LANDFILL SUITABLITY ANALYSIS USING AHP METHOD AND STATE OF HEAVY METALS POLLUTION IN SELECTED LANDFILLS IN OMAN

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Abstract

Site suitability or vulnerability for landfills analysis is a complex procedure which involves evaluating of various factors. Multi-criteria decision analysis is a useful tool in making landfill site suitability decisions by providing consistent weightings. In this study, the necessary criteria were gathered through literature review. Eleven different criteria were defined to assess suitability of three unlined landfill sites in Muscat (Al Amirat, Al Mabella and Bousher) as a first study on landfill site suitability and leachate assessment in Oman. The data on the status of each landfill in relation to different criteria were gathered both from maps, field investigations and were analyzed using analytical hierarchy process (AHP) pairwise comparison method. It is found that Al Amirat with a score of 0.375 is the most suitable site while Bousher with a score of 0.309 is the most vulnerable unlined landfill. leachate from the most suitable landfill (Al Amirat) was assessed for heavy metals contamination. The results of heavy metals investigation showed that the leachate was contaminated with considerable concentrations of Al, V, Cr, Mn, Co, Ni, Cd, Ba, Pb and Fe. Since various types and amounts of waste are entering landfills, more caution should be given in selection of landfills sites at the first place to avoid any threat to the environment. The criteria used in this study will give better understanding to decision makers and justify the uncertainty in decision-making for the future site selection in Oman.

Keywords: Landfill, Heavy metals, Oman, Leachate

Introduction

Waste is an old and growing problem in the world. Its generation is one of the most significant concerns that threaten the environment (Leao *et al* 2004). Different methods for waste management exist. Landfilling is the predominant method of disposal in most of the countries because it is the most economical option and it allows most solid wastes to be decomposed under controlled conditions. Thus, this method is still and expected to be applied for the disposal of solid wastes (Pichtel 2005). Landfill activities in cities have a serious impact on different aspects like economy, ecology and the environmental health of the area. With population growth, lager amount of wastes are generated and unfortunately the problem is getting even bigger (Akbari *et al* 2008).Landfill operations are a source of concern to the local people because of problems such as gases, leachate, water pollution, litter, flies, dust, odor, fire, traffic and noise (EPA 1993).

Before locating any site for landfill practices, assessment of landfill site suitability should be conducted. This requires preliminary assessment of site conditions and potential impacts on the environment (***EPA*** 2006). During the selection of most suitable location for a landfill, some factors should be considered to minimize the impact of landfill on the surrounding environment like geology, hydrogeology and others (EPA 2006). Unfortunately, site selection is generally based on geographical rather than geological and hydrogeological considerations. Therefore, it is common to find landfills surrounded by residential areas. Factors like hauling distance and land availability were only considered during site selection. Obviously, such sites pose a serious health impact due to groundwater quality deterioration and airborne contamination. However, with the growing knowledge and awareness, new factors are considered such as topography, soil structure, geology, hydrogeology and others (EPA 2006; Kabite 2011). For landfill site suitability analysis, Multicriteria Decision Analysis (MCDA) is commonly used to provide decision makers the most satisfactory alternative.

The evaluation of land suitability is based on the environmental characteristics of the site and proximity to vulnerabilities. However, choosing safe site for landfill activities or even identifying its actual suitability for such practices is not an easy mission. It is tedious, costly and requires multi- criteria decision making which is difficult to handle (Kabite 2011). That’s why most of the existing landfills do not fall within the criteria of safe distances to sensitive areas (Mohobane 2008). Thus, inorder to assess the site suitability of existing landfills and identify different sites vulnerabilities, a detailed assessment of site conditions should take place including a review of available information and a program of site investigation (EPA 2006)

Analytic hierarchy process (AHP) is and continues to be one of the most popular analytical techniques for complex decision making problems and is widely used due to its flexibility and easy to use. An AHP hierarchy can have many levels to characterize a decision condition. The selected factors governing the suitability of the site are weighted using the Analytical Hierarchy Process (AHP) which is aided by pairwise comparison matrix that uses a scale of relative importance. Once the weights are determined, the score of alternatives is evaluated to get the rank of the alternatives (Sener 2004). Landfills pose a big problem to the environment in which during landfill operations, different kinds of hazards including gas and leachate are produced (Modin 2012). The leachate problem is worsened by the fact that many landfills lack an appropriate bottom liner or collection system; increasing the possibility of dissipation of leachate through the landfill layers to contaminate ground water (kanmani & Gandhimathi 2013). It can cause serious pollution problems when it gets in contact with the surrounding soil, surface water and ground water leading to detrimental effects on living organisms (Adeolu *et al* 2011). One of the most hazardous components in leachate is heavy metals. There is a growing concern regarding the buildup of heavy metals in soil and ground water. Different kinds of wastes are responsible for the presence of heavy metals in the landfills (Adeolu *et al* 2011).

Sultanate of Oman produces about 1 million ton of waste per year. It is one of the various countries that use unlined landfills to manage its waste. These landfills lack gas and leachate collection systems. Moreover, most of these sites lack the main criteria required for landfill site selection. Muscat landfills are located in vicinity to residential areas. The main reasons for closing the sites are because the sites became full, population movement towards the site, continuous flaring and continuous citizen complaints. Thus, the objective of this study was to assess the suitability/vulnerability of three existing landfills, Al Mabella, Al Amirat and Bousher in Muscat using AHP pairwise comparison as a first study on landfill sites vulnerability assessment in Oman. Also, to evaluate the extent of heavy metals contamination in the leachate of the most suitable site from this study.

Waste management situation in Oman and study area description

The components of the waste in Muscat are organic, sewage, industrial, construction, agricultural, textiles, metals, plastics, transport, and paper. More than half of the waste generated in Muscat is organic. The disposal method applied in Muscat is landfilling in which MSW are deposited in a confined area, spread in thin layers, compacted with tractors to reduce its volume and covered with a layer of soil (MM 2010). There are more than 368 waste disposal sites in Oman. Five of them are located in

Muscat in which all of them are closed except one. Three unlined landfills in Muscat: Al Mabella, Al Amirat and Bousher were studied inorder to identify the vulnerability of each site. Table 1 shows the location of these landfills.

Table 1.Location of Al Amirat, Al Mabella and Bousher closed unlined landfills

	Al Amirat landfill	**Al Mabella landfill**	**Bousher landfill**
Location (UTM)	E 655578 N 2597008	E 613160 N 2610248	E 638166 N 2599528

These unlined landfill lack gas and leachate collection systems. Most of the sites are fenced and guarded and the waste is compacted and covered with layers of soil in all the sites (MM 2010). Table 2 shows the status and management of the unlined landfills in Muscat.

Table 2. Status and management of the unlined landfills in Muscat

	Al Amirat	**Al Mabella**	**Bousher**
Start Operating	1982	1984	1985
Current sitiuation	Closed in 2010, (accepting demolition waste only)	Closed in 2010	Closed in 2004
Compaction	Yes	Yes	Yes
Distance from population centre	0.3 km	0.4 km	0.9 km
Fenced	Yes	No	Yes
Weight recorded	Yes	Yes	Yes
Guarded	Yes	Yes	Yes
Control gate	Yes	Yes	Yes
Covering of waste	Yes	Yes	Yes

When these unlined landfills were established, factors like hauling distance and land availability were mainly considered during site selection. However, with the growing knowledge and awareness, new criteria are considered. The Total waste quantities accepted in these landfills has increased from 2001 to 2009 as shown in Table 3.

Table 3.Total waste quantities accepted in Al Mabella, Al Amirat and Bousher landfills in 2009 (MM 2010)

	Al Mabella unlined Landfill	**Al Amirat unlined landfill**	**Bousher unlined landfill**
Total in Tons (2001)	73824	18540	49104
Total in Tons (2009)	645376	658549	Not Available

Material and methods

Multicriteria Decision Analysis (MCDA) is commonly used for landfill site selection to provide decision makers the most satisfactory and preferable alternative (Sener 2004). The AHP method is a decision making method implemented by such an analysis to identify the priority of alternatives when many criteria are considered. It ranks the alternatives based on the decision maker's judgments regarding the importance of each criteria. It is a powerful and flexible decision making tool to help people set priorities and make the best decision (Kabite 2011). In this study, classification and rating of classes for every criterion was based on international standards extracted from various literatures (Sener 2004 ; Akbari 2008 ; EPA 1993; EPA 2006; Kabite 2011; Khanlari 2012; Leao *et al* 2004). The relative importance or preference of criteria was determined using the pair-wise comparison matrix in which Saaty's nine-point weighing scale has been applied. In this step, all identified factors were compared against each other in a pair wise comparison matrix which is a measure of relative importance/preference among the factors as numerical values. The scale for comparison consists of values ranging from 1 to 9 which describe the intensity of importance, by which a value of 1 expresses equal importance and a value of 9 is given to those factors having an extreme importance over another factor as shown in Table 4.

Table 4. Scale of pairwise comparison

Intensity of importance	**Definition**
1	Equal importance
2	Equal to moderate importance
3	moderate importance
4	Moderate to strong importance
5	strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

In AHP, at first the decision problem was decomposed into simpler decision problems to form a decision hierarchy. Then, pairwise comparisons were done. Pairwise comparison method is mainly used because it is hierarchical, statistical and easy to use. It is a precise method with high trustworthiness. Here, two criteria and their importance to each other were considered at a time which provides easier ranking. The comparison matrix was developed for 11 criteria. After that, the weights and scores were produced by means of a sequence of multiplication equations.

The criteria assessed in this study were proximity to faults (PF), proximity to roads (PR), proximity to airports (PA), proximity to residential areas (PRA), proximity to wadies (PW), proximity to coastal zone (PCZ), proximity to ground water wells (PGWW), proximity to surface water (PS), permeability to strata (Per), ground water depth (GWD) and geology (G). All the criteria assessed were selected based on the most criteria used in landfill selection decision making except proximity to wadies which was added as a geography specific criterion to this study. Wadies constitute a common feature in the topography of Oman where water floods aggressively in the incidents of heavy rain. Thus, consideration of proximity to wadies as a criterion for landfill suitability analysis is significant in this study. Buffer distances allow distances between landfill and sensitive land uses and act as a primary control of potential impacts. Buffer distances side by side to proper site management during different stages of landfill development and operation and after closure is required to protect sensitive lands. These buffer distances should be maintained for a specified post-closure time, which will be at least 25 years (EPA 2006).

Waste management systems should maintain an adequate distance from environmentally sensitive areas (EPA 2006). Buffer zones for different criteria from various sources and studies summarized by Sener (2004) and from other studies (Akbari 2008 ; EPA 1993; EPA 2006; Kabite 2011; Khanlari 2012; Leao *et al*. 2004) were referred and used. Each criterion was divided into five classes; very high, high, moderate, low, very low. The different sites data regarding each criterion were extracted from various maps and from multiple field investigations. The geological map of Muscat, Quriyat and Seeb were studied. Also, the soil texture of the studied sites was classified by soil texture analysis using hydrometer method (Carter & Gregorich 2008). The weights and consistency ratios (CR) were calculated using AHP priority calculator by Goepel (2014). Scores for all landfills were derived from multiplying criteria weight and landfill site's weight that are derived in relation to that criteria and then summing the corresponding products (Kabite, 2011).

Parallel to this work, a borehole was constructed in vicinity to Al Amirat unlined landfill and the rock type in the area was identified. Also, leachate from the same was analyzed for heavy metals in order to assess its pollution potential. Leachate samples were collected from Al Amirat unlined landfill on monthly basis for 4 consecutive months, from October, 2012 to January, 2013 and were handled according to standard methods for the examination of water and waste water (APHA 2005). Heavy metals such as Beryllium (Be), Aluminum (Al), Vanadium (V), Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Rubidium (Rb), Mercury (Hg), Strontium (Sr), Cadmium (Cd), Barium (Ba), Lead (Pb) and Iron (Fe) were analyzed using Inductively Coupled Plasma (ICP-MS) type Aurora M90 ICP-MS.

Results and Discussion

Proximity to Faults (PF)

Faults are recognized as considerable environmental risk to landfill sites (EPA 2006). Five suitability classes were assigned to this factor as shown in Table 5. After studying the Quriyat and Muscat maps, it has been found that Al Amirat site is located 1 km away from fault, while Al Mabella and Bausher are located 2.2 km and 0.5 km from faults, respectively (MPM 1986). This factor makes Bausher the most unsuitable site for landfill activities posing a high risk to the environment. Faults increase permeability of rocks increasing the probability of ground water pollution with leachate (Kabite 2011).

Proximity to Roads (PR)

Landfill location must be close to roads network to aid transportation and reduce relative costs. (Khanlari *et al*. 2012). However, based on the effect of waste transportation on public health, the area was classified into six buffer zones classes: 0 – 100m, 100 – 700m, 700 – 1500m, 1500 – 4000m, 4000 – 7000m. The proximity of study sites (Al Amirat, Al Mabella and Bausher landfills) to roads were investigated through site observation and it was found to be 1, 0.25 and 0.8 km, respectively.

Proximity to Airport (PA)

Landfills attract birds that cause risk to the flying aircrafts, also, some possible effects of landfill like odor and noise may cause inconvenience to the passengers (Kabite 2011; EPA 2006). Considering the effect of landfill on passengers, landfills should be located at a certain distance from airports. Five buffer zones were set: 0 – 3000m, 3000 – 4000m, 4000 – 5000m, 5000 – 7000m and 7000 – 30000m as shown in Table 5. The proximity of the study sites to airport was investigated using topographical maps of Quriyat, Muscat and Seeb (MPM 1986). It has been found that the proximity of the study sites to airport were 30, 16 and 14.5 km for Al Amirat, Al Mabella and Bausher landfills, respectively.

Proximity to Residential Area (PRA)

Landfills far from residential area are not preferable due to high transportation cost of collected waste. Extensive studies on different aspects of resident's reaction to landfill existence in vicinity show a great opposition. Thus, landfills are not preferred to be located within residential area. Safe distances from the residential areas were determined (Khanlari *et al*. 2012) as shown in Table 5. The proximity to residential area was determined though field visits; it has been found that Al Amirat, Al Mabella and Bausher landfills were 0.3, 0.4 and 0.9 km away from residential areas, respectively.

Proximity to Wadies (PW)

Wadies are drainage courses formed by water. Wadis are generally dry year round, except after a rain. Any Leachate or surface runoff can directly contaminate the wadi system leading to ground water contamination.

Thus, proximity to wadies is an important criterion which was added to be specific to the area under study in which wadies are common characteristics of Oman topography. Accordingly, four different zones were specified considering relative distance from wadies as shown in Table 5. Data on this criterion were gathered through field investigations. It has been found that the wadies in Al Amirat and Bausher landfills were either within the landfill zone or at their edges occurring in the class (0 – 50m), while Al Mabella landfill was 0.4 km away from wadies.

Proximity to Coastal Zone (PCZ)

The coastal zone is characterized by high underground water level. Moreover, the probability of existing residential and site seeing areas in here are high. Therefore, a 5 kilometer buffer is applied to coastal zone. The suitability classes for coastal zone are shown in Table 5. Maps have shown that Al Amirat, Al Mabella and Bausher landfills are 18, 12 and 11.5 km away from coastal zone (MPM 1986).

Proximity to Ground Water Wells (PGWW)

Proximity to ground water wells is one of the most important environmental criteria in landfill suitability test. It helps in protecting ground water wells from contamination via leachate of landfills. Since potential leachate leaks will travel down gradient, landfills should be placed greater than 304.8 m up gradient from water wells (Sener 2004). The further the ground water well is located from the landfill site, the minimum is the landfill contamination risk. The area was classified into five classes with buffer zones of 0 – 500m, 500 – 800m, 800 – 1200m, 1200 – 2000m and >2000m as illustrated in Table 5. From field investigations, it has been found that Al Amirat, Al Mabella and Bausher landfills were 2.1, 2 and 1.9 km away from GW wells, respectively.

Proximity to Surface Water (PS)

Waste disposal sites should not be in vicinity to surface water sources where the underground water level is high (Akbari *et al*. 2008). Accordingly, four different zones were specified considering relative distance from surface water. Any contamination from the landfill can adversely affect the water bodies. The polluted runoff coming from landfills has a high capability to contaminate the surface water. Thus, inorder to protect this surface water from contamination, landfills shouldn’t be established in vicinity to surface water sources like Aflaj and others. Based on this, buffer zones were created by different researchers and 4 distinct classes were assigned: 0 – 500, 500 – 1000m and >1000m as shown in Table 5. Based on field investigations and topographical maps of Muscat, Quriyat and Al Seeb, it has been observed that Al Amirat, Al Mabella unlined landfills were > 1 km away from surface water sources, while Bausher landfill was 1.3 km away.

Permeability of strata (Per)

Impermeable layers in the subsoil minimize the risk of ground water pollution. The location with subsoil layers which have a high impermeability is more preferable. For example, clay layers have a low permeability (Sener 2004). Furthermore, permeability determines the movement of leachate and gases that cause ground water and air pollution. Thus the permeability should be very low to minimize such impacts. Clay textured soil is the best for landfill practices because it's impermeable to leachate.

The permeability of the site was determined by soil texture analysis. In this study, hydrometer method (Carter & Gregorich 2008) was used to determine the soil textural class in the 3 different unlined landfills. It has been found that Al Mabella and Bausher soil texture were both loamy sand while Al Amirat soil texture was Sandy clay loam. The soil of fine texture is the most suitable, posing lower risk to the environment. Thus, the area was classified into five classes, coarse texture (sand, loamy sand), moderately coarse texture (sandy loam), medium texture (loam, silt loam, silt), moderately fine texture (sandy clay loam, clay loam, silty clay loam), fine texture (silty clay, clay, sandy clay) as shown in Table 5.

Ground Water Depth (GWD)

A high groundwater level causes more risk regarding groundwater pollution as leachate percolate and pollute the ground water. The landfill location with the lowest groundwater level is more suitable for a landfill (Sener 2004). Based on that, five classes were assigned: 0 – 10 m, 10 – 20 m, 20 – 40 m, 40 – 50 m, and >50m. From field investigations, Al Amirat was found to be in the 0-10m class while Al Mabella and Bausher fall within the 10-20m and 20-40m class, respectively.

Geology (G)

The geological makeup of the landfill site is an important parameter for the determination of its suitability for waste management practices (EPA 2006). Low permeability rocks such as shale, marl, claystone and schist are suitable for landfill practices, while rocks like limestones, sandstones, dolomite and alluviums and terraces have low suitability to waste management practices (Khanlari 2012) as they tend to be relatively permeable. The geological map of Muscat, Quriyat and Al Seeb (MPM 1986) were studied. It has been observed that the dominant rock types in this region are mainly limestone, dolomite, dunite, schist, alluvial fans and terraces. Therefore, the influence of the geology on the suitability of landfill site is developed accordingly (Table 5). After drilling an exploratory borehole in Al Amirat region, it has been found that Al Amirat is comprised of about 3 meters deep alluvium followed by schist formations. While the maps showed that Al Mabellah site is mainly located in an area of alluvial fans and terraces and Bausher site consists of mainly white nodular limestone (MPM 1986). The higher the permeability of the geological unit, the lower is the site suitability for landfilling practices and the higher is its vulnerability. Al Amirat site was found to be the most suitable in terms of geology, as the low permeability schist represents the dominant rock exposing at the surface.

Table 5. Suitability classes for different criteria under study (Sener 2004; Akbari 2008; EPA 1993; EPA 2006; Kabite 2011; Khanlari 2012; Leao *et al*. 2004)

Criteria	Class/ buffer zone	Suitability
Proximity to faults (m)	0 – 60	Very Low
	60 – 500	Low
	500 – 4000	Moderate
	4000 – 8000	High
	> 8000	Very High
Proximity to roads (m)	0 – 100	Very Low
	100 – 700	Low
	700 – 1500	Moderate
	1500 – 4000	High
	4000 – 7000	Very High
Proximity to airports (m)	0 – 3000	Very Low
	3000 – 4000	Low
	4000 – 5000	Moderate
	5000 – 7000	High
	7000 – 30000	Very High
Proximity to Residential area (m)	0 – 3000	Very Low
	3000 – 5000	Low
	5000 – 6000	Moderate
	6000 – 8000	High
	>8000	Very High
Proximity to Wadies (m)	0 – 300	Very Low
	300 – 500	Low
	500 – 1000	Moderate
	1200 – 2000	High
	> 2000	Very High
Proximity to Coast (m)	0 – 5000	Low
	5000 – 7000	Moderate
	>7000	High
Proximity to GW wells (m)	0 – 500	Very Low
	500 – 800	Low
	800 – 1200	Moderate
	1200 – 2000	High
	> 2000	Very High
Proximity to Surface water (m)	0 – 500	Very Low
	500 – 1000	Moderate
	>1000	High
Permeability of strata	Coarse texture	Very Low

	Moderately coarse texture	Low
	Medium texture	Moderate
	Moderately fine texture	High
	Fine texture	Very High
Ground Water Depth (m)	0 – 10m	Very Low
	10 – 20m	Low
	20 – 40m	Moderate
	40 – 50m	High
	> 50	Very High
Geology	Dunite & schist	Very High
	Limestone & dolostone	Low
	Alluvial fans and terraces	Very Low

AHP pairwise comparison analysis

Criteria and their weights for landfill suitability analysis were identified using AHP pairwise comparison method.

Table 6. Criteria and their weights for landfill suitability analysis

	PF	**P**	**P**	**PR**	**P**	**PC**	**PG**	**PS**	**Pe**	**GW**	**G**	**Weigh**
PF[1]	1	3	5	2	1/2	1/2	1/2	1/	1/3	1/2	1/	0.068
PR[2]	1/	1	2	1/3	1/5	1/5	1/5	1/	1/5	1/5	1/	0.024
PA[3]	1/	1/2	1	1/5	1/7	1/7	1/7	1/	1/7	1/7	1/	0.016
PRA[4]	1/	3	5	1	1/2	1/2	1/2	1/	1/2	1/2	1/	0.058
PW[5]	2	5	7	2	1	1	1/2	1	2	1	2	0.126
PCZ[6]	2	5	7	2	1	1	1	1	2	1	2	0.117
PGW[7]	2	5	7	2	2	1	1	1	2	1	2	0.144
PS[8]	2	5	7	2	1	1	1	1	2	1	2	0.133
Per[9]	3	5	7	2	1/2	1/2	1/2	1/	1	1/2	2	0.106
GWL[10]	2	5	7	2	1	1	1	1	2	1	2	0.133
G[11]	1	3	5	2	1/2	1/2	1/2	1/	1/2	1/2	1	0.075
Total												1.00

[1] Proximity to Faults , [2] Proximity to Roads , [3] Proximity to Airports , [4] Proximity to Residential Areas , [5] Proximity to Wadies , [6] Proximity to Coastal Zone , [7] Proximity to Ground Water Wells , [8] Proximity to Surface water , [9] Permeability to strata , [10] Ground Water Depth, [11] Geology

Table 6 shows that some factors like proximity to ground water, proximity to surface water, depth to ground water are more important than others for landfill suitability analysis. This is mainly due to the desire to protect ground water resources from landfill leachate contamination. However, proximity to airports was the least important factor in this decision making matrix. The consistency ratio (CR) for this comparison was 0.019 which is less than 0.1 indicating a reasonable level of consistency in the pairwise comparison and consistent judgment. In order to solve the decision problem, all the evaluating criteria were considered separately as shown in Table 7.

Table 7 .Comparison and weights of each landfill with regard to different criteria

	Proximity to faults				**Proximity to roads**				**Proximity to airports**			
	Amirat	Mabella	Bousher	Weight	Amirat	Mabella	Bousher	Weight	Amirat	Mabella	Bousher	Weight
Amirat	1	1	3	0.429	1	3	1	0.429	1	1	1	0.333
Mabella	1	1	3	0.429	1/3	1	1/3	0.143	1	1	1	0.333
Bousher	1/3	1/3	1	0.143	1	3	1	0.429	1	1	1	0.333
	Proximity to residential areas				**Proximity to wadies**				**Proximity to coastal zone**			
	Amirat	Mabella	Bousher	Weight	Amirat	Mabella	Bousher	Weight	Amirat	Mabella	Bousher	Weight
Amirat	1	1	1	0.333	1	1/2	1	0.250	1	1	1	0.333
Mabella	1	1	1	0.333	2	1	2	0.500	1	1	1	0.333
Bousher	1	1	1	0.333	1	1/2	1	0.250	1	1	1	0.333
	Proximity to GW wells				**Proximity to surface water**				**Permeability of strata**			
	Amirat	Mabella	Bousher	Weight	Amirat	Mabella	Bousher	Weight	Amirat	Mabella	Bousher	Weight
Amirat	1	1	1	0.333	1	1	1	0.333	1	5	5	0.714
Mabella	1	1	1	0.333	1	1	1	0.333	1/5	1	1	0.143
Bousher	1	1	1	0.333	1	1	1	0.333	1/5	1	1	0.143
	Ground water depth				**Geology**							
	Amirat	Mabella	Bousher	Weight	Amirat	Mabella	Bousher	Weight				
Amirat	1	1/2	1/3	0.163	1	5	4	0.683				
Mabella	2	1	1/2	0.297	1/5	1	1/2	0.117				
Bousher	3	2	1	0.540	1/4	2	1	0.200				

According to the results in Table 7, it has been concluded that from proximity to fault point of view, Al Amirat and Al Mabellah landfills were the most suitable (weight : 0.429). Moreover, with regard to proximity to road criterion, Al Amirat and Bousher landfills were the most suitable (weight: 0.429), while Al Mabella landfill with weight 0.143 was the most un suitable. All the landfills showed equal vulnerabilities (weight: 0.333) regarding proximity to airport, proximity to residential area, proximity to coastal zone, proximity to groundwater wells and proximity to surface water. Comparing the landfills vulnerabilities based on proximity to wadies, Al Amirat and Bousher landfills were found to be the most vulnerable (weight: 0.250), while regarding permeability of strata , Al Mabella and Bousher landfills were high in vulnerability (weight: 0.143). In terms of ground water depth, Bousher landfill was the most suitable (weight: 0.540), while Al Amirat landfill was the most vulnerable (weight: 0.163). On geological point of view, Al Amirat was the most suitable site (weight: 0.683), whereas Al Mabella landfill was the least suitable (weight: 0.117). The CR for comparison of landfills with each criterion, PF, PR, PA, PRA, PW, PCZ, PGWW, PS, Per, GWD, G were 0 except for GWD and G which were 0.01 and 0.026, respectively. Consistency ratios of 0.01 and 0.026 are less than 0.1 indicating consistent judgment and reasonable level of consistency. The scores of all landfills were determined by multiplying criteria weight by landfill site weight that was derived previously concerning the same criteria and then calculating the total as shown in Table 8.

Table 8. Score calculation for landfill sites

Criteria	**Amirat Landfill**	**Mabella Landfill**	**Bousher Landfill**
PF	0.068 x 0.429	0.068 x 0.429	0.068 x 0.143
PR	0.024 x 0.429	0.024 x 0.143	0.024 x 0.429
PA	0.016 x 0.333	0.016 x 0.333	0.016 x 0.333
PRA	0.058 x 0.333	0.058 x 0.333	0.058 x 0.333
PW	0.126 x 0.250	0.126 x 0.500	0.126 x 0.250
PCZ	0.117 x 0.333	0.117 x 0.333	0.117 x 0.333
PGW	0.144 x 0.333	0.144 x 0.333	0.144 x 0.333
PS	0.133 x 0.333	0.133 x 0.333	0.133 x 0.333
Per	0.106 x 0.714	0.106 x 0.143	0.106 x 0.143
GWD	0.133 x 0.163	0.133 x 0.297	0.133 x 0.540
G	0.075 x 0.683	0.075 x 0.117	0.075 x 0.200
Score of	0.375	0.315	0.309

Table 8 shows that in comparison to the other sites, Al Amirat landfill was the highest in score (0.375). This means that this site satisfies most of the criteria set in this study. This is because it was more suitable in relation to criteria like proximity to roads, permeability of strata and geology. Bousher landfill was the most vulnerable in which the score calculated for this site was the least (0.309) mainly due to factors like proximity to faults and permeability to strata which were found to be important factors in the determination of landfill site suitability. Although all landfills are vulnerable due to lack of proper design, Bousher found to be the most vulnerable. Control measures need to be set, management practices have to be developed to ensure a similar level of protection for sensitive land uses where these buffer distances are not available. Since most of the criteria assessed in this study may not have been considered in landfill site selection, these landfills are found to be vulnerable and unsuitable to be located in such areas. Thus, the criteria considered in this study should be considered by decision makers to assess the existing landfills and to select the most suitable sites for future landfills. Moreover, buffer distances for the above criteria should be established during the selection of the future landfill sites and maintained thereafter to avoid any unwanted impacts on the environment. Furthermore, the tool used in this study provides essential support to the process of decision making.

Assessment of leachate of the most suitable unlined landfill (Al Amirat)

The leachate of Al Amirat landfill was analyzed and the results are shown in Table 9.

Table 9. Heavy metals concentrations in landfill leachate (mg/l)

Heavy Metal	Mean ± SD[1]	Minimum	Maximum	Leachate heavy metals content in Kuwait (Al Yaqout & Hamoda, 2003)	Leachate heavy metals content in India (Nagarajan *et al.*, 2012)
Al	2.050 ± 0.689	1.490	3.020	1.2 – 12.4	NA[2]
V	0.977 ± 0.170	0.870	1.230	NA	NA
Cr	2.800 ± 0.608	2.440	3.710	NA	0.14 – 0.28
Mn	0.503 ± 0.073	0.400	0.570	NA	NA
Co	0.128 ± 0.022	0.110	0.160	NA	NA
Ni	0.773 ± 0.153	0.680	1.000	0.4 - 0.6	0.31 - 0.38
Cu	0.185 ± 0.013	0.170	0.200	0 – 0.2	0.71 – 0/89
Zn	0.943 ± 0.104	0.810	1.030	0.2 – 4.8	1.29 - 2.10
Hg	BDL[3]	BDL	BDL	NA	NA
Se	BDL	BDL	BDL	NA	NA
Rb	1.950 ± 0.428	1.690	2.590	NA	NA
Sr	1.755 ± 0.283	1.510	2.150	NA	NA
Cd	0.017 ± 0.002	0.014	0.018	NA	0.02 - 0.05
Ba	0.857 ± 0.186	0.720	1.130	NA	NA

Pb	0.130 ± 0.024	0.100	0.160	NA	1.1 – 1.31
Fe	39.25 ± 3.095	35.0	42.0	1.4 – 54.6	58.40 - 63.41

[1] Standard Deviation [2] Not Available [3] Below Detection Limits

The findings in Table 9 show that Al, V, Cr, Mn, Co, Ni, Ba, Pb, Fe, Cu, Zn, Rb, and Sr were all detected in the leachate samples, while Hg and Se were below detection limits. The order of heavy metals concentration were Fe > Cr > Al > Rb > Sr > V > Zn > Ba > Ni > Mn > Cu >Pb > Co > Cd > Hg from highest concentration to lowest concentration. The presence of these metals indicates the disposal of a variety of waste in the landfill in which some of these metals were detected and reported in considerable amounts in a country with similar socio-economic and environmental settings by Al Yaqout & Hamoda in 2003. Fe was the predominant metal in leachate (39.25 mg/l), while Cd was the lowest (0.017 mg/l). The high level of Fe indicates the dumping of steel scrap in the landfill. This explains the brown dark color of the leachate which is a product of oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with humic acid (Kanmani & Ganghimathi 2013). The level of Pb in the leachate (0.13 mg/l) indicates the disposal of lead batteries, lead based paints, plastics, and pipes in the site (Moturi 2004). Moreover, the detection of Ni (0.773 mg/l) in excess can be attributed to the disposal of batteries in the site. The levels of Al, Cr, Mn, and Ba were 2.05 mg/l, 2.8mg/l, 0.50mg/l, and 0.857mg/l, respectively. Their presence in the samples indicates the disposal of considerable amounts of steel in the site, whereas Al might come from a wide range of sources of household items, electronics and even from plant tissues ashes (Reinhart 1993). The concentrations of Cu (0.185 mg/l), Zn (0.943 mg/l) and Fe (39.25 mg/l) were similar to the concentrations found in Al Qurain landfill leachate in Kuwait (Al Yaqout & Hamooda, 2003) but lower than the concentration detected in Erode city landfills in India (Nagarajan *et al*., 2012) , while Rb (1.950 mg/l) and Sr (1.755 mg/l) were present in considerable amounts. The presence of V (0.9775 mg/l) and Mn proves the disposal of considerable amounts of steel in the landfill, while Co comes from batteries (Adeoleu *et al*. 2011) and Cu from paints, blades, bottle caps, insecticides, pharmaceuticals and cosmetics (Kanmani & Ganghimathi 2013). The presence of Zn (0.943 mg/l) can be attributed to the disposal of batteries, fluorescent lamps (Moturi, 2004), food wastes and burning tyres at the site (Adeoleu *et al*. 2011). The results of heavy metals investigation showed that the concentration of Al, Cu, Zn and Fe were within the ranges detected by Al Yaqoot and Hamooda (2003), while Cu and Zn values were lower than the values reported by Al Slaibi for Gaza unlined landfill (2009). The concentrations of Cu, Zn, Cd, Pb and Fe were lower than the concentration of Erode city landfills leachate in India, while the concentrations of Ni and Cr were higher (Nagarajan *et al*., 2012) . But since the landfill environment depend on various characteristics and factors and also changes over time as the waste decompose, there are no measurements that provide conclusion on the long term fate of heavy metals in the environment because data present are scarce. Also, there is no much information concerning the movement of heavy metals through the soil (James 1977). The overall and individual effect of these contaminants should be considered as surface and ground water contamination may happen. This effect is increased by the fact that leachate pools are present along a valley channel in which heavy rain will result in the transfer of leachate contaminants to regions closer to farms and residential areas posing a hazard to the environment. Moreover, heavy metals are non degradable and their continuous accumulation forms a serious risk to human health (Moturi *et al*. 2004). Thus, Rehabilitation of such old unlined landfills should take place with continuous monitoring programs of ground water sources around the area to contain any contamination that might occur. Since various types and amounts of waste are entering landfills, more caution should be given in the selection of landfills sites at the first place to avoid any future threat to the environment.

Conclusion

The current study investigates the suitability of three sites in an arid area (Oman) on the basis of different criteria. The results show that Bousher is the most unsuitable landfill site with a score of 0.309, while Al Amirat is the most suitable site (score: 0.375). The assessment of heavy metals in the leachate of the most suitable site has showed that leachate was contaminated with heavy metals. The findings highlight the importance of multicriteria decision analysis in landfill site selection to prevent any vulnerability to the environment from landfills. The criteria used in this study should be considered by decision makers in order to carry out assessment studies on different existing landfill sites as well as to select the most suitable sites for future landfills.

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