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Pollution by leachate and gas from improperly designed landfill: A case study

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Abstract
For effective preservation of environment and required protection of groundwater, the Municipality of the Holy Capital (Makkah), Kingdom of Saudi Arabia plans to appropriately and properly close the old landfill at Muassim area in Makkah with a particular synthetic cover layer that prevents rainwater from reaching the very inside of the landfill and mixing up with its components. This affects subsequently the quality of the groundwater in the nearby valleys (*Wadis*). Furthermore, for safeguarding the air environment, the said Municipality intends to construct a network for the collection of gases and considering the possibility of making use of it in energy production. This paper comprises the results of the quality of both underground water and atmosphere near Muassim Landfill.

INTRODUCTION

Muassim landfill is situated at Muassim Quarter which is approximately 8 kilometers to the north east from the Holy Massjid in Makkah and occupies an area of about 2 square meters. It was constructed in 1400AH (1980AD) with a view to getting rid of disposals of waste materials and garbage collected by municipality cleaning services and resulting from residential and commercial humanitarian activities.

The landfill has continued to render service and to receive waste materials collected by Municipality till 1424AH (2003AD) where it reached its full capacity by that date.

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However, no environmental aspects were taken into account when the landfill was constructed. It lacks internal lining, a network for collection of the landfill leachate or station for its treatment, station for collection, treatment or making use of gas. This affected negatively the quality of air environment in the quarter and make the groundwater nearby the landfill area subject to exposition to due pollution with liquid resulting from infiltrating of rain water into the inside of the landfill, via their direct fall on the landfill or their reaching it from surrounding areas (Mor et al., 2006).

This study aims at evaluating the quality of both underground water and atmosphere near Muassim Landfill. The project intendeds to develop a program for the observation of pollution and the movement of polluting materials which are associated with the landfill and maintenance plan. After due completion, this project is expected to comply with both (Santilli et al., 2005) and program of carbon trade and lessen to greater extent the emission of the hot gases .

FRAMEWORK OF THE STUDY

This project is primarily concerned with the study of the impact of the landfill on the underground water in the area as well as on knowing the extent of extending the pollution area in the nearby valleys (Wadis).The project's aims at developing a program for supervising the quality of water and the Landfill's impact on it. It also comprises the study of available options for the construction of an engineering cover with its known elements so as prevent the entering of rainwater into the inside of the Landfill and its exiting from it, because this will adversely affect the quality of the nearby groundwater (Kjeldsen et al., 2002). The project is expanded to study options available for the construction of a final engineering cover with its known elements so as to prevent the passage of rainwater into the inside of the landfill and impede its exiting from it and adversely affect the quality of the nearby underground water. The projects comprises the study of both the quantity and quality of the emitted gasses as well as pollution of the surrounding aerial environment and construction of network that accumulates, processes and utilizes gas. To sum up, the project's works cover the under mentioned works as well as other works that are required for the construction of the final landfill and protection of environment:

1- Survey works
2- Geophysical works.
3- The study of underground water.
4- The study of the landfill' gas and air quality
5- The Design of the final cover of the Landfill.
6- The design of network that accumulates and processes landfill's liquids.
7- The design of a network that accumulates and processes landfill's gasses.

This paper focuses on the landfill leachate and gas components of the overall project.

UNDERGROUND WATER AND LANDFILL LEACHATE

The objective of this section of study is to make available information and data required for designing the system of collecting and processing Landfill's liquids (leachate) in an attempt to protect underground water from polluting with the Landfill's liquids (Salem et al., 2008).

Description of Current Situation

There are six existing boreholes (BH) for taking samples of underground water in the area; three of them are located inside the boundaries of the Landfill and the other three are situated outside it. The boreholes are numbered serially from 1 to 6 (BH1) to (BH6) and their symbols as indicated in Figure 1 are according to Latin letters as follows: MLG1, MLG2, MLG3, MLG4, MLG5, MLG6. The groundwater quality at the site is presented in Table 1.

Figure 1: Sites of the existing wells for withdrawing water samples in the Landfill area.

Table 1: The results of analyzing groundwater samples in the area

Element	Unit	MLG1	MLG2	MLG3	MLG4	MLG5
Depth		11	12	11	5	4
Groundwater Level	m	8.9	7.3	9.3	1.2	2.2
Temperature	^{0}C	37.66	42.42	38.44	33.03	33.41
Ph		8.42	8.32	8.09	7.0	6.91
	mV	-46.73	-43.07	-36.10	-0.35	1.4
Elecreical Conduct	mS/m^3	47.90	30.47	28.71	15.725	13.87
	μS/cm	58771.67	39192.33	35912.00	18056.5	16105
Soluable Acids	%	30.76	19.82	18.64	10.23	9.019

Landfill's Liquids (Leachate)

Landfill's liquids or leachate as it is often called constitute water that leak from the landfill's surface to its inside and mix up with the components of the Landfill such as waste materials and exit through it or its peripherals to the groundwater carrying with it the metal salts, organic compounds and other particles that have been dissolved. Therefore, five sites for digging wells have been selected of the twelve proposed sites as indicated in Figure 1 and 2; and that groundwater samples or landfill's leachate have been taken and their pollution level measured (Table 2).

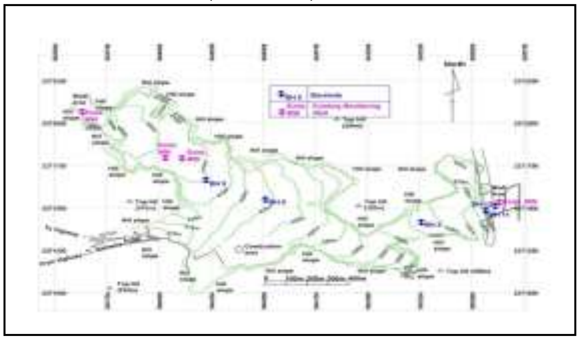

Figure 2: The sites of wells that have been dug for taking samples of groundwater and landfill's leachate

Table 2: The results of the analysis of the samples of the leachate of Muassim Ladfill.

Element	Unit	BH-6	BH-5
Depth	**M**	22.2	22.62
Level of groundwater	**M**	17.5	10
Temperature	**⁰C**	43.06	35.6
Electrical Conduct	**mS/m^3**	47.23	13.08
Electrical Conduct	**µS/cm**	63376	15963
Dissolvable Salts Group	**%**	30.46	8.623
Saltiness		29.83	7.51
Soluble Oxygen	**%**	35.1	39.3
Soluble Oxygen	**mg/L**	1.85	2.58
Acidity pH		9.5	8.0
Acidity pH	**Mv**	82.2	-33.2
ORP		-243.2	-185.6

The analysis of groundwater in the western and eastern valleys (*WASDIS*) surrounding the Landfill indicates that there is a remarkable pollution of the Landfill's liquids, especially the vicinity wells situated on the boundaries of the Landfill (Renou et al., 2008). Figure 3 displays groundwater samples taken from wells at different distances in the Landfill. Furthermore, the alteration in the color of the samples indicates the intensity of pollution and its dissemination in western direction. On the eastern aspect, the condition is not different but the pollution is not in the same intense due to the site topography and quantity of waste materials buried at various points of the Landfill.

Since this is the case, it is essential to impede the exit of Landfill's liquids from the site and its passage to groundwater to prevent it against pollution. To do this process, two scenarios have been studied; the first is focused on the necessity of establishing an impede or subterranean leachate barrier that blocks liquids and prevent them from passage to groundwater and the second requires the construction of two sample- taking well systems; one at the exit of the eastern valley (*WADI*) and another at the western exit for withdrawing water quantity coming from the Landfill for either processing or disposal.

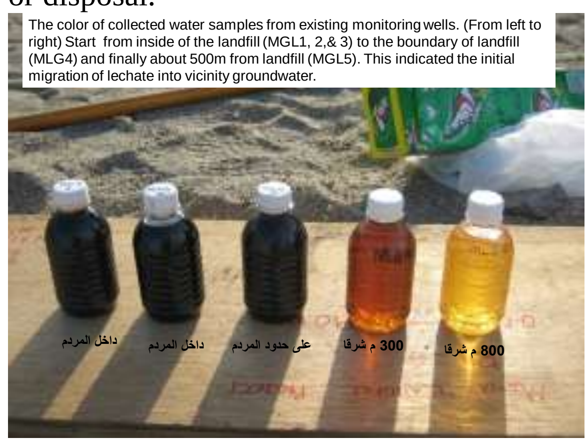

Figure 3: Groundwater samples taken from wells at different distances in the Landfill (From left to right: samples from inside landfill (2), sample from landfill boundary, sample from 300 m East of the landfill, sample from 800 m East of landfill.

Subterranean Leachate Barrier

The main objective of building the subterranean leachate barrier is to prevent the exit of the landfill's liquids to the outside end of the site and pollute vicinity groundwater in the valleys (*WADIS)*(Amos & Younger, 2003).Figure 4 shows the site of the subterranean leachate barrier at the exit of the Landfill to the valley (WADI) from western direction. The geophysical survey comprised this area but it was supposed that a test well was to be dug at the very site so as to verify whether the information resulting from the geophysical study was accurate. However, when we returned to the area, it was extremely difficult for us to move in the digging machinery due to very huge accumulation of construction waste materials which made impossible the moving of such machinery to the site for digging the wells. Hence, the digging process on the part was totally cancelled and for compensation we increased the number of wells on the eastern side.

Therefore, we were compelled to rely on the results of the geophysical study and resistivity measurements field inspection of other points at the site for conducting the feasibility study of building a subterranean leachate barrier in the area. Figure 5 displays an image for the results of the measurements of electrical resistance for the section of valley (*WADI*) at the site proposed for constructing the subterranean leachate barrier.

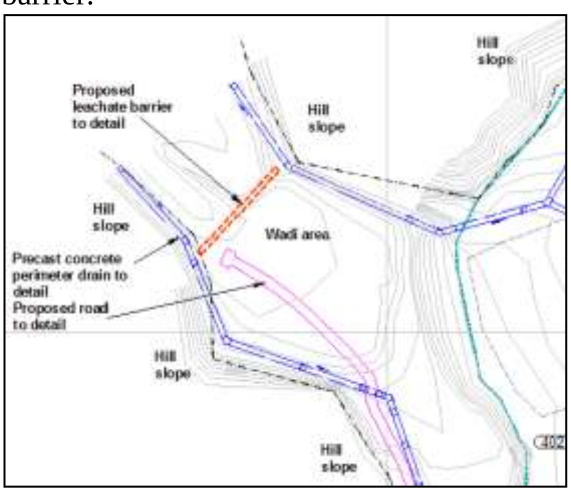

Figure 4: The proposed site of the subterranean leachate barrier.

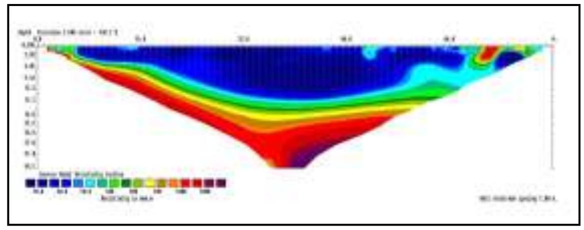

Figure 5: A section of the results of the electrical resistance at the site of leachate barrier

From Figure 6 it becomes clear that the valley (WADI) looks like a V or U-shape canal, replete with materials such as sands which are saturated with the liquids of the landfills or its groundwater. At the center, the depth of the rocky layer reaches 16 meters above the ground surface. From the study and inspection of the area, it is probable that jointing articulation and cracks incidents extend in this area a number of meters inside the rocky bottom. This necessitates that the area is to be injected with materials that reduces the permeability of grouting. The leachate barrier is supposed to do the following:

- Block quantity of water and contaminated liquids coming from the landfill and secure the process of its processing and final disposal.
- Prevent the passage of the Landfill's liquids (leachate) to the valley's groundwater, so as not to be contaminated.
- Prevent groundwater from entering the Landfill during the four seasons at which the level of ground water fluctuates.

The depth of the leachate barrier extends from the rocky bottom layer till it reaches the highest possible level for the Landfill's liquids in the area. Furthermore, it is essential that the geo-synthetic cover of the Landfill extends above the leachate barrier so as to facilitate the passage of surface water above the barrier and prevent it from entering inside it as indicated in Figure 6.

Designing of Leachate Barrier

Figure 6 displays a supposed drawing for the Leachate barrier site and surrounding areas and its final image after completion of construction and performance of its function. For building the leachate barrier, we use geo-synthetic clay liner material for securing the required water insulation. This requires the digging of trenches that reach the bedrock layer. Figure 7 shows a drawing for a method of digging before placement of the insulating material. However, it is necessary to inject the cracked rocky layer with inoffensive material such as calpintonite or with certain synthetic materials which are specialized for this purpose. Figure 8 shows clarifying drawing that indicates the section from the front aspect.

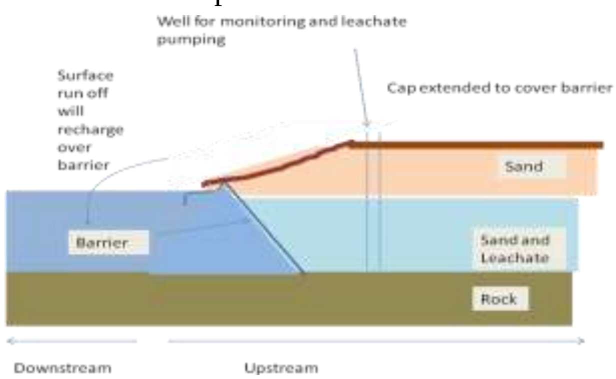

Figure 6: An illustrative drawing for the extension of the final cover above the leachate barrier.

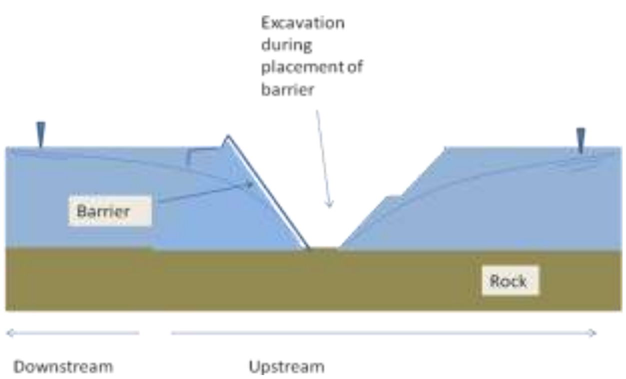

Figure 7: An illustrative drawing for the proposed site for placing the insulator.

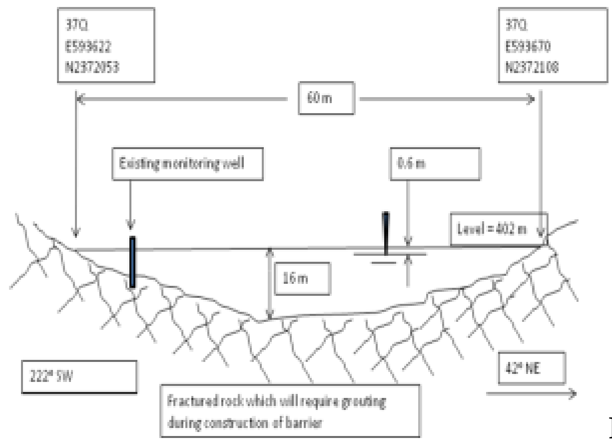

Figure 8: A front image for the valley's section after the construction of the leachate barrier.

System of Liquid Drawing Wells

The site of the current liquid drawing wells (Hudak, 2001) as well as those might be formed later have been selected and specified from the drawings resulting from the geophysical study. Furthermore, deeper and more distant ground surface wells from the rocky bottom layer have been determined. Then deeper points, at which landfill liquids may accumulate and constitute a source for groundwater contamination, have been connected as indicated in Figure 9. Then after the land surface level which is directly above the line connecting the deeper points have been specified. This was followed by drawing a comprehensive and expressive profile for the bedrock layer under the line connecting the points. Another similar profile for the connecting points and topography of the rocky layer have been drawn with a view to determining the level of the Landfill's liquids. After that the deep concave sites of the rocky layer for determination of the sites of the liquids drawing wells in the Landfill as indicated in Shape Figure 10.

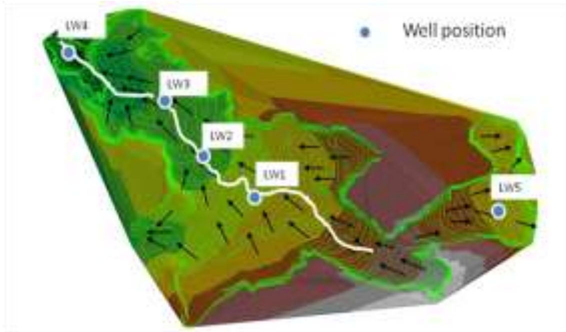

Figure 9: A movement line for Landfill liquids at low points on the bedrock layer and the proposed sites of the Landfill's liquids drawing wells.

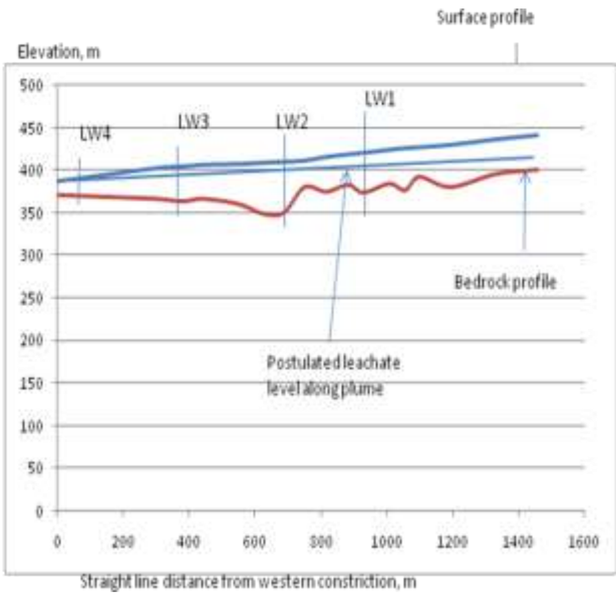

Figure 10: A profile of the most appropriate sites for liquids drawing wells.

Design of the Landfill's liquids –drawing wells

It is better to use rotary drill for digging Landfill's liquids –drawing wells with 12 inches diameter , together with the support of all aspects of the wells with a PVC pump so as to prevent it from collapse. Based on the report of the engineer supervising the implementation, it is to determined whether there is necessity for laying a screening wall on the lower half of the well's length in order to prevent the entrance of sands and soil into the wells. Furthermore, digging must extend to approximately meter or two meters inside the bottom rocky layer. Figure 11 displays an illustrative drawing for building the well inside the landfill and penetrating the waste materials layer. However, the well which is situated near the western periphery is considered outside the boundaries of waste dumping area; and hence around it there will be no waste materials layer.

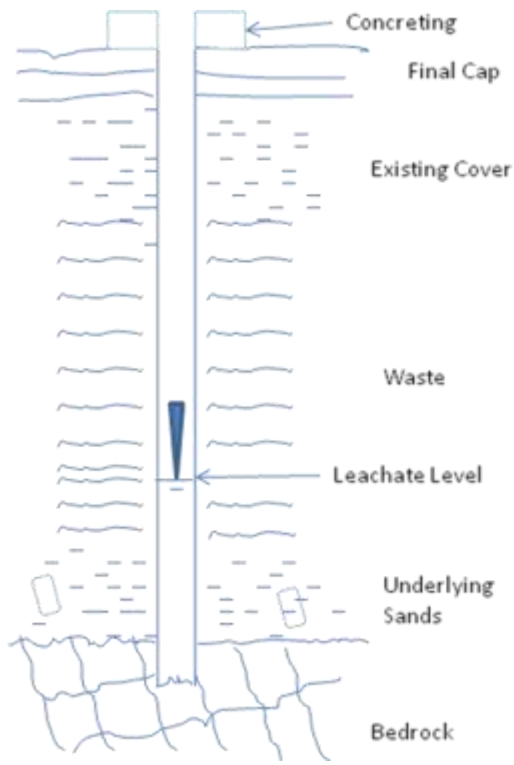

Figure 11: shows an illustrating draw for liquids- sucking wells within the boundaries of the Landfill.

LANDFILL GAS

A number of gasses are produced as a result of bacterial reactions and dissolution of organic materials inside the Landfill (Spokas et al., 2006). However, the type of waste materials in the Landfill determines the quantity and chemical structure of such gasses. Furthermore, we can benefit from such gasses, particularly methane gas , in the production of energy. However, certain gasses are detrimental to the both air environment and health of individuals

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living near the Landfill site. Such harmful gasses comprise carbon monoxide, carbon dioxide other volatile organic compounds. After closure of the Landfill, the production of such gasses continues for a very long period of which sometimes extends for scores of years. Therefore, it is essential to control the exit and fate of the gas. The most effective and the commonest method for the collection of gases is via vertical wells that are connected to a network pumps that convey the gases to the processing station. At the processing station, methane gas is utilized in the production of energy and the processing of the remaining gases is completed via the burning of gasses at a very high temperature.

Field Work and Measurement of the Percentage of Main Gasses

The sites of gas wells currently found at the Muassim Landfill and coordinates of the site are shown in Figure 12. Table 3 displays the results of measurements of the components of the Landfill's gasses and coordinates of samples taking. The also shows that the percentage of methane ranges between 11 to 60% whereas the concentration of the average percentage of carbon dioxide ranges between 0-45%. Furthermore, the results of measurements indicate that methane can be used in the production of energy and that it be burnt at regular temperature via the organized torch for taking advantage of its value in the programs of carbon trade (Park & Shin, 2001).

Table 3: Maximum and minimum values as well as average (mean) percentage of various gasses in gas wells and, wells depth.

Element	Average / Mean	Max Level	Min Level	Standard Deviation
CH_4	53.5	62.5	0.2	13.9
CO_2	39.4	45.4	0.0	9.0
O_2	1.3	20.1	0.0	3.9
Bal	7.8	80.3	0.0	17.6
Depth (m)	7.0	14.0	2.4	1.9

Figure 12: A map of the sites of gas wells currently found at the Muassim Landfill and coordinates of the site.

Estimation of the resulting quantity of Gas and its Production Rate

For estimation of the quantity of the gas resulting from chemical reactions and dissolution of organic materials buried already in the Landfill, the program of Environmental Protection Agency of America (EPA) for calculating the rate of producing Landfill gasses (Wanichpongpan & Gheewala, 2007). In Figure 13 and 14 displays the rate of producing methane (CH_4) and carbon dioxide (CO_2) as well as other carbon organic gasses (not belonging to methane) in cubic meters and metric tons respectively. For operation of the program, the quantity of the current waste materials has been divided over the number of years during which the Landfill received them; once equally and other gradually via annual 10% increase. When we compare the results of these two cases, it becomes conspicuous that there is no statistically significant difference, particularly in the remaining years of the active hypothetical live of the Landfill.

From Figure 13, it can be remarked that the rate of overall production of gasses that are not related to methane reached its climax in 2007, where its annual score was around 120000 metric tons, then it started to decrease till will reach an annual figure of 20000 metric tons by 2030, then this is followed by further reduction

till it becomes only 10000 metric tons an annum by 2050. Moreover, the rate of methane production reached in 2007 an annual quantity of nearly 60000 metric tons, but its current production reaches about 45000 metric tons a year.

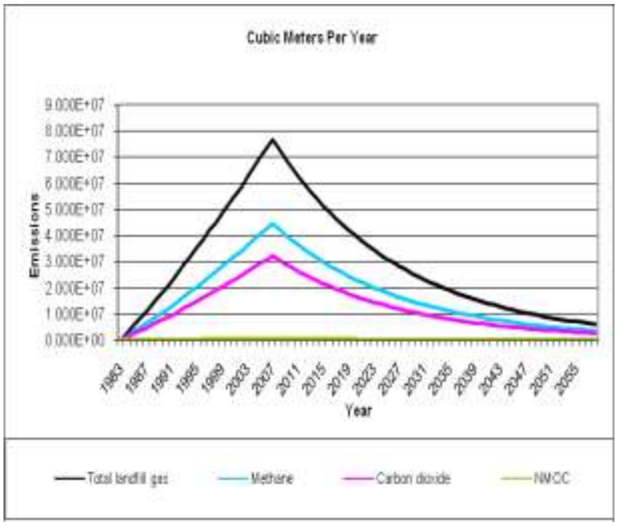

Figure 13: The rate of producing Landfill Gasses in Cubic Meters from 1983 to 2055

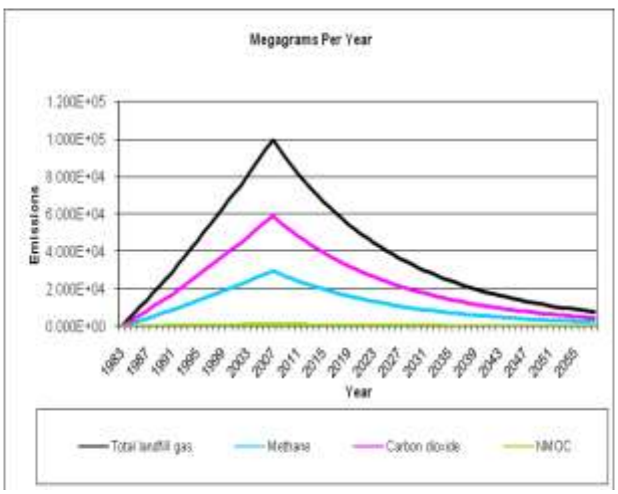

Figure 14: The rate of producing Landfill Gasses in Metric Tons from 1983 to 2055 When the existing gas well are inspected, it is found that some of them are not functional and needs maintenance due to descending happened to the area surrounding each well as indicated in Figure 14. Likewise, the network linking the wells with the main conveying pipe was thoroughly reviewed and it was found that a great number of the network pipes are damaged and that they are not considered connected to the network due either the fractures, holes or cut happened to them. It seems that most of the damage that affected the wells and network is due to the land descending which usually happens to the surface of the Landfill as a result of bacterial dissolution of organic materials. Such descending usually leads to creation of empty pockets in the body of the Landfill; and that land descends due to the impact of soil weight over it and absence of effective maintenance works which are required to restore the affected parts and transport gas that they collect from the surrounding wells.

CONCLUSION

This paper comprises the results of the quality of both underground water and atmosphere near Muassim Landfill—an improperly designed landfill in Makkah, Saudi Arabia. The objective of this study is to make available information and data required for designing the system of collecting and processing Landfill's liquids (leachate) in an attempt to protect underground water from polluting with the Landfill's liquids. The groundwater adjacent to the landfill boundary was found to be heavily polluted with landfill leachate. The site was found to be emitting greenhouse gases unrestricted; even some of the gas pipes were found broken and clearly required maintenance.

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