	ND	ND
Cd	ND	1.1	1 to 3.3		0.4 to 2.1	0.0001 to 0.002	0 to 0.1
Mn	254.24	520	84.7 to 466.28	53 to 137	12.89 to 370.54	ND	ND
Pb	191.18	27	3 to 10.8	ND	123 to 193	0.0066 to 0.015	0.0026 to 0.17
Ni	ND	ND	2.77 to 8.97	ND	7.63 to 12.35	ND	ND

ND: not detected

3. Biological contamination

It is important to measure the biological soil contamination in order to assess the degree of threat posed on human health. Human health is jeopardized by soil contamination through the run off and leachates that eventually end up in ground and surface waters. Total coliforms, solely, aren't necessarily harmful for human health. However, they indicate that the present soil samples host different types of disease-causing pathogens (ATSDR, 2011).

Reported results exceeded the limits found in uncontaminated soil by more than thousand folds as normally total coliforms are found in the order of 1.8 cfu/g (Badmos et al., 2017). Seasonal variation was evident while assessing microbial contamination. Except for S1a, S4a & S4b, all samples collected during winter were found to have more than double the coliforms recovered during summer. It is also worth noting that samples collected 1 & 2 Km away from the dumpsites had significantly less bacterial isolates than samples collected from dumpsites (Table 17). In soil bacterial isolates can show a high growth rate when favorable conditions are met, most importantly, pH and available carbon compounds are factors that would affect proliferation of bacteria. The fact that winter had higher pH values and more organic waste content justifies the higher levels of colonies formed during winter as a result of putrefaction and increased decomposition of organic matter in the vicinity of the dumpsite. Additionally, winter season allows higher rate of precipitation of bacterial from air to soil surfaces (Artiningsih et al 2018; Akinneye & Ogunleye, 2019). The decrease in bacterial isolates is a positive sign indicating that coliforms have decreased along with the decrease in organic matter and leachate haven't yet been carried to nearby areas. Thus, the dumped wastes have contributed to the present microbial contamination found in dumpsites.

Table 17: Microbial burden of the collected soil samples

	Fecal Coliform (cfu in 1 g)			E. coli (cfu in 1 g)		
Sample Label	Winter Sample Results	Summer Sample Results	Mean value	Winter Sample Results	Summer Sample Results	Mean value
S1	67 x 10^4	8100	339050	2 x 10^4	<10	10^4
S1a	<10	78 x10^2	3900	<10	3400	1700
S1b	<10	30	15	<10	<10	<10
S2	62 x 10^4	27 x10^3	323500	30 x 10^4	16 x 10^2	150800
S2a	<10	<10	<10	<10	<10	<10
S3	14 x 10^4	28 x10^2	71400	2 x 10^4	<10	10^4
S3a	<10	<10	<10	<10	<10	<10
S3b	<10	<10	<10	<10	<10	<10
S4	>10x10^5	58 x10^3	529 x10^3	3 x 10^4	26 x10^3	28 x10^3
S4a	20	60	35	<10	<10	<10
S4b	30	80	55	<10	20	10
S5	>10x10^5	54 x10^3	527000	16 x 10^4	140	80070
S5a	80	<10	40	80	<10	40
S5b	<10	<10	<10	<10	<10	<10
S6	>10x10^5	10 x10^3	505000	6 x 10^4	50	30x10^3
S6a	28 x 10^2	690	1745	2800	<10	1400
S6b	38 x 10^2	<10	1900	<10	<10	<10
S7	24 x 10^4	83 x10^4	535000	<10	18 x10^4	90 x10^3
S7a	<10	<10	<10	<10	<10	<10
S7b	<10	80	40	<10	<10	<10
S8	<10	40	20	<10	40	20

4. Environmental health indices

RI indicated a low ecological risk only in dumpsite S7 (RI<110). Moderate ecological risk was found to be caused by dumps S3 and S4 with RI falling between 110 and 200. Dumps S1, S2 and S5 have considerable ecological risk as the formulated RI value fell between 200 and 400. Only dumpsite S6 was found to have a very high ecological risk with RI value exceeding 400 (figure 4). This indicates that S6 needs to be addressed first in the remediation plan. According to Muller (1960), the Igeo values in all dumpsites had Cr, Mn, Ni, Cu, Zn, Cd and Pb falling in class 1, being uncontaminated to moderately contaminated area; Fe fell under class 6, being extremely contaminated, for having an Igeo value above 5. However, only in dumpsite S6, Zn & Pb fell in class 2 being moderately contaminated and Cu & Zn in class 3 being moderately to heavily contaminated (Figure 5). The PLI values ranged between 0.6 and 5 (PLI>1) indicating that all dumpsites, except dumpsite S7, had deteriorated soil quality.

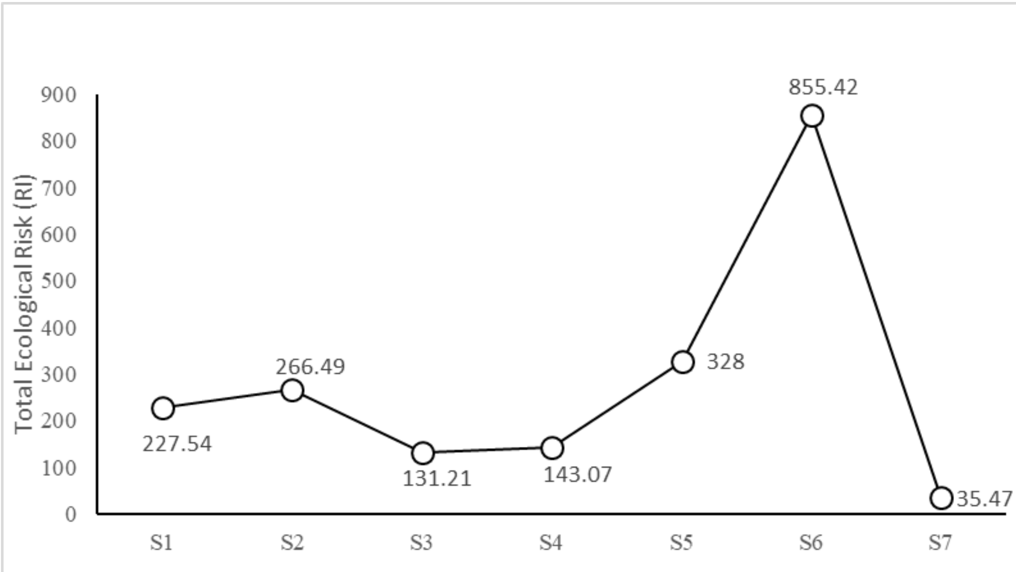


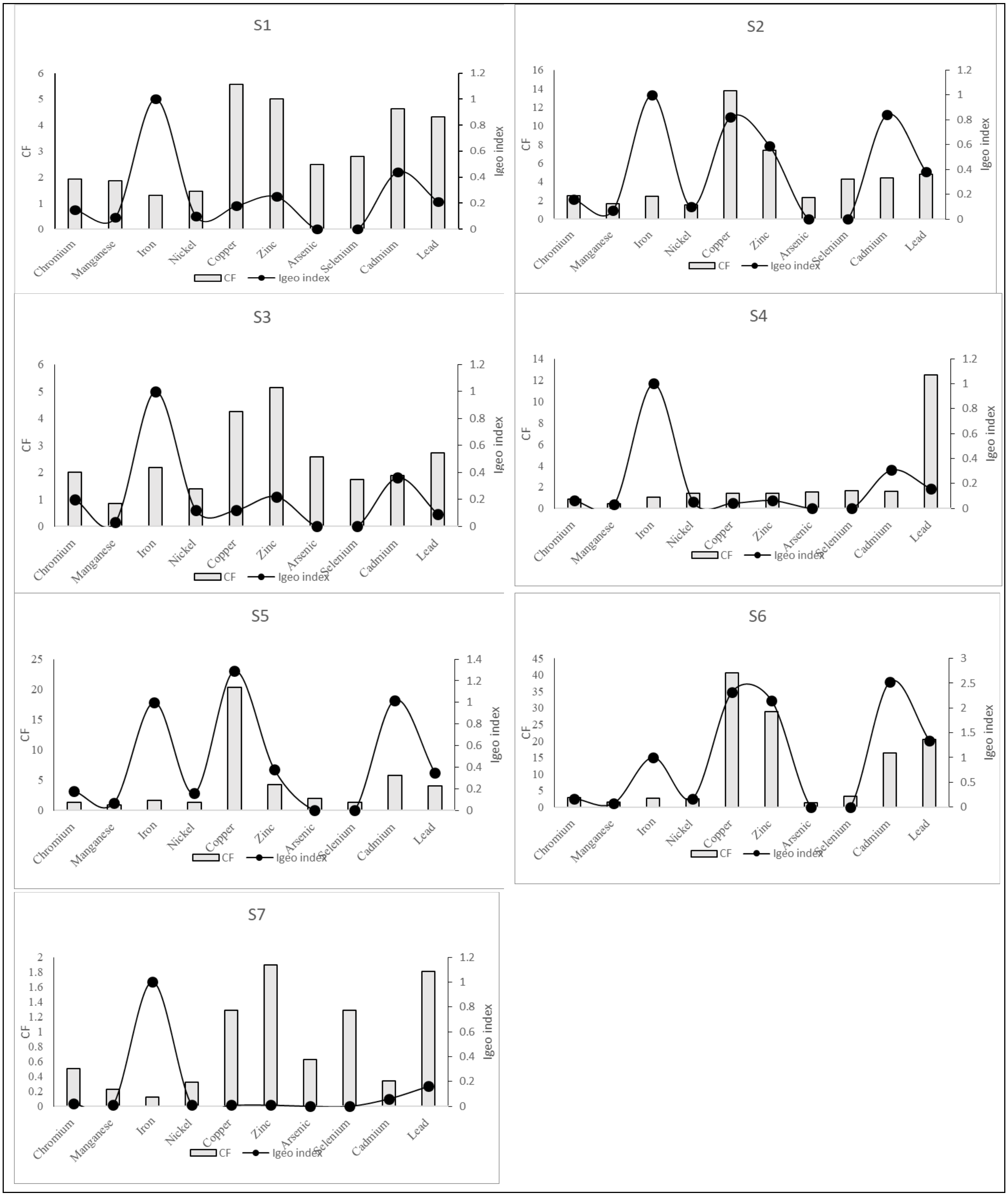
Figure 4: Total ecological risk of dumpsites

Contamination factor of most elements indicated moderate contamination (Table 18). The latter would allow us to further understand the extent of contamination the dumpsites have caused so far; It is also an indicator of the aspects that needs to be addressed in the remediation plan.

Table 18: Classification of metals in soil based on contamination factor

CF classification	S1	S2	S3	S4	S5	S6	S7
CF< 1 Low contamination	Fe, Ni	K , Mn	K, Mn, Ni	K, Cr, Mn, Fe, Ni, Cu, Zn	-	K, As	-
1<CF<3 moderate contamination	K, Cr, Mn, As & Se	Fe, Cr	Fe, Cr, Zn, As, Se, Cd, Pb, Cu	As, Se, Cd, Pb	K, Cr, Mn, Fe, Ni, As, Se	Cr, Mn, Fe, Ni and Se	Fe, Cr, Zn, As, Se, Cd, Pb, Cu,

							K, Mn, Ni, Na
3<CF<6 considerable contamination	Cu, Zn, Cd, Pb	Cd, Pb	-	-	Na, Zn, Cd, Pb	-	-
CF>6 Very high contamination	Na	Cu, Zn, Na	Na	Na	Cu	Cu, Zn, Na	-



*Igeo index for iron is multiplied by 480, 919, 716, 588, 1125, 1181 and 85 in S1,S2, S3, S4,S5, S6 and S7, respectively.

Figure 5: Environmental health risk indices

Water quality index indicated that all water samples had good quality except for samples W1, W4 and W9 that had excellent water quality according to the physiochemical parameters used in the table 19.

Table19: Water quality index for water sources

	EC		DO		TDS		pH		Sulfate		Ammonia		Nitrate		WQI	
Pi	1		4		2		1		2		3		2			
Sample	Result	Ci	Result	Ci	Result	Ci	Result	Ci	Result	Ci	Result	Ci	Result	Ci	∑Ci* Pi	∑Ci* Pi/ ∑Pi
W1	563.8	100	8.465	100	257.8	90	7.9	90	29.4	90	0.1	80	1	90	1370	91.33
W2	620	100	8.71	100	302	90	7.74	90	61.2	80	0.903	20	1	90	1170	78.00
W3	564.75	100	7.055	90	273.4	90	8.04	80	22.9	100	0.1	80	0.7	90	1340	89.33
W4	527.75	100	7.62	100	256.35	90	7.97	90	24.65	100	0.1	80	1.55	90	1390	92.67
W5	505.15	100	8	100	248.1	90	7.81	90	41.3	90	1.1	10	4.55	70	1120	74.67
W6	650	100	7.08	90	344	90	8.07	80	32	90	0.1	80	1.82	90	1320	88.00
W7	720	100	7.86	100	336	90	8.04	80	41	90	0.1	80	3.42	80	1340	89.33
W8	710.95	100	7.815	100	349.5	90	7.885	90	69.5	80	0.262	60	0.7	90	1290	86.00
W9	530	100	8.87	100	244	90	8.28	80	33.3	90	0.1	80	1.19	90	1360	90.67

B. Water

1. Physiochemical parameters

The reported mean pH values ranged between 7.74 and 8.28 (Figure 6). According to the WHO guidelines for drinking water quality (2011) and the general surface water properties, pH values are considered to be normal ranging from 6.5 to 8.5 and 5 to 9, respectively. W1, W4 & W5, used for drinking purposes, are within permissible limits. Similarly, for the rest sampled water sources, results were in compliance with pH values found in uncontaminated surface waters. Our findings suggest that water is slightly alkaline in nature and falls within permissible limits. The latter condition isn't necessarily unsafe, on the contrary, it was shown that water alkalinity is associated with reducing bone resorption by that decreasing the risk of osteoporosis, also decreasing high levels of sugar and blood pressure (Butler, 2017). However, alkalinity is sometimes considered an indicator of heavy metal pollution. As for irrigation uses, it could cause some elements such as calcium and magnesium to precipitate in soil hindering plant growth (Brunton, 2011).

TDS and EC are important parameters for allocating water use and assessing its quality. Water has the characteristic of dissolving organic and in-organic minerals affecting taste and appearance of water (Ayenew & Meride, 2016). TDS in our water samples ranged between 244 and 349.5 mg/L (Figure 6). According to WHO drinking water guidelines, our findings for W1, W4 & W5 are considered to be within the normal range as TDS values shouldn't exceed 500 mg/L. The rest water sources are also within the common values for irrigation (0-2000mg/L) (Ayers & Westcot, 1985). However, high TDS concentrations aren't known to have alarming effects on human health, but are associated with cases suffering from kidney or heart diseases (Sasikaran et al., 2012). EC is a measurement of the ionic suspension in water that allows current transmission. Another characteristic of pure water is it being a good insulator; thus an increased conductivity is an indicator of ionic concentration. WHO (2011) recommends that EC values should stay below 1000 mg/L. The mean EC values reported for our samples ranged between 505 and 720 mg/L indicating that they are within permissible limits (Figure 6). This indicates that water sources aren't highly ionized because of the low levels of dissolved solids. Thus, our findings suggest that the water could be used also for irrigation purposes as osmotic pressure, essential for crop yield, wouldn't be altered by precipitation of salts (Crowin, 2017). Water pH ranges came out to be higher than most of the reported pH values for water sources taken near dumpsites that ranged between 6.69 & 7.59 in Western Nigeria, 7.2 & 7.8 in India, 7 in Abuja Nigeria and 6.89 & 7.53 in Kaduna, Nigeria. TDS values were about ten times higher than ones reported in Abuja, Nigeria that ranged between 37 and 99 mg/L. However, our current TDS levels were found less than ones reported in Western and Kaduna Nigeria ranging between, respectively (Saidu , 2016; Folaranmi et al., 2007). As indicated by Asaduzzaman et al (2017), the above results are expected, as elevated levels of TDS would increase water conductivity and result in decreased pH levels. Thus, our findings of low TDS values have caused the elevated pH levels. This indicate that the dumpsites haven't yet influenced water quality.

Nitrate is usually found in traces in natural waters; it's also considered to be a contaminant in drinking water only when its concentration exceeds 10 mg/L (WHO, 2011). Exposure to high levels is associated primarily with increased incidences of methaemoglobinaemia (blue baby syndrome) in infants (Hansen et al., 2017). Our samples had a mean nitrate ranging between 0.7 and 4.55 mg/L (Figure 6). The results indicate that the water have acceptable levels of nitrates as all concentrations fell below the set permissible limits. Ammonia levels were all found to be in traces below detection limit (0.1 mg/L) except in samples W2 & W8 with 0.9 and 0.2 mg/L, respectively (Figure 6). The latter values are also considered to be negligible as the normal surface water ammonia levels is 12 mg/L and 0.2 mg/L in drinking water. Levels of ammonia exceeding these values can cause unpleasant taste and odors in drinking water and upon long exposure could alter metabolism processes (WHO, 2001).

Sulfate naturally occurs in surface water in minute concentrations reaching maximally 100mg/L. Sulfate isn't associated with any health risk unless it exceeds 1200 mg/L in drinking water causing a laxative effect as it can affect the GI lining. Thus, the desired limit set was 250mg/L (WHO, 2011). Our samples had levels of sulfate falling behind this limit as they ranged between 22.9 and 69.5 mg/L (Figure 6). Similarly, phosphate has no direct effect on human health but it could cause environmental deterioration. Eutrophication of water sources is a common phenomenon associated with high concentrations of phosphate. The Nigeria Standard for Drinking water quality (NSDWQ) recommends that phosphate levels should stay under 5 mg/L. Our samples were found to have phosphate concentrations ranging between 0.05 and 1.19 mg/L and indicating that phosphate isn't a concern in our water sources (Figure 6).

Dissolved oxygen (DO) is an important indicator of the presence of organic matter in water sources. During high levels of organic matter, DO is depleted due to the prevalent microbial activity that aims to decompose the present oxidizable substances, which in turn increases the consumption of oxygen. DO in our samples ranged between 7 and 8.87 mg/L. In unpolluted fresh waters, DO was found to be less than 10mg/L (Figure 6). It was also found to cause an unpleasant odor and taste in drinking water if it exceeds 80% (Kimstach & Chapman, 1996). This indicates that our collected water samples are within the normal reported ranges. COD, an indicator of the organic and inorganic matter in water, was found to have a mean value below detection limit (12.5mg/L) in all samples except W2 & W8 that had 13 and 8 mg/L COD respectively (Figure 6) (Kimstach & Chapman, 1996). Naturally, COD in surface water is found to be less than 20 mg/L and less than 1 mg/L in drinking water (Kimtach & Chapman, 1996; WHO, 2011). COD levels in our collected water samples are in compliance with fresh waters levels; however, might be higher than drinking water levels. DO and COD are critical parameter that indicate water eutrophication. Long term ingestion of water with algal blooms and organic matter residues, though not visible by the naked eye as parameters haven't yet should alerting concentration, could cause health impacts mainly related to liver function and gastrointestinal tract (Akpor & Muchie, 2011). DO was also found to be higher than Kaduna and Abuja water samples that ranged from 6 to 8 and 6 to 6.9, respectively. On the contrary, COD levels were found to be less than other studies that reported elevated levels of COD in Bangladesh and Nigeria (Saidu , 2016; Folaranmi et al., 2007). Levels of DO & COD were unexpected. accounting for the extremely high concentration of total coliforms in all water samples except for sample W5, DO should've been much lower and COD should've shown a higher level than reported ones. However, this is justified by the fact that total coliforms are facultative aerobic and anaerobic bacteria (Moon et al., 2017). Additionally, water have been affected by the high count of bacteria through the low levels of sulfates reported. In theory, physiochemical properties of surface water haven't yet been affected by the dumpsite leachates; However, the high microbial contamination of surface water makes water sources not suitable for any use be it for irrigation purposes or drinking.

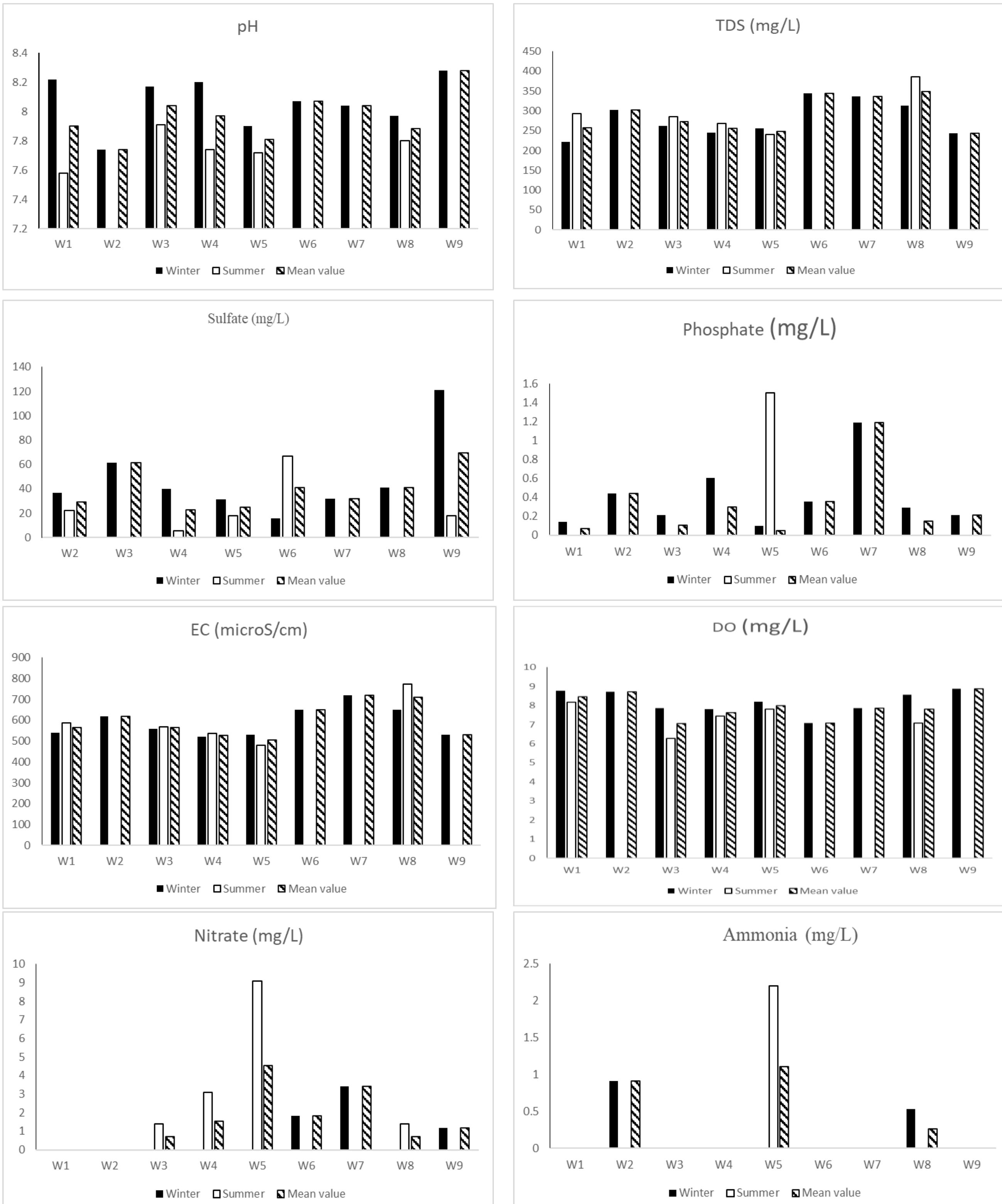


Figure 6: Physiochemical parameters for collected water samples

2. Heavy metals

In the collected water samples mean sodium concentrations ranged between 9.8 and 32 mg/L. Sodium is an important element to monitor as it is associated with risks of kidney diseases or hypertension that contribute to fatality rates (Ayenew & Meride, 2016). According to WHO (2011), 200mg/L of sodium in drinking water is considered to be a safe concentration. The values reported for our water samples fall far below the permissible limit set. Seasonal variation was clear measuring this element. All samples had almost double or more the concentration of sodium in summer than in winter, except for samples W3 and W8, where a higher concentration was found in winter (Table 20). Potassium is another element essential to measure as it causes impaired body function like heart rhythm disorders, blood pressure variation and muscle weakness (Ayenew & Meride, 2016). WHO (2011), has set 12mg/L as the allowed level concentration of potassium in drinking water. Our water samples had potassium concentrations ranging between 1 and 10 mg/L, indicating that they all are within permissible limits. Seasonal variation wasn't present while measuring potassium concentration in all samples except for sample W5. Sample W5 showed 14 times greater concentration in summer than winter season also by that exceeding the permissible limit for drinking water (Table 20). Concentrations of sodium and potassium exceeding 40 and 2 mg/L, respectively, in water used for irrigation would alter water and soil salinity which could affect soil fertility and plant cycle (Ayers & Westcot, 1994). All samples were found to have acceptable levels of sodium and potassium except for samples W2, W5, W7, W8 &W9 that had potassium concentrations slightly higher that 2mg/L (Table 20). It is important to note that heavy metal toxicity depends on several factors primarily the dose, period of exposure, frequency and the ionic state of the metal itself. Several heavy metals are classified as carcinogens or possible ones like As, Cd & Pb. Additionally, metals like Se, Mn, Ni... are associated with different types of health risks including respiratory problems, renal and hepatic disease, neurological effects and gastrointestinal disorders. As for the use of water with concentrated levels of heavy metals for irrigation purposes, bio-magnification of heavy metals would result by plant absorption, thereby, increasing the risk of human exposure to heavy metals (WHO, 2011; Sutton et al., 2014; Qamar et al., 2015). All reported concentrations of metals in our water samples weren't found to be contaminated by any type of heavy metal as concentrations fell below detection and permissible limits set by the WHO (Table 20).

Table 20: Heavy metal concentration in water samples

Sample	W1			W2	W3			W4			W5			W6	W7	W8			W9	WHO(2011)
Element (mg/L)	Winter	Summer	Mean	Winter	Winter	Summer	Mean	Winter	Summer	Mean	Winter	Summer	Mean	Winter	Winter	Winter	Summer	Mean	Winter	
Sodium	8.35	14.7	11.525	14	10.9	8.75	9.825	7.17	14.8	10.985	8.63	56.2	32.415	12.5	11.2	16.4	9.9	13.15	14.4	200
Potassium	1.39	1.9	1.645	2.69	1.32	0.737	1.0285	1.27	1.44	1.355	1.09	14.4	7.745	10.4	3.77	3.11	2.35	2.73	2.32	12
Chromium	<0.0005	<0.001	<0.0005	0.0006	<0.0005	<0.001	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	<0.001	<0.0005	0.001	0.0009	<0.0005	<0.001	<0.0005	0.0008	0.05
Manganese	<0.0005	0.001	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.014	0.007	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.1
Iron	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.3
Nickel	0.0006	0.001	0.0008	0.004	0.0008	<0.001	0.0008	0.0006	0.001	0.0008	0.0006	0.003	0.0018	0.009	0.008	0.004	<0.001	0.002	0.002	<1
Copper	<0.001	<0.005	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.005	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	1
Zinc	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	<0.005	<0.005	5
Arsenic	<0.0005	0.0006	<0.0005	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	0.01
Selenium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.04
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.005
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.05

3. Biological contamination

According to the EPA & WHO (2011), the maximum contaminant level (MCL) for total coliforms and E.coli colonies in water is <1 cfu in 150ml and zero, respectively. In general, samples collected during winter season had higher bacterial isolates than ones collected during summer. Except for sample 5, that only showed a maximum count of total coliforms in summer of 3 cfu in 100ml, all water samples collected had a mean of bacterial count higher than permissible limits set (Table 21). Results for coliforms found in water samples are expected to be high during winter. The latter is justified by the fact that as runoffs increase more waste and bacterial isolates are carried from dumpsites to water sources (Aleya et al., 2010). The use of water having high counts of fecal coliforms and E.coli is considered to be critical as they are associated with various gastrointestinal diseases, typhoid, fever and urinary tract infections (Badmos et al., 2017).

Table 21: Biological burden in water samples

	Total Coliform (cfu in 100mL)			Fecal Coliform (cfu in 250mL)			E coli (cfu in 250mL)		
Sample Label	Winter	Summer	Mean	Winter	Summer	Mean	Winter	Summer	Mean
W1	>100	>100	>100	>100	51	-[1]	>100	<1	>100
W2	>100	-	>100	>100	-	>100	>100	-	>100
W3	>100	>100	>100	10	21	15	10	<1	5
W4	<1	>100	>100	<1	6	3	<1	<1	<1
W5	<1	3	1	<1	2	1	<1	<1	<1
W6	>100	-	>100	>100	-	>100	>100	-	>100
W7	>100	-	>100	>100	-	>100	>100	-	>100
W8	>100	>100	>100	>100	>100	>100	>100	<1	>100
W9	>100	-	>100	-	>100	>100	>100	-	>100

[1]: water sample dried in summer season

C. Heath risks

Health risks were estimated using equation (6) based on statistically significant relative risks for lung and liver cancer found by Fazzo et al (2011) for population living near a dumpsite area in Italy. Attributable cases ranged from 0.03 to 0.1 and 0.57 to 1.96 for liver and lung cancer, respectively. Our findings seem to be in low ranges for two main reasons. First, incidence rate per 100,000 is considered to be a low rate 3.22 and 24.56 for liver and lung and lung cancer, respectively (Tables 22). Secondly, population size of the studied areas is also small as they are rural areas. Had the areas under study been more heavily populated, with same incidence rate, AC values would have escalated. However, the current attributable cases show significant impact for the persistence of dumpsites. At this incidence rate with the present dumpsites, approximately 40 % of the incidence cases would be purely due to the exposure to dumpsites. Similarly, for lung cancer cases, 13% of incident cases would be due the exposure to dumpsites. As for congenital anomalies, attributable cases ranged between 1 and 2 cases consisting of 2 to 4% of the total incident cases (Table 22). Similarly, the percentage of AC is expected to be low especially that population size was further diminished as only female population is the exposed portion in this health outcome.

Table 22: Attributable and incident cases of liver and lung cancer and congenital anomalies

	Population size[1]		Attributable cases[2]			Incident cases[3]			% of Attributable cases[4]		
Location	Males and females	Females	Liver cancer	Lung cancer	Congenital anomalies	Liver cancer	Lung cancer	Congenital anomalies	Liver cancer	Lung cancer	Congenital anomalies
V1	2325	1162.5	0.03	0.07	1	0.07	0.57	27.9	39	13.04	2
V2	8000	4000	0.10	0.26	2	0.26	1.96	96	39	13.04	2
V3	7500	3750	0.09	0.24	2	0.24	1.84	90	39	13.04	2
V4	3750	1875	0.05	0.12	0.5	0.12	0.92	45	39	13.04	1
V5	6500	3250	0.08	0.21	2	0.21	1.60	78	39	13.04	2
V6	2000	2000	0.03	0.06	1	0.06	0.49	24	39	13.04	4
V7	7250	3625	0.09	0.23	2	0.23	1.78	87	39	13.04	2

1 Every village's population size was given by the union of municipalities. Female population size was considered to be half the population size of the village (mundi, 2019) used only while calculating AC of congenital anomalies

2 $AC = Rate \times ER \times Popexp$ (6)

$$AC\ liver\ cancer = 2325\ x \left(\frac{3.2}{100000}\right) x \frac{1.64-1}{1.64} = 0.03$$

$$AC\ lung\ cancer = 2325\ x \left(\frac{24.56}{100000}\right) x \frac{1.15-1}{1.15} = 0.07$$

$$AC\ congenital\ anomalies = 1162.5x \left(\frac{24}{1000}\right) x \frac{1.02-1}{1..02} = 1$$

Where:
AC is Attributable cases
Rate is the Incidence rate of the disease in the general population being unexposed
liver cancer (3.22 per 100000), lung cancer (24.56 per 100000) (MOPH,2016) & congenital anomalies (24 per 1000)(Francine et al., 2014)
ER is the excess risk in the exposed population (relative risk(RR) - 1)/RR
RR liver cancer is 1.64, RR lung cancer is 1.15 and RR (Fazzo et al., 2011) congenital anomalies is 1.02 (Forastiere et al., 2009)
Popexp is the number of exposed people

3

$$IC\ of\ Liver\ cancer = \frac{3.2\ x\ 2325}{100000} = 0.07$$

$$IC\ of\ Lung\ cancer = \frac{24.56\ x\ 2325}{100000} = 0.56$$

$$IC\ of\ congenital\ anomalies = \frac{24\ x\ 1162.5}{1000} = 27.9$$

Where:
IC is the incident cases

4 $\%AC = (AC/IC) * 100$
(7)

D. Remediation plan

AHP indicated that the best solution having the least economic and social burden and highest environmental value is A3: Landfill mining (42% priority). While applying the sensitivity analysis and assuming the criteria had almost equal weights, mining came out to have the highest priority among the other alternative (Table 23). This indicates that the final decision is consistent and reliable. Mining has been shown to be an effective technique in several countries to reduce their landfill waste content by 70% sometimes reaching 90%. On the other hand, mining's mere purpose is to help in land reclamation and recovery of recyclables (glass plastic wood etc...) Technically, landfill mining is economically costly, which is clear in the pairwise comparison whereby it came in third place with 9% priority. However, AHP showed an overall priority for it being the remediation plan as its environmental advantages out ways its economic burden (64% priority).

Table 23: Pairwise comparison matrices

AHP	C1	C2	C3		
Alt	0.1	0.6	0.29	Priorities[1]	% Priorities
A1[2]	0.5537	0.0567	0.2898	0.17343725[2]	17.3437248
A2	0.0588	0.2097	0.0551	0.14765684	14.7656845
A3	0.0936	0.6457	0.0995	0.42565953	42.5659526
A4	0.2939	0.0879	0.5556	0.24324638	24.324638

1	$AHP = \sum Wa * Wc$	Where: Wa is the weight of every alternative Wc is the weight of the criteria
2	A1: (0.51* 0.1)+(0.06*0.6)+(0.28*0.29)= 0.17 Similarly, the rest of the alternatives' priorities were calculated	

Sensitivity analysis:

	C1	C2	C3		
Alt	0.300	0.400	0.300	Priorities	% Priorities
A1	0.5537	0.0567	0.2898	0.275744	27.57441
A2	0.0588	0.2097	0.0551	0.118026	11.80262
A3	0.0936	0.6457	0.0995	0.316226	31.62258
A4	0.2939	0.0879	0.5556	0.290004	29.00039

Several factors intervene to allow a successful end result of landfill mining implementation. In brief, dump mining is a series of mechanical operations starting with site preparation (road ways access and base preparation; dumpsite lining; setting health and safety measures on site from clothing and equipment; identifying waste placement areas); Excavation is the next step, where materials are divided into manageable stockpiles and bulky material are picked out. Piles are then passed by a conveyor belt through a trommel screen, which size and type are chosen based on the MSW composition and the type of materials intended to recover. The process yields different categories of waste. Ones retained in the trommel screen are passed by belt to a resource recovery area where items are manually separated and metals and recyclables are recovered. As for the fine soil left, it is usually used as soil cover, or enrichment factors are added upon to be sold as soil fertilizer or amendment. Materials that are neither recovered as a secondary raw source (recyclables, reusable material) nor soil amendment, supposed to be not more than 30% of the excavated waste, are recommended to be returned to a receiving area to be agreed on. After excavation process is complete, the former dumpsites land should be rehabilitated to be available areas for other recreational activities. Knowing that lands aren't highly contaminated by heavy metals, as revealed by soil quality assessment, phytoremediation would be an appropriate cleanup technique. Although it's a time exhausting process, it is still considered an effective and economical efficient way for soil remediation. Specific plant species are grown in the dumpsite, preferably ones that already are grown in the studied area. Plants would scavenge metals present in soil and later on they are collected and disposed. Figure (7) illustrates the phases of the remediation plan.

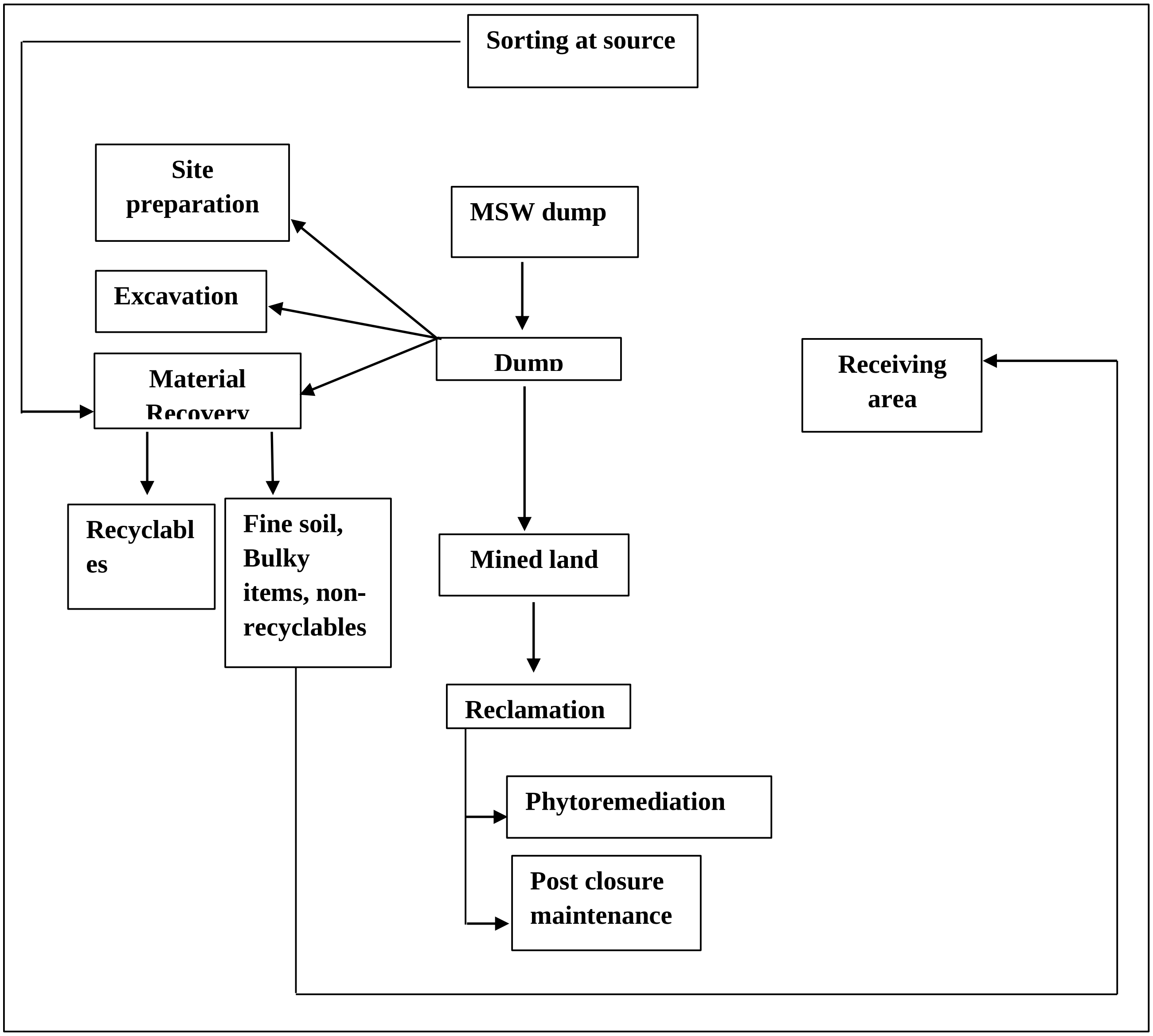


Figure 7: Phases of the remediation plan

According to the applied AHP, landfill mining was ranked first as the best remediation plan for the dumpsites remediation. However, this plan's success is also dependent on other factors. Previous experiences have proved mining to be cost effective after a cost-benefit analysis that compared the capital and operational cost with benefits coming from cost avoidance of post-closure care, recyclable materials recovery and land and space reclamation (Zhou et al., 2015). Thus, if a fund were found, a cost benefit analysis along with waste composition assessment is needed prior mining. If results were promising in terms of revenues, the above plan wouldn't only be a remediation plan but a corner stone to achieve a circular economy and reduce extensive resource expenditure. Particularly, the sorting at source step which would ensure closing the loop by maintaining a good quality of recyclables, reducing process of separation and making sure that dumpsites won't be resorted to as a technique for solid waste management.

CHAPTER V

CONCLUSIONS

Several soil parameters including TN, pH, DO, COD, salinity and sulfate levels, were altered due to the dumpsites. Additionally, soil samples had high levels of total coliforms. This goes back to the mineralization of high levels of organic matter that would increase the nitrogen content in soil particularly in the form of ammonia by that increasing soil pH. Additionally, the deficiency found in phosphates levels was attributed to the oxidization of by autotrophic bacteria and iron binding to free phosphorous ions. Reported results would have a direct effect on soil fertility and crop yield. There wasn't any specific trend for heavy metals concentration between dumpsites. Almost all elements were found to have a moderate contamination factor, with Fe, Cr, Zn, Cu & Mn being the most prevalent in all dumps. S6 was found to have the highest ecological risk indicating the need for it to be remediated first. It was also found that liver and lung cancer & congenital anomalies cases attributed to the exposure to the dumpsites would be 39 %, 13% & 2% of the total incident cases in the villages, respectively.

Water parameters and heavy metal concentrations weren't significantly altered and were found to be within permissible limits. The latter goes primarily to the fact that soil is silty and high pH levels in soil would further decrease solubility of metals; Thus, leachate percolation to water sources was hindered. However, biological contamination was evident as total coliforms were exceeding normal ranges, which is attributed basically to the runoffs and wastewater effluents. The use of water having high counts of fecal coliforms and E.coli is considered to be critical as this is associated with various gastrointestinal diseases, typhoid, fever and urinary tract infections.

According to the applied AHP, landfill mining was ranked first as the best remediation plan for the dumpsites remediation. Mining is a process with several steps that could be exhausting. However, it's an initiative towards achieving a circular economy and reclaiming natural resources that were drained by the dumpsites. After mining is completed, it is necessary to remediate the contaminated soil of the former dumps. The suggested method, that had proven its efficacy, is phytoremediation.

Limitations of this study are mainly related to the calculation of attributable cases. The female population size exposed to the dumpsites was estimated as approximately half (50%) of the villages' population. Additionally, relative risk of exposure was based on findings of other countries that might have different dumpsite characteristics than our studied area. Attributable cases were calculated based on incident rates in Lebanon not in our particular studied area. As for the suggested remediation plan, it would seem theoretically suitable, but practically implementation faces economical barriers and a fund is needed.

It is recommended that the next step prior implementation is conducting a cost benefit analysis to estimate the expenses and revenues for such a method. It is also important to move into conducting a site assessment to reach a consensus on the location that would receive what is left from mining process. However, if the analysis reveals that mining weren't financially acceptable, it is best to resort to the alternative ranked second in the AHP, closing ex-situ (A4). Additionally, it is vital to stress on the importance of sorting at source and reducing scavenging activity in order to successfully achieve a circular economy. The latter should be backed with informative campaigns about the risks of resorting to waste dumping in free spaces and the importance of people being involved in this solid waste management plan.

APPENDIX A

Figure 1: Dumpsite S1

Figure 2: Dumpsite S2

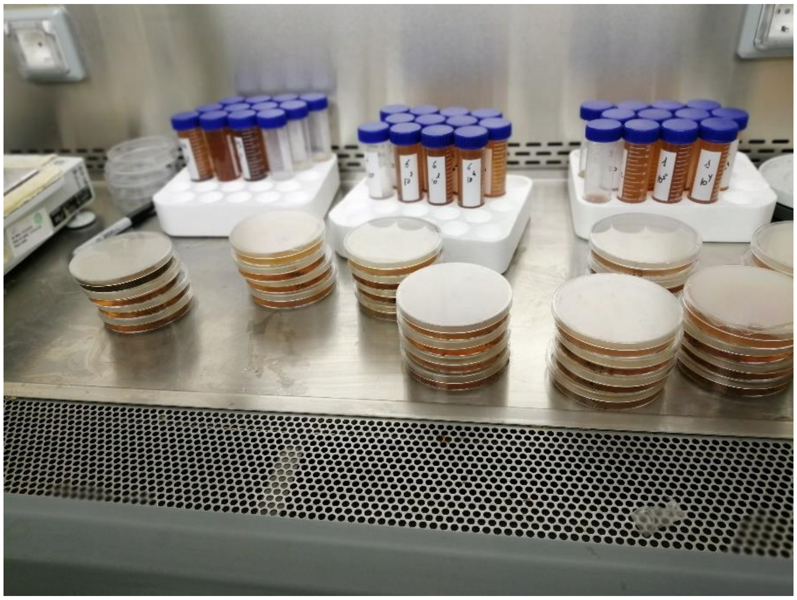
Figure 3: Dumpsite S3

Figure 4: Dumpsite S4

Figure 5: Dumpsite S5

Figure 6: Dumpsite S6

APPENDIX B



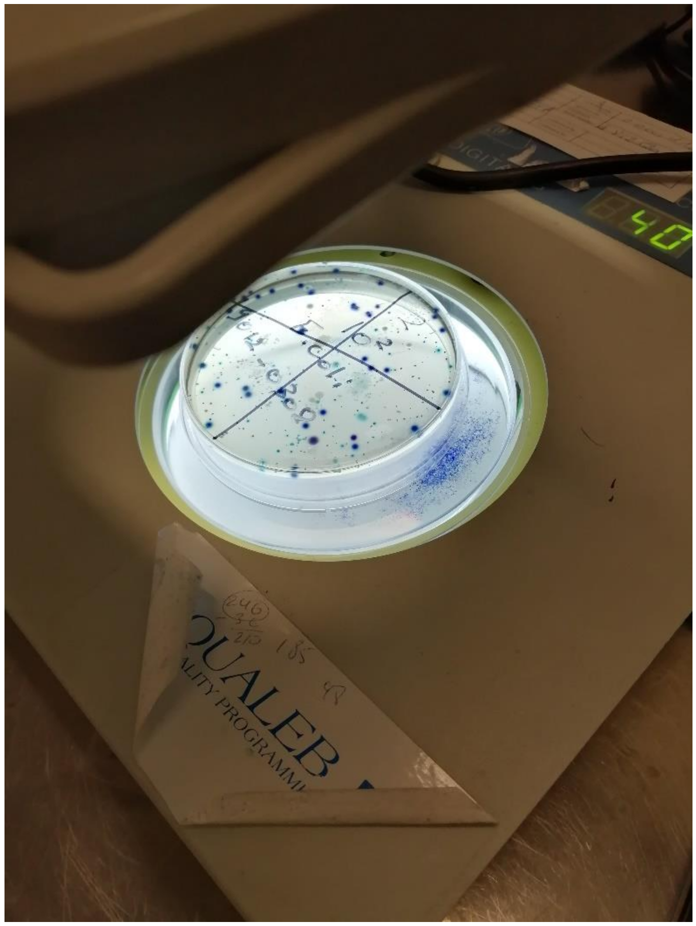


Figure 1: Lab work

APPENDIX C

Table 1: Soil physiochemical parameters

	COD (mg/kg)	pH	TN(mg/Kg)	Sulfate(mg/kg)	TDS (mg/L)	EC (uS/cm)	Phosphae (mg/kg)
S1	432.5 +/- 357.09	8.3 +/- 0.83	1500 +/- 223.61	117	97 +/- 69.5	194 +/- 140.0	<1
S1a	320 +/- 113.14	8.5 +/- 0.79	1600 +/- 141.42	51.5	95 +/- 94.4	190 +/- 188.8	<1
S1b	437.5 +/- 434.87	8.6 +/- 0.80	2300 +/- 100.00	367	75 +/- 71.3	149 +/- 142.8	8.1
S2	170 +/- 84.85	8.5 +/- 0.75	700 +/- 100.00	301.6	116 +/- 135.8	317 +/- 152.7	<1
S2a	125 +/- 91.92	8.6 +/- 0.77	1600 +/- 141.42	283	65 +/- 55.2	129 +/- 109.6	<1
S3	1697.5 +/- 1460.18	8.3 +/- 1.37	1900 +/- 1063.01	535	32 +/- 13.8	64 +/- 27.6	<1
S3a	352.5 +/- 456.46	8.7 +/- 0.79	900 +/- 424.26	<50	33 +/- 16.1	66 +/- 32.0	<1
S3b	290 +/- 141.42	8.7 +/- 0.74	700 +/- 360.56	<50	54 +/- 38.0	108 +/- 76.4	<1
S4	435 +/- 473.76	8.7 +/- 1.08	900 +/- 0.00	537	132 +/- 143.3	254 +/- 272.9	3.31
S4a	352.5 +/- 243.95	8.4 +/- 0.96	2700 +/- 282.84	50	63 +/- 58.8	127 +/- 117.4	<1
S4b	122.5 +/- 45.96	8.5 +/- 0.84	1700 +/- 100.00	34.2	53 +/- 40.0	107 +/- 79.9	11.25
S5	332.5 +/- 81.32	8.5 +/- 0.71	1500 +/- 100.00	296.5 +/- 232.6381	174 +/- 127.0	350 +/- 253.1	2.54
S5a	885 +/- 1208.19	8.5 +/- 0.82	1400 +/- 781.02	61	52 +/- 37.1	103 +/- 74.2	<1
S5b	267.5 +/- 337.02	8.4 +/- 0.88	1900 +/- 781.02	50.7	45 +/- 33.5	90 +/- 66.5	<1

S6	1995 +/- 1477.85	8.4 +/- 1.17	2400 +/- 1838.48	511	192 +/- 214.4	386 +/- 429.2	<1
S6a	125 +/- 35.36	8.4 +/- 0.84	1900 +/- 141.42	<51	59 +/- 46.0	118 +/- 91.9	4.45
S6b	335 +/- 431.83	8.6 +/- 0.74	2000 +/- 223.61	37.6	50 +/- 37.2	100 +/- 75.0	<2
S7	552.5 +/- 53.03	8.6 +/- 1.53	1100 +/- 1131.37	591	155 +/- 187.8	310 +/- 375.5	11.1
S7a	345 +/- 388.91	8.5 +/- 0.72	1500 +/- 282.84	35.5	38 +/- 24.9	73 +/- 51.6	<1
S7b	29.5 +/- 394.27	8.6 +/- 0.67	1800 +/- 500.00	381	61 +/- 51.2	121 +/- 101.8	<1
S8	407.5 +/- 449.01	8.4 +/- 1.17	1600 +/- 781.02	50 +/- 3.7	25 +/- 0.4	50 +/- 1	<1
Limits1		6.8-7.5	1000 to 1500	<3000		<2000	

Table 2: Soil heavy metal concentrations

mg/kg	Sodium	Potassium	Chromium	Manganese	Iron	Nickel	Copper	Zinc	Arsenic	Selenium	Cadmium	Lead
S1	1149 +/- 977	5460 +/- 1867	66 +/- 13	401 +/- 35	11170 +/- 12205	34 +/- 5	41 +/- 16	121 +/- 2	19 +/- 11	1 +/- 1	1 +/- 0	21 +/- 0
S1a	282 +/- 12	770 +/- 20	70 +/- 1	25 +/- 0	6175 +/- 120	26 +/- 1	13 +/- 3	29 +/- 5	22 +/- 2	1 +/- 0	0.1 +/- 0.4	2 +/- 0
S1b	282 +/- 161	3735 +/- 375	89 +/- 17	427 +/- 66	21900 +/- 7354	59 +/- 9	20 +/- 2	64 +/- 7	2620 +/- 3692	1 +/- 0	0.6 +/- 0.6	8 +/- 3
S2	883 +/- 605	1877 +/- 2648	86 +/- 18	352 +/- 80	21250 +/- 212	36 +/- 4	100 +/- 119	177 +/- 146	18 +/- 0	2 +/- 1	1 +/- 0	23 +/- 20
S2a	317 +/- 51	3945 +/- 3656	87 +/- 33	390 +/- 379	19650 +/- 12799	40 +/- 7	25 +/- 18	63 +/- 1	16 +/- 2	0.1 +/- 0.4	0.1 +/- 0.4	11 +/- 5
S3	8781 +/- 11906	2720 +/- 764	68 +/- 28	179 +/- 56	18700 +/- 141	32 +/- 11	31 +/- 7	124 +/- 25	20 +/- 18	1 +/- 1	0.1 +/- 0.3	13 +/- 5
S3a	1920 +/- 2461	11920 +/- 11993	140 +/- 40	568 +/- 11	35150 +/- 4879	77 +/- 21	282 +/- 370	968 +/- 1262	11 +/- 1	2 +/- 0	5 +/- 6	9 +/- 3
S3b	303 +/- 109	3195 +/- 2454	82 +/- 6	374 +/- 391	24570 +/- 21397	45 +/- 21	20 +/- 9	57 +/- 3	6 +/- 6	1 +/- 0	0.1 +/- 0.4	7 +/- 3
S4	770 +/-	1815 +/-	29 +/-	98 +/-	9055 +/-	32 +/-	10 +/-	34 +/-	12 +/-	0.9 +/-	0.1 +/-	60 +/-

	39	318	2	41	6569	19	1	5	11	0.9	0.3	63
S4a	165 +/- 213	2240 +/- 1640	39 +/- 52	219 +/- 288	10325 +/- 13400	30 +/- 40	10 +/- 13	29 +/- 36	3 +/- 2	0.3 +/- 0.5	0.1 +/- 0.2	4 +/- 3
S4b	232 +/- 55	4425 +/- 2086	82 +/- 8	348 +/- 115	19800 +/- 4384	48 +/- 3	18 +/- 7	66 +/- 16	9 +/- 4	1 +/- 0	0.4 +/- 0.1	12 +/- 2
S5	426 +/- 478	2690 +/- 410	47 +/- 51	180 +/- 193	14590 +/- 16419	31 +/- 32	148 +/- 200	102 +/- 112	15 +/- 8	0.6 +/- 0.7	1 +/- 1	19 +/- 22
S5a	227 +/- 270	6340 +/- 4228	91 +/- 104	456 +/- 513	17485 +/- 17416	55 +/- 64	20 +/- 24	63 +/- 72	7 +/- 8	0.5 0.5	0.2 0.3	7 +/- 7
S5b	410 +/- 122	8045 +/- 2510	138 +/- 2	678 +/- 44	32600 +/- 9475	78 +/- 15	28 +/- 4	112 +/- 26	13 +/- 6	2 +/- 1	0 +/- 0	15 +/- 10
S6	912 +/- 139	3940 +/- 1640	99 +/- 30	332 +/- 45	23050 +/- 6293	57 +/- 1	295 +/- 318	695 +/- 460	11 +/- 5	2 +/- 0	2 +/- 2	99 +/- 49
S6a	252 +/- 278	2280 +/- 580	62 +/- 57	104 +/- 44	5675 +/- 2171	31 +/- 23	15 +/- 15	45 +/- 39	10 +/- 9	0.4 +/- 0.4	0.2 +/- 0.3	6 +/- 2
S6b	143 +/- 164	1542 +/- 1002	70 +/- 74	191 +/- 202	7745 +/- 7432	48 +/- 52	17 +/- 19	42 +/- 43	9 +/- 10	0.3 0.4	0.2 0.3	4 +/- 3
S7	493 +/- 467	1081 +/- 1003	17 +/- 15	49 +/- 34	992 +/- 1398	7 +/- 5	9 +/- 10	46 +/- 59	5 +/- 4	1 +/- 0.1	0.04 +/- 0.4	8 +/- 11

S7a	212 +/- 262	3170 +/- 1768	55 +/- 63	312 +/- 360	18080 +/- 19544	41 +/- 48	13 +/- 16	36 +/- 43	4 +/- 4	0.4 +/- 0.4	0.1 +/- 0.4	6 +/- 6
S7b	317 +/- 62	5515 +/- 64	117 +/- 21	777 +/- 156	41500 +/- 3818	80 +/- 5	21 +/- 13	78 +/- 23	10 +/- 3	1 +/- 1	0.2 +/- 0.3	15 +/- 2
S8	109 +/- 144	3042 +/- 3729	34 +/- 46	215 +/- 290	8605 +/- 11345	23 +/- 27	7 +/- 9	24 +/- 28	8 +/- 10	1 +/- 10	0 +/- 8	5 +/- 6

APPENDIX D

Below is a sample calculation done to reach the 4 pairwise comparison matrices. First step is to identify the eign or importance value of each alternative. In this examples A1 and A2 were compared for the environmental criteria.

A1	**Environmental criteria**	**A2**
+	Life span	++
+	By product	++
+	Natural resource	++

A1 and A2 are very similar in terms of their contribution to achieve environmental conditions. Importance value was assigned for the alternative that was best for conservation and reclamation of natural resources, being a sustainable solution that could persist for couple of years while having minimal environmental disadvantages or ones that could be easily mitigated. Thus, 4 was the allocated importance value indicating that importance of A2 over the other is clear but not strong.

Importance of A1 over A2 with respect to environmental conditions								
9	7	5	3	1	3	5	7	9

**If importance value is on the left side of 1, we put the actual importance value.*

If the importance value is on the right side of 1, we put the reciprocal value.

After comparison of all 4 alternatives with respect to environmental criteria the following matrix was formed:

$$\begin{bmatrix} 1 & 1/4 & 1/6 & 1/3 \\ 4 & 1 & 1/4 & 7 \\ 6 & 4 & 1 & 7 \\ 3 & 1/7 & 1/7 & 1 \end{bmatrix}$$

Which is equivalent to the table below

C2	A1	A2	A3	A4
A1	1	1/4	1/6	1/3
A2	4	1	1/4	7
A3	6	4	1	7
A4	3	1/7	1/7	1

Second step is to calculate the principal Eigen vector or priority vector by finding the geometric mean (GM) of each row using equation (8). Having the priority vector now, it's important to calculate to calculate the consistency index (CI) using equation (9). It is a measure that shows how consistent our matrices are. It is important that the largest eign value be equal to the number of comparisons λmax=n. Consistency ratio (CR) is the calculated, using equation (10) to show how much the calculated value is deviated from the expected real one (RI). Table 1 illustrates the equations used to calculate the priority vector of the pairwise comparison table, below example, based on environmental criteria.

$$\begin{bmatrix} 1 & 1/4 & 1/6 & 1/3 \\ 4 & 1 & 1/4 & 7 \\ 6 & 4 & 1 & 7 \\ 3 & 1/7 & 1/7 & 1 \end{bmatrix} = \begin{bmatrix} 0.06 \\ 0.21 \\ 0.65 \\ 0.09 \end{bmatrix}$$

Table 1: Calculation of the priority vector

<table>
<tr>
<td>(8)</td>
<td>

$$GM = (1/n)^\wedge(aij * aij \ldots)$$

(A1): 1*1/4*1/6*1/3=$(0.014)^{(1/4)}$= 0.316

(A2): 4*1*1/4*7=$(7)^{(1/4)}$= 1.169

(A3): 6*4*1*7=$(168)^{(1/4)}$= 3.6

(A4): 3*1/7*1/7*1= $(0.061)^{(1/4)}$ =0.49

$$\sum GM = 0.316 + 1.169 + 3.6 + 0.49 = 5.58$$

Normalize for priority vectors:

A1: 0.316/5.58 = **0.06**

A2: 1.17/5.58 = **0.21**

A3: 3.6/5.58= **0.65**

A4: 0.49/5.58= **0.09**

</td>
<td>Where:
aij is the element of row i column j
n is the number of rows</td>
</tr>
<tr>
<td>(9)</td>
<td>

$$CI = (\lambda max - n)/(n - 1)$$

<table>
<tr><td>C2</td><td>A1</td><td>A2</td><td>A3</td><td>A4</td><td>Priorities</td></tr>
<tr><td>A1</td><td>1</td><td>1/4</td><td>1/6</td><td>1/3</td><td>0.06</td></tr>
<tr><td>A2</td><td>4</td><td>1</td><td>1/4</td><td>7</td><td>0.210</td></tr>
<tr><td>A3</td><td>6</td><td>4</td><td>1</td><td>7</td><td>0.65</td></tr>
<tr><td>A4</td><td>3</td><td>1/7</td><td>1/7</td><td>1</td><td>0.09</td></tr>
<tr><td>∑</td><td>14.00</td><td>5.39</td><td>1.56</td><td>15.33</td><td></td></tr>
</table>

</td>
<td>Where:

CI is the consistency index

λmax is the principal eigen value it is obtained from the summation of products between each element of eigen vector and the sum of columns of the reciprocal matrix</td>
</tr>
</table>

	λmax= (14*0.06)+(5.39*0.2)+(1.56*0.65)+(15.33*0.09)= 4.28 CI = (4.28-4)/4-1= 0.09	
(10)	$$CR = CI/RI$$ RCI values for different values of n (Saaty, 1980): n: 2, 3, 4, 5, 6, 7, 8, 9, 10 RI: 0, 0.58, 0.9, 1.12, 1.24, 1.32, 1.41, 1.45, 1.51 CR=0.09/0.9=0.1 CR should be less than or equal to 10% to indicate that the present inconsistency is acceptable.	Where: CR is the consistency ratio RI is the appropriate Consistency index set by Saaty (1980)

Similar matrices were formed comparing alternatives with respect to C1 and C3.

Also, a fourth matrix was formed to calculate then weights of the three criteria (Table 2)

Table 2: Pairwise comparison matrices

Weights	C1	C2	C3	Priorities	% Priorities
C1	1	1/4	1/4	0.10	10.48
C2	4	1	3	0.60	60.46
C3	4	1/3	1	0.29	29.06
Sum	9.00	1.58	4.25		

λ max	3.1
CI	0.1
CR	0.1

C1	A1	A2	A3	A4	Priorities	% Priorities
A1	1	5	7	3	0.55	55.37
A2	1/5	1	1/3	1/5	0.06	5.88
A3	1/7	3	1	1/5	0.09	9.36
A4	1/3	5	5	1	0.29	29.39
Sum	1.68	14.00	13.33	4.4		

λ max	4.3
CI	0.1
CR	0.1

C2	A1	A2	A3	A4	Priorities	% Priorities
A1	1	1/4	1/6	1/3	0.06	5.67
A2	4	1	1/4	7	0.21	20.97
A3	6	4	1	7	0.65	64.57
A4	3	1/7	1/7	1	0.09	8.79
Sum	14	5.39	1.56	15.33		

λ max	4.28
CI	0.09
CR	0.10

C3	A1	A2	A3	A4	Priorities	% Priorities
A1	1	4	6	1/3	0.3	30.0
A2	1/4	1	1/4	1/6	0.1	5.5
A3	1/6	4	1	1/6	0.1	10.0
A4	3	6	6	1	0.6	55.6
Sum	4.4	15.0	13.3	1.7		

λ max	4.4
CI	0.1
CR	0.1

REEFERNCES

Anikwe, M. N., K (2002). Long term effect of mincipal waste disposal on soil properties and productivity of sites used for urban Agriculture in Alakaliki Nigeria. *Bioresource Technology*, 83(3), 241-250.

Ahlback, J, (2011). Green Jobs Assessment in Lebanon. UNDP

Artiningsih, A, et al., (2018). Distribution of Escherichia Coli as Soil Pollutant around Antang Landfills. *Journal of Physics: Conference Series*, 979 (2018) 012042

Ayenew, B & Meride, Y, (2016). Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia. *Environmental Systems Research*. 5(1)

Ayers, R & Westcot, D, (1985). Food and Agriculture Organization of the United Nations

Asaduzzaman, M et al., (2017). Assessment of pH and Total Dissolved Substances (TDS) in the Commercially Available Bottled Drinking Water. *Journal of Nursing and Health Science*, 6(5):35-40

Azzi, E, (2017). Waste Management Systems in Lebanon The benefits of a waste crisis for improvement of practices. Kth Royal Institute of Technology School of Architecture and The Built Environment

Abiodun, A , et al., (2018). Effects of Municipal Waste Disposal Methods on Community Health in Ibadan – Nigeria. *Polytechnica* 1: 61–72

Aleya, L et al., (2010). Survival of pathogenic and indicator organisms in groundwater and landfill leachate through coupling bacterial enumeration with tracer tests. *Desalination*

Akpor, O, & Muchie, M, (2011). Environmental and public health implications of wastewater quality. *African Journal of Biotechnology.* 10(13): 2379- 2387

Akinneye, J, & Ogunleye, A, (2019). The Bacteriological Assessment of Two Dumpsites in the City of Akure, Ondo State, Nigeria. *International Journal of Research and Scientific Innovation*. 6(4): 78- 83

Burcea, S. (2015). The Economical, Social and Environmental Implications of Infomal Waste Collection and Recycling. *Theoretical and Empirical Researches in Urban Management*, 10(3), 14-24.

Badmos et al., (2017). Impact of Dumpsites on the Quality of Soil and Groundwater in Satellite Towns of the Federal Capital Territory, Abuja, Nigeria. *Journal of Health & Pollution*. 7(14): 15-22

Badmus et al., (2014). Groundwater Assessment of Hand Dug Wells around Open Landfill in Ibadan Metropolis for Domestic and Irrigation Purposes. *Journal of Water Resource and Protection*. 6: 1412-1424

Banunle et al., (2020). Municipal waste dumpsite: Impact on soil properties and heavy metal concentrations, Sunyani, Ghana. *Scientific African* ,8

Brinkhof, P, (2012). Multi-Criteria Analysis for Assessing Sustainability of Remedial Actions Applications in Contaminated Land Development. *Chalmers*. 2011:14

Butler, N, (2017). Is alkaline water good for you. *Medical News Today*

Brunton, V, (2011). Irrigation water quality. *New South Wales Department of Primary Industries, Department of Primary Industries*

Chimuka, L. e. a. (2005). Metals in environmental media: a study of trace and plantinum group metals in ThohyandouSouth Africa. *Water SA*, 31, 581-588.

Chandra,A et al., (2006). Leachate Characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental Monitoring and Assessment*. 118(1-3):435-456

Corwin,D & Yemoto,K, (2019). Measurement of Soil Salinity: Electrical Conductivity and Total Dissolved Solids. *Soil Science Society of America Journal*. 83(1): 1-2

Chapman, D & Kimstach, V, (1996). Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition. WHO

Chaudhari,K, 2013. Studies of the physicochemical parameters of soil samples. *Advances in Applied Science Research*.4(6):246-248

Chaaya, M et al., (2017). The protracted waste crisis and physical health of workers in Beirut: a comparative cross-sectional study. *Environmental Health*. 16: 39

Dubey, A. e. a. (2016). Landfill mining as a remediation technique for open dumpsites in India. *Procedia Environmental Sciences*, 35, 319 – 327

Damanhuri, E, et al., (2005). Stability of Landfills- The Bandung Dumpsite Desaster . *International Waste Management and Landfill Symposium. Sardinia, Cagliari, Italy*

Frostell, B. e. a. (2014). Progress and challenges to the global waste management system. *Waste Management & Researc*h, 32(9) 800–812.

Folaranmi et al.,(2007). Studies on the Impact of Municipal Waste Dumps on Surrounding Soil and Air Quality of Two Cities in Northern Nigeria. *Journal of Applied Sciences*. 7: 421-425.

Fazzo,M et al., (2011). Ecological studies of cancer incidence in an area interested by dumping waste sites in Campania. *Annali dell'Istituto Superiore di Sanità*. 47(2): 181-191

Forastiere, F et al., (2009). Systematic review of epidemiological studies on health effects associated with management of solid waste. *Environmental Health*. 8: 60

Ghani, A & Zohoori, M., (2017). Municipal Solid Waste Management Challenges and Problems for Cities in Low-Income and Developing Countries. *International Journal of Science and Engineering Application*. 6: 39-48

Herbert et al., (2008). Nitrogen Mineralization in Selected Solid Waste Dumpsites in Port Harcourt, Nigeria. *Journal of Applied Sciences and Environmental Management*. 12(3): 89 - 93

Hansen, B, et al., (2017). Groundwater nitrate response to sustainable nitrogen management. *Scientific Reports*. 7, 8566

Hussain et al., (2014). Quality Assessment of Soil at municipal solid waste dumpsite and possibilities of reclamation of land. *International Journal of Innovative Science, Engineering & Technology*. 1(7): 274-294

Hindustantimes, (2016). Methane trapped beneath makes Ghazipur landfill a ticking time bomb

Hindustantimes, (2016). NASA satellites capture thick smog caused by Deonar fire

ISWA. (2007). Key Issue Closing of open dumps.

Joseph et al., (2008). Dumpsite Rehabilitation Manual. Anna University, Centre for Environmental Studies

Jonnalagadda, S. B., & Mhere, G. (2001). Water quality of the Odzi River in the eastern highlands of Zimbabwe. *Water Research*. 35(10):2371–2376.

Kannel, P et al., (2007). Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment. Environmental Monitoring and Assessment.132: 93–110

Kabir, R & Shamoye, F, (2016). Health Effects of Solid Waste Disposal at a Dumpsite on the Surrounding Human Settlements. *Journal of Public Health in Developing Countries*. 2(3): 268-275

Kimani, N, (2007). Environmental Pollution and Impact to Public Health; Implication of the Dandora Municipal Dumping Site in Nairobi, Kenya. The United Nations Environment Programme (UNEP)

Kass,S & Gilberth,P , (2006). Adverse Birth Outcomes Associated with Open Dumpsites in Alaska Native Villages. American Journal of Epidemiology. 164(6):518-28

Kubo et al., (2016). Potassium behavior and clay mineral composition in the soil with low effectiveness of potassium application. *Journal Soil Science and Plant Nutrition*. 64(2)

Kerry, F, (2016). Twenty-four people missing after deadly garbage dump accident in Guatemala, Business Insider

Lemanowicz,J & Jaworska, H, (2019). Heavy metal contents and enzymatic activity in soils exposed to the impact of road traffic. *Scientific Reports*. 9,19981

Mbeng , L, et al., (2009). Developing Sustainable Waste Management Practice: Application of Q Methodology to construct new Strategy Component in Limbe- Cameroon. *The Open Waste Management Journal*. (2): 27-36.

Muller, G, (1969). Index of geo-accumalation in sediments of Rhine River. Geochemical Journal. 2: 108-118

Martuzzi, M. e. a. (2009). Cancer mortality and congenital anomalies in a region of Italy with intense environmental pressure due to waste. *Occupational and Environmental Medicine*, 66(11), 725.

Mavropoulos et al. (2016). A Roadmap for closing Waste Dumpsites The World's most Polluted Places. International Solid Waste Association (ISWA).

Moon, C et al., (2017). Dynamics and genetic diversification of Escherichia coli during experimental adaptation to an anaerobic environment. *PeerJ — the Journal of Life and Environmental Scienc*es. 5: e3244

MOPH, (2016). National Cancer Registry

Nandi, F, (2014). Capital dumps a fortune at its landfills. The times of India City

Newman et al. (2015). Wasted Health The Tragic Case of Dumpsites. International Solid Waste Association (ISWA).

Ngabirano et al., (2016). Effects of seasonal variations in physical parameters on quality of gravity flow water in kyanamira sub-county, Kabale District, Uganda. *Journal of Water Resources*. 8:1297–1309

Netaji,C, et al., (2017). Open Dumping of Municipal Solid Waste – Impact on Groundwater and Soil. *International Journal of Current Engineering and Scientific Research*. 4(6): 2394-0697

Obasi et al., (2012). Assessment of Physico-chemical Properties and Heavy Metals Bioavailability in Dumpsites along Enugu-port Harcourt Expressways, South-east, Nigeria. Asian *Journal of Applied Sciences*. 5 (6): 342-356

Okieimen et al., (2011) Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. *International Scholarly Research Notices Ecology*. 2011

Olurin et al., (2014). Groundwater Assessment of Hand Dug Wells around Open Landfill in Ibadan Metropolis for Domestic and Irrigation Purposes. *Journal of Water Resource and Protection*. 6(15): 1412-1424

Osuocha, K, et al., (2016). Seasonal impact on phyto-accumulation potentials of effected edible vegetables grown in Ishiagu quarry mining effluent discharge soils. *African Journal of Environmental Science and Technology*. 10(1): 34-43

Pondhe, G. e. a. (2015). Public Health Risk and Environmental Impact Associated with Disposal of Urban Waste at Sangamner City, Ahmednagar, Maharashtra, India. *International Journal of Preventive and Public Health Sciences*, 1(2), 5-8.

Perlez,J, (2016). China Cites Negligence as Cause of Landslide That Killed 73. The New York Times

Pesce, S. F., & Wunderlin, D. A. (2000). Use of water quality indices to verify the impact of Cordoba City (Argentina) on Suquýa River. *Water Research*. 34(11): 2915–2926

Qamar, Z et al ., (2015). The uptake and bioaccumulation of heavy metals by food plants,their effects on plants nutrients, and associated health risk:a review. *Environmental Science and Pollution Research*. 22:13772–13799

Saha, A, et al., (2015). Impact of municipal waste dumping on soil and water around a dump site in Rajshahi city. Institute of Environmental Science, Rajshahi University

Santa, R. (2001). A Guide to Closing Solid Waste Disposal Sites in Alaska Villages. *Alaska Department of Environmental Conservation.*

Schmitz, K, (2017). Gibbs Free Energy, Work, and Equilibrium. 13:99-157

Sullivan et al., (2017). Soil Test Interpretation Guide. Oregon State University

Saaty, T, (1980). The Analytic Hierarchy Process. McGraw-Hill International, New York, NY, U.S.A.

SYNOVA. (2019). People produce vastly more waste than our planet can sustain.

Salameh et al., (2014). Congenital Anomalies: Prevalence and Risk Factors. *Universal Journal of Public Health.* 2(2): 58-63

Saidu, S, (2016). Assessment of dumpsite impact on soil and groundwater quality in Tudun Wada, Kaduna. Ahmadu Bello University

Sasikaran, S et al (2012). Physical, chemical and microbial analysis of bottled drinking water. *Ceylon Medical Journal* 57(3):111–116

Sutton, D et al., (2014). Heavy Metals Toxicity and the Environment. *Health & Human Services*. 101: 133–164

Tazdiat et al., (2019). A Study of the Impact of Municipal Solid Waste on Some Soil Physicochemical Properties: The Case of the Landfill of Ain-El-Hammam Municipality, Algeria. *Applied and Environmental Soil Science.*

Tanee et al., (2017). Physicochemical Characteristics of Soil from Selected Solid Waste Dump Sites in Port Harcourt, Rivers State, Nigeria. *Journal of Applied Sciences and Environmental* Management. 21(6): 1153-1156

Turekian, K et al., (2007). Distribution of elements in some major units of earth's crust. Geology SocAm Bull. 72:175-192

UNEP. (2005). Training Modules Closing of an Open Dumpsite and Shifting from Open Dumping to Controlled Dumping and to Sanitary Landfilling.

Uba et al., (2008). Assessment of heavy metals bioavailability in dumpsites of Zaria Metropolis, Nigeria. *African Journal of Biotechnology*. 7(2): 122-130

Victor et al., (2006). Soil quality around a solid waste dumpsite in Port Harcourt, Nigeria. *African Journal of Ecology.* 44(3):388 – 394

Wilson, D et al., (2012). Comparative analysis of solid waste management in 20 cities *Waste Management & Research*, 30, 237–254.

Wilson et al. (2015). Global Waste Management Outlook Summary for Decision-Makers. International Solid Waste Association (ISWA).

Winsor, M, (2016). Angola's Yellow Fever Outbreak Death Toll Rises To 158 Amid Luanda's Sanitation Crisis. International Business Times

Weil, R and Brady, R, (2017). Phosphorous and Potassium. The Nature and Properties of Soils. 15th ed (14): 6433-695

Wright, J, (2003). Environmental Chemistry. Routledge Introduction to Environments

World Bank, (2018). Global Waste to Grow by 70 Percent by 20150 Unless Urgent Action is Taken: World Bank Report.

WHO, (2011). Guidelines for drinking-water quality, fourth edition

WHO, (2016). Angola grapples with worst yellow fever outbreak in 30 years

Wade, K, (2019). Got a plant with a problem. PlantProbs

Yasmin, A. e. a. (2014). Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city. *Journal of King Saud University - Science*, 26(1), 59-65.

Yao et al., (2012). Influence of Traffic Activity on Heavy Metal Concentrations of Roadside Farmland Soil in Mountainous Areas. *International Journal of Environmental Research and Public Health*. 9(5): 1715–1731.

Zohoori, M. G., A. (2017). Municipal Solid Waste Management Challenges and Problems for Cities in Low-Income and Developing Countries. I*nternational Journal of Science and Engineering Applications*, 6(2).

Zhou, C et al., (2015). A cost-benefit analysis of landfill mining and material recycling in China. *Waste Management*. 35:191-198