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Selection, Design, and Management of Sanitary Landfill Site(s) for Mosul City

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ABSTRACT

In this paper, two landfill disposal sites proposed by the Mosul municipality were compared, assessed and designated the east and west landfill sites, respectively. Forty selected parameters related to landfill site suitability were used for the comparison. The suitability of the site for each parameter was graded as "poor," "fair," "good," or "excellent," depending on the adequacy of the parameter relative to guidelines and landfill criteria. The proposed sites appeared to meet most of the criteria required for similar facilities. Based on the soil characteristics, groundwater quality, area capacity, and other specific parameters, however, the proposed east landfill site is superior to the west landfill site. Mixed and area method models seemed suitable for these sites. The results indicated that soil cover is urgently needed for the west site and, to a lesser degree, the east site. Calculations based on Iraqi experience in landfill construction revealed that the east landfill site can be operated for 10 years, with 7 m of waste high. For the west landfill site, the height of waste for the same period approaches 15 m. Due to the complexity of the site topography, high cost burden, and lack of experience in implementing such project, it would be necessary to operate this site for 5 years with a waste height of 6.5 m. Importantly, the findings of the study reveal no evidence for potential groundwater contamination. It is concluded that construction of a proper sanitary landfill site for integrated solid waste management is a major necessity and should be a priority for the city of Mosul.

Keywords: Evaluation;(ISWM), landfill; site criteria; solid waste disposal.

اختيار وتصميم وإدارة موقع(مواقع) الطمر الصحي لمدينة الموصل

الخلاصة:

تم في هذا البحث مقارنة موقعين مقترحين من قبل بلدية الموصل بقصد استخدامهما كموقعي طمر صحي. تم تطبيق (40) معيارا مصنفة (جيد، مقبول وسيء) لبيان صلاحية الموقعين لهذا الغرض. ظهر أن الموقعين يحملان العديد من المعايير التي تؤهلهما لهذا الاستخدام . واعتمادا على خصائص التربة ونوعية المياه الجوفية ومساحة الأرض المتاحة وغيرها فقد بدا أن موقع الطمر الصحي في الجهة الشرقية هو الأفضل من موقع الطمر في الجهة الغربية. كما أوضحت النتائج ان الموقع الأخير يحتاج إلى تربة تغطية أكثر بكثير مما يحتاجه موقع الطمر في أي الجهة الشرقية.كذلك ظهر أن ارتفاع كدس النفايات لا يزيد عن(7) أمتار وبفترة تشغيلية أمدها (10) سنوات في الموقع الشرقي و (15) مترا في الموقع الغربي ولنفس فترة التشغيل..

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وجراء تعقيدات العمل فـي الموقع الغربي ولمحدودية المساحة المتاحة والكلفة العالية لتأهيله فقد اقترح ان يكون ارتفاع كدس النفايات الصلبة(6.5) مترا وفترة التشغيل(5) سنوات.
أوضحت النتائج ان لا خوف يتوقع من تلوث المياه الجوفية لانخفاض مستوياتها وان تنفيذ موقع طمر صحي نظامي هو من الضروريات في الإدارة المتكاملة النفايات الصلبة في المدينة.

INTRODUCTION

Mosul City has no controlled system for solid waste disposal. Waste is either burned in pits, dumped in random locations, or disposed of in uncontrolled dumps without treatment. Such practices harm public health and well-being, negatively influence aesthetics, and degrade the environment. In addition, Mosul City lacks both an integrated solid waste management (ISWM) policy and a strong reuse and recovery plan. Therefore, it is not surprising that only about 25% of the estimated 1000 to 1100 tons of daily generated solid waste is collected by the city.[1]Currently, Mosul city disposes its major generated solid wastes into two open dumps located on two banks of the city for the time being. These dumps should be rehabilitated as an engineered sanitary landfill sites.

Landfill site selection is an important step in implementing a waste management program. From an environmental engineering prospective, an important objective of this process is to select a site that will provide the highest public health and environmental protection in the event of landfill containment failure by making the best use of the land resources available[2,3] Determining sites for landfills in developing countries such as Iraq is a challenging task. Financial, technical, institutional awareness and human resources are generally limited, which makes it difficult to construct and operate landfills that meet high environmental standards.

A proposed landfill site can be selected despite not fulfilling all the requirements. Although engineering design can compensate for inadequate site conditions, the modifications are usually costly. Various criteria that should be considered in landfill siting have been proposed, including environmental, economic, and sociopolitical requirements, some of which may conflict. With increased environmental awareness, new legislation, and the development of improved procedures and tools, the landfill site selection process has become much more sophisticated.

Here, the acceptability of two proposed landfill sites in Mosul, Iraq is compared, based on criteria relevant for the conditions in this region.

Materials and Methods

The Mosul municipality proposed two potential landfill sites, located on either side of the city (east and west). These sites currently serve as open dumps and are the only available solid waste disposal options for the city for the time being. The areas of the east and west sites are 801,300 m^2 and 367,700 m^2, respectively.[4] Figure 1 shows the location of these sites with respect to the city center and related features. Fig.2 shows the east site and relation to surrounding. A thorough and careful study of available literature concerning Mosul solid waste and their characteristics was performed.[5] Other studies related to landfill siting was consulted. [6] Many visits were made to the proposed sites, and soil and water samples were obtained for quality characterization.

Guidelines and criteria followed or recommended by authorized agencies abroad were carefully considered,[7] and practical and comprehensive criteria for the evaluation of potential landfill sites were developed (Table 1)[8]. Criteria were grouped into **five**

major categories and subdivided into specific site characteristic factors under each category. Altogether, there were 40 specific site characteristics that made up the site evaluation criteria. The suitability of site soils to be used in landfill components was tested with physical and chemical methods.

Figure (1). Location of both sites with respect to city center

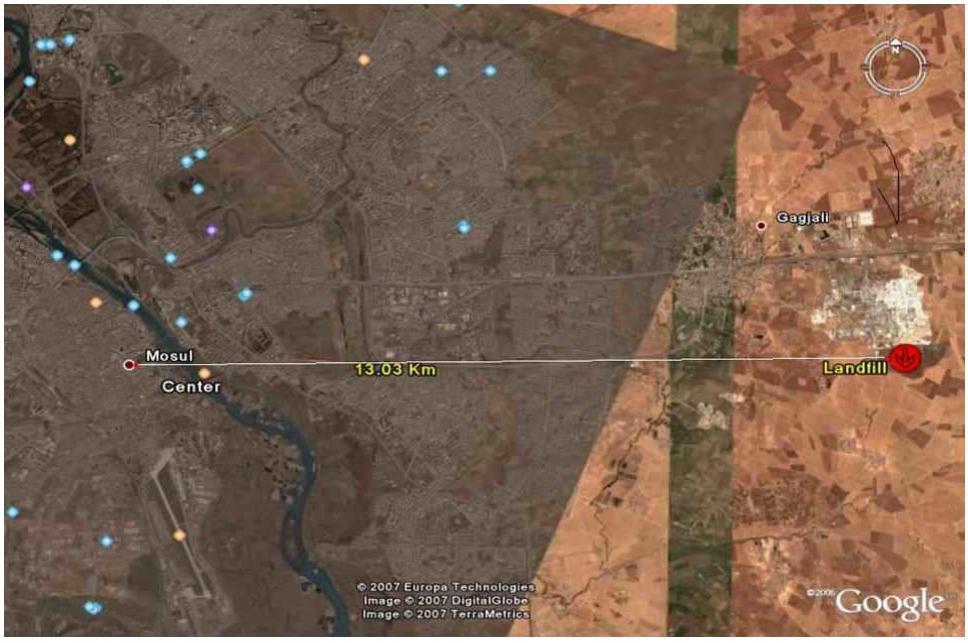

Figure (2). East landfill and its surroundings.

Table (1). Categories of landfill site criteria*

Water Protection	**Geology**
Aquifer	Bedrock
Flood plain	Cover soil availability
Ground water	Fault areas
Proximity to drinking water source	Hydrogeology
Surface hydrology	Seismic impact zones
Wetlands	Soils
Water quality	Topography
Transportation	Unstable areas
Access	**Land Use**
Haul route	Aesthetics
Proximity to water source	Acreage available
Traffic congestion	Airport safety
Traffic safety	Buffer area available
On-Site Environment	Existing land use
Air quality	Adjacent land use
Wildlife resource	Mitigation issues
Archeological/historic resources	Noise
Biological resources	Property acquisition
Support infrastructure	Property devaluation
Threatened species	Sensitive receptors
Wind direction	Utility availability
	Zoning

- **reference 9**

Results

East landfill site

The east site is located 13 km east of the city center and 1.9 km from a suitable main road. It is located in the polluted industrial zone, surrounded by marble and concrete block factories (Figure 3). The old compost plant is close to this site. Some small villages are scattered south of the site. The site is characterized by clay soil and an underlying sandy aquifer. A small community is located about 1500 m east of the site. Several wells used by the community for domestic water supply are scattered in the area. The groundwater table is in the range of 18 to 22 m, and its quality is poor. The area of the site is approximately 80 ha. A preliminary survey showed a 6-m difference between the highest and lowest points of the site. The site is presently used as a temporary dump area. The surrounding area of the site is used for private construction material industries and is covered by stone residue from the nearby factories. This site is almost 1.89 km east of the Mosul-Erbil highway. The area is relatively flat, and the average slope of the site is 2% to 4%.

Based on preliminary calculations, the east landfill site is expected to hold solid waste for a period of 10 years, with a total height of 7 m.

West landfill site

The west site is located 12 km west of the city center and about 700 m from the main nearby highway. It is a bedrock area surrounded by quarries (Figures 3&4). The proposed site is a natural depression surrounded by high hills. There are small valleys in the area with seasonal water flow. A wastewater sludge collection sump was created. This issue
should be considered in the design of the landfill and should be culverted or diverted before land filling commences. The groundwater table is approximately 100 m from the ground surface, with very poor water quality. A preliminary survey suggested that the site has a variable elevation, with differences exceeding 40 m between the highest and lowest points. There is a nearby area (approximately 20 km away) that is covered with clay soil that might be suitable for landfill liner. No flooding has been reported in the area in the past 30 years. The site area is approximately 36 ha.

Based on preliminary calculations, the west site is expected to hold solid waste for 5 years, with a solid waste height of 6.5 m.

Overall site characteristics

Neither site is located near an airport or other important location. The area is free from cracks, faults, and relatively far from flooding areas. No major or minor river or any type of water course is located near to the sites. Hydraulic conductivity and other specific soil characteristics (Atterberg limits, water contents, gypsum, organic matter content, etc.) were determined for use in the evaluation process.

Figure (3):location of right landfill related to city center.

Figure (4). Relationship of the west landfill site to its surroundings

Site comparison

In the final step, the two sites were compared based on the selected evaluation criteria. Collected data and conceptual designs were used to assess how well each site met the selected criteria. Each site was rated as "poor" (score, 40-49), "fair" (50-74), "good" (75-89), or "excellent" (90-100) for each criterion (Table 2). Although both sites were adequate according to the weighted importance of each criterion, the east landfill site appeared to be a better choice over the west landfill site.

Discussion

The general conclusion from the site visits and investigations in the present study was that these proposed sites fulfill criteria consistent with the overall land-use plan. The sites are easily accessible from major roadways or thoroughfares, and use of these sites as landfills is not predicted to cause any inconvenience for residents of the surrounding communities. Operation of the site will not adversely impact environmentally sensitive resources. The site areas are sufficiently large to accommodate solid waste from the community for a reasonably long period of time (10 - 30 years).

Table (2). Landfill site comparison*

Criteria	Left site	Right site
Aquifer	Good	Excellent
Flood plain	Fair	Excellent
Ground water	Excellent	Excellent
Proximity to drinking water source	Excellent	Excellent
Surface hydrology	Excellent	Poor
Wetlands	Excellent	Excellent
Water quality	Excellent	Excellent
Bedrock	Excellent	Poor
Cover soil availability	Excellent	Poor
Fault areas	Excellent	Excellent
Hydrogeology	Excellent	Good
Seismic impact zones	Excellent	Excellent
Soils	Excellent	Poor
Topography	Excellent	Poor
Unstable areas	Excellent	Excellent
Air quality	Good	Excellent
Wildlife resource	Excellent	Excellent
Archeologic/historic resources	Excellent	Excellent
Biologic resources	Excellent	Excellent
Support infrastructure	Excellent	Poor
Threatened species	Excellent	Excellent
Wind direction	Excellent	Excellent
Access	Good	Good
Haul route	Excellent	Poor
Proximity to water source	Good	Good
Traffic congestion	Good	Good
Traffic safety	Good	Good
Aesthetics	Good	Excellent
Acreage available	Excellent	Poor
Airport safety	Excellent	Excellent
Buffer area available	Good	Good
Existing land use	Good	Excellent
Adjacent land use	Good	Excellent
Mitigation issues	Excellent	Poor
Noise	Good	Excellent
Property acquisition	Excellent	Excellent
Property devaluation	Good	Good
Sensitive receptors	Good	Excellent
Utility availability	Excellent	Good
Zoning	Good	Good

Grade range (%): excellent (90-100), good (75-89), fair (50-74), and poor (40-49)

The groundwater tables are below the bases of the landfills, an ideal situation for avoiding groundwater contamination by construction. The proposed landfill sites lie in areas without fractured bedrock, karst topography, etc., which helps to ensure groundwater protection. Regardless, the water quality was so bad at both sites that it is not suitable for use by humans or animals. The sites contain no water bodies or protected areas (lakes, streams, wetlands, etc.). The sites are not river floodplains, susceptible to frequent flooding, or found in unstable areas. At $\leq 1 \times 10^{-7}$ cm/s for both sites, the hydraulic conductivity, as a major characteristic of site soil, is within an acceptable range for good groundwater protection.

The potential landfill sites are satisfactory in terms of budgetary constraints, including those of site development, prolonged operation, closure, post-closure care, and possible remediation costs. Based on the nature of the sites, soils, and groundwater tables, a combination of trench and area methods of landfill operation is recommended for the west landfill site, and an area method is recommended for the east landfill site. Geological and topographical factors played an important role in this choice.

Soil is urgently needed for the west landfill site, which is almost completely bedrock. To a lesser degree, soil is also needed for the east landfill site, which is almost all clay and sandy clay. An advantage of the proposed sites is that they are both owned by the municipality. By eliminating problems related to private land ownership, municipality ownership of the sites can reduce the overall cost of landfill operation.

Based on the obtained data, both sites proposed by the municipality meet most of the analyzed criteria. The east landfill site area was predicted to hold solid waste for a period of 10 years with a total height of 7 m, whereas the west site can operate for 5 years with a solid waste height of 6.5 m. These calculations were made with consideration of the limited experience in Iraq for performing such projects.

The scores used in Table 2 to categorize the landfill site as poor, fair, good, or excellent are relative scores that represent the degree of validity or compliance of each factor or parameter to the criterion. For example, for the criterion "proximity to water sources," a site that is 200 m from water sources would be scored as "good," whereas a site that is 400 m from the source would be scored as "excellent". Similarly, if the water quality is bad at one site and is graded as "fair," and it appears that the quality is worse at the other site, then the grade given to the former would be "good" or "excellent," based on how bad the quality is. Moreover, if the effect of a specific parameter on the site was low, then it was given a higher score.

A step-by-step landfill siting process should be adopted and described in detail in landfill regulations for Iraq. The process outlined in this document can be used as starting point, with additional steps or parallel processes included to address other aspects of landfill siting. For example, steps to address social issues and public participation should be included, because public environmental awareness is an important aspect in landfill implementation. A detailed set of Iraqi criteria and constraints should be introduced, including those developed here. Landfill regulations should include guidelines for a leachate management strategy, addressing potential contamination problems and appropriate leachate treatment options for local agencies.

Finally, the Mosul municipality should apply the ISWM tool, to look at solid wastes as an economic resource. Such practices may add economic benefits to landfill construction, as well as lengthen the service of landfills.

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