Environmental Impact of Municipal Solid Waste Landfills in Semi-Arid Climates - Case Study – Jordan

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Abstract: Landfilling is the most commonly used method for solid waste disposal in Jordan. It is an important source of pollution, which can be displayed through analysis of data for climatic conditions, hydrology and geology of the country. The migration of gas and leachate from the landfill body into the surrounding environment present a serious environmental concern, which include groundwater pollution, air pollution with impact on climate through methane emission and potential health hazards. This paper presents an overview of these environmental concerns from landfilling practices and their adverse environmental effects. In this paper, a number of remedial measures needed to minimize these environmental and socio-economic effects are suggested, with in total ten long term and eight short term measures for improving of the solid waste management system of Jordan.

Keywords: Gas and leachate generation, climate change, environmental impacts, remedial measures.

1. INTRODUCTION

Landfilling is the simplest and normally cheapest method for disposing of waste [1]. In most low-to medium-income developing nations, almost all generated solid waste goes to landfill. Even in many developed countries, landfilling is the most popular disposal method. In the European Union, although policies of reduction, reuse, and diversion from landfill are strongly encouraged, more than half of the member states still send an excess of 75% of their waste to landfill [2]. Additionally, although the proportion of waste to landfill may in future decrease and the total volumes of municipal solid waste (MSW) being produced are still increasing significantly for many developed countries. Landfill is therefore expected to remain a relevant source of groundwater pollutant for the foreseeable future [3-6].

The impact on water resources from landfills in arid areas must be noticed. Even if low costs and high availability of marginal land have made landfilling the most commonly used waste disposal method, landfilling has many effects on water resources. In fact, most arid areas suffer from the sever rainfall erosion which could increase the possibility of surface and ground water contamination. Disposal of liquid waste is not uncommon in landfills in arid areas. Jordan, as an example for the semi-arid and arid regions, has seen a large increase in population during the past five decades as a result of population growth and forced migrations [7]. Accompanied of this increase, economical and cultural development has improved the standard of living and changed consumer habits in the community, resulting in a clear increase in the volume of waste. The rate of production of MSW in Jordan has been estimated at about 1,960,000 tons annually with an average generation rate of 0.95 kg/cap/day in urban and 0.85 kg/cap/day in rural areas [8] and is expected to reach 2.5 million ton by 2015. There is clear a lack in waste management practices, especially the proper landfilling, coupled with the rapid increase in solid waste, which poses a negative effect on health and environment. Nowadays landfilling practiced in Jordan is still simply dumping the waste in trenches with leveling and compacting by trash compactors to reduce the size and the thickness of the layers, and finally cover the waste with soil (trenches method) [9], see Fig. (**1**). The trenches method is used in

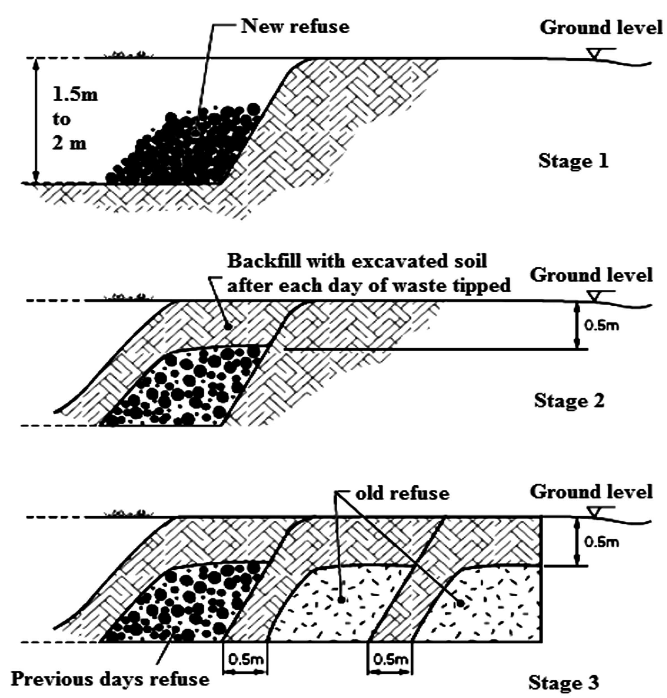

Fig. (1). Trenches landfill method used in Jordan.

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most of Jordanian landfill due to their simple set-up and low operational requirements. The construction of a trench must be carefully pursued in order to minimize the leachate of pollutants into the soil and groundwater. In this work, we will determine and assess the direct and indirect environmental impacts of landfill and dump sites in Jordan. Furthermore, suggestion of the appropriate control method to minimize negative effects of landfills on human and the environment will be addressed.

2. LANDFILL GAS EMISSIONS

Organic waste can be decomposed forming gaseous products. When the degradation process slowly moves from aerobic condition to anaerobic condition, the carbon dioxide level continues to be high, gradually falling as the methane concentration builds up [10]. Other than methane and carbon dioxide, there are also some trace levels of gases being generated during the degradation process including hydrogen, nitrogen, etc. Landfill gases, especially methane and hydrogen, are highly flammable and if they are not collected, used for energy utilization or flared off, they will lead to potential fire and explosion hazard. In some cases, incidents of fires and explosions due to lateral gas migration away from landfills have been reported in the literature [11]. Landfills worldwide are estimated to produce 40 million metric tons of methane each year, which is approximately 7.5% of the methane produced and released each year into the earth's atmosphere by all natural and anthropogenic sources [12]. Landfill gas (LFG) emissions have a number of pollutants of concern to human health and the environment so landfills are identified as a hazardous air pollutant source under the Urban Air Toxic Strategy [13]. In Jordan, it was found that the methane emission from Akaider landfill will reach 12 million M^3/year by the year 2021 and if it is utilized properly, the LFG will not only generate a green energy, but it also will create a source of revenue [14]. In another study the production of methane gas from Al Rusaifeh and Akaider landfills was estimated to generate electricity at very low cost with an annual savings of 4.65 M$. This could be achieved by the replacement of fuel oil with the generated biogas [12]. On the ground, the only positive utilizing experience was gained when a biogas company (a non-profit organization) owned equally by central electricity generating company and Greater Amman Municipality was established in 1997 on Al Rusaifeh closed landfill. The main objectives from the company were to reduce the greenhouse gases (GHG) emissions from the landfill, as well as utilizing the fresh organic waste in the production of methane gas for power generation. The electricity generated was around 2.62 GWh during the period from 2000 when the factory start working to 2009. Also the factory managed to reduce the emission of a total of 106.38 million M^3 of biogas during the same period [15]. Recently, because of the company success in achieving its goals an agreement with Finland government was signed to buy carbon credits from the factory in a price of 7.78 Euros/ton of Carbon dioxide (CO_2) within the Clean Development Mechanism (CDM) of the Kyoto protocol [16]. The plant reduces the emission of 5000 tons of methane and saves 6000 tons of diesels. In a UNDP study [17] conduct for Jordan's Landfills the cost of emission utilization has been estimated compared to the potential revenues from the CDM. The result is presented in Fig. (**2**).

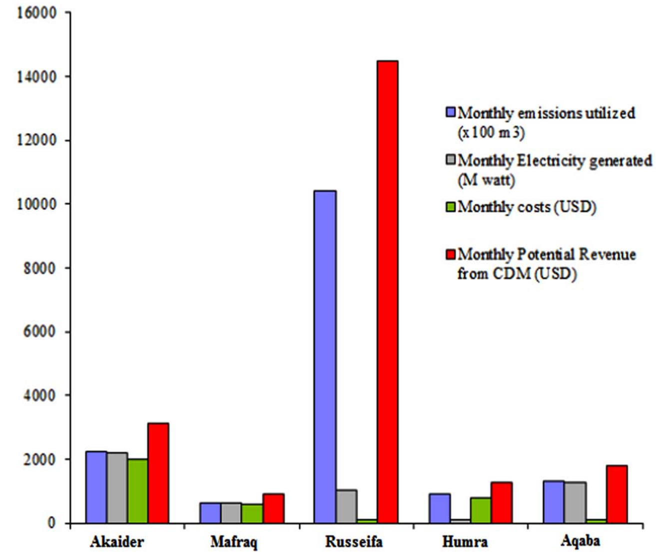

Fig. (2). Estimated costs compared to potential revenues from the CDM from Jordan's Landfills. UNDP study [17].

3. LANDFILL LEACHATE EMISSIONS

Solid waste disposed in landfills is usually subjected to series of complex biochemical and physical processes, which lead to the production of both leachate and gaseous emissions. When leachate leaves the landfill and reaches water resources, it may cause surface water and ground water pollution [18-21].

It has been well recognized that the quantity of leachate generated in a landfill depends on the climate in which the landfill is situated, as well as the type of waste and the water content at which it is landfilled. In arid climates, landfills will either not produce any significant leachate, will only produce leachate seasonally, or may produce leachate only as a result of compression of an initially wet waste [22]. For climates where annual precipitation is less than 400 mm, virtually all precipitation is evapotranspired [23]. In cases where no significant leachate is produced, it may be possible to relax the standards required for the design of a landfill by omitting the leachate collection system and under liner. However, this will depend on geological and groundwater conditions at the sites. If groundwater exists close to the surface, or if the site is underlain by, e.g. sands and gravels or cavernous limestone, it may be sensible to provide a leachate control system regardless of climate. However, even in an arid climate, there are occasional wet years or wet seasons. The influence of warm climate on landfill performance is complex and the increase in leachate production after precipitation is rapid [24]. The calculated values of climate water balance based on the precipitation, evaporation and runoff data we made in many cases in Jordan from the available past and present data were always negative [25]. However, co-disposal of waste water (septic wastewater) inside the landfill, which is practiced in most of the Jordanian landfills, increased the leachate production significantly and should be considered as a major source of leachate generation [6]. For those kinds of landfills, an under liner would probably be required. On the other hand, generation and chemical characteristics of leachate depends also upon other factors, such as the MSW composition, moisture content, capillary action, water content of subsurface soil and ambient temperature.

The MSW composition in Jordan is mainly organic in nature and has high moisture content at about 52%, see Fig. (**3**). Beside as mentioned before that many landfills in the country receive both solid waste and septic wastewater. Septic wastewater poses a challenge to the environment as it is hard to treat. Akaider site receives over 5000 m^3/day of septic wastewater. The climate at that site is arid to semi-arid; where the highest mean monthly average temperature is 25.3C° while the lowest monthly average temperature is 8.8C°. The rainy season is between October and May, and the average yearly rainfall is 485 mm. Thus, a lack of moisture may hinder the waste degradation process. The potential use of septic wastewater to wet the dry solid waste on emissions was explored [9]. It has been illustrated that wetting the waste would increase the rate of gas production and make gas capture and beneficial use justifiable. There are at present 21 landfills in Jordan (listed in Table **1**), the majority of these landfills are without leachate collection facilities. The lack of leachate collection facilities coupled with the fact that most landfills do not have impermeable liner system, increase the risk that leachate will contaminate nearby water [26, 27]. They have proven in their studies that the Akaider landfill leachate constitutes a serious threat to the local aquifers in the Yarmouk Basin. In Table **2**, the characteristics of leachate collected from Akaider landfill site is presented.

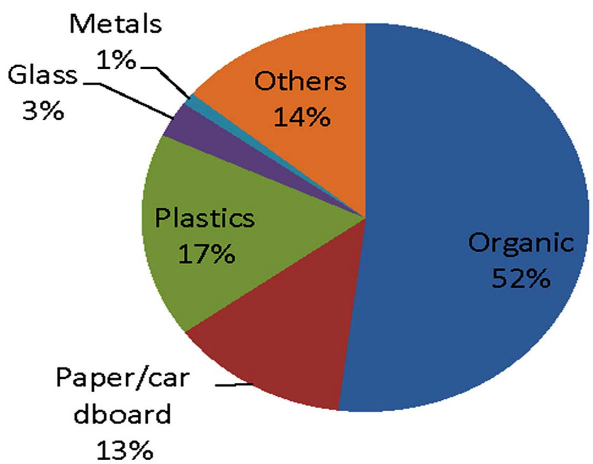

Fig. (3). The Physical Composition of MSW in Jordan [8].

4. ENVIRONMENTAL IMPACTS

In the beginning of the 1970, the authorities in Jordan realized the pollution associated with the solid waste practices through uncontrolled landfills, open dumping and partial combustion. Action was taken but it was not accompanied with the proper landfilling practices on the ground, which poses negative impacts on the human health

Table 1. Domestic Landfills in Jordan [69]

No	Site Name	Operating Date	Governate	Area in Dunm	Received Waste Tons/Day
1	Akaider	1980	Irbid	806	800
2	Al-Husaineyat	1986	Mafraq	180	170
3	North Badia	2003	Mafraq	360	43
4	Al-Ruasihed	2003	Mafraq	179	4
5	Al-Hamra	1990	Al-Salt	275	450
6	Al-ghabawi	2003	Amman	1947	2500
7	Madaba	1974	Madaba	87	500
8	Dhulil	1991	Zarqa	270	295
9	Dair alla	1998	Balqa	363	290
10	Azraq	1983	Zarqa	250	17
11	Noth shuneh	1983	Irbid	200	67
12	South shuneh	1988	Al-Balqa		55
13	Ghor Al-Mazra'a	1997	Karak	205	22
14	Lajoon	1995	Karak	485	190
15	Ghor Al-Safi	1997	Karak	153	25
16	Tafilah	1990	Tafilah	450	65
17	Al-shoubak	1983	Ma'an	26	45
18	Eyil Neimat	1984	Ma'an	274	42
19	Ma'an	1994	Ma'an	502	90
20	Al-Quaira	2000	Aqaba	270	25
21	Aqaba	2000	Aqaba	60	115

and environment. Many problems connected to this could threaten the ground water and surface water resources beside the spread of odors, insects, rats, smoke and gases resulting from the decomposition of waste. In the following section, we will focus more on the air quality and ground water impacts.

Table 2. Characteristics of the Leachate Samples Collected from Akaider Landfill Site [26]

Parameters	L1	L2	L3	L4	L5	L6
pH	7.79	7.63	7.96	7.93	7.91	7.84
Temp.$^{(c)}$	20	20	20	20	20	20
Turbidity $^{(NTU)}$	40	40	150	160	130	110
EC $^{(\mu s/cm)}$	3.6	3.75	4.86	4.72	4.89	4.84
Alkalinity$^{(mg/l)}$	670	665	2300	2400	2000	2700
Cations $^{(mg/l)}$						
Fe	0.16	0.15	18.16	15.25	11.34	13.55
Mn	1.1	0.11	0.78	0.52	0.41	0.44
Ca	219	332	443	181	233	340
Na	556	538	485	778	735	256
K	65.2	61.6	1266	1273	1282	1371
Anions$^{(mg/l)}$						
Cl	10.3	11.2	1996	2650	2170	2338
So_4	73.0	82.5	1105	1088	1164	11065
Heavy Metals $^{(mg/l)}$						
Cd	0.012	0.013	0.16	0.52	0.42	0.37
Zn	95	90	261	169	174	159
Cu	0.12	0.25	0.52	0.044	0.048	19.45
Pb	0.19	0.89	1.70	1.50	0.65	1.5

4.1. Air Quality Impacts

LFG is produced when organic material decomposes anaerobically, consisting of 45% to 60% methane gas, 40% to 60% carbon dioxide, and 2% to 9% other gases which are mostly emitted to the atmosphere. LFG is becoming a significant contributor to atmospheric methane, unless recovery control systems are implemented [28]. Although methane and carbon dioxide are produced in almost equal amounts in landfills, methane production is of greater concern. Landfills are the largest anthropogenic source of atmospheric methane in many developed countries. In Europe, 30% of anthropogenic methane emissions are from landfills. In the USA, they contributed approximately 37% in 1997; the largest fraction of all anthropogenic sources [29]. Different factors can affect the flow of landfill gas can be seen in Fig. (**4**). Normally, landfill gases flow through diffusion where gases move from areas with high gas concentration to areas with lower gas concentration [30]. Another type of movement is due to pressure, when gas accumulates in landfill it creates areas of high pressure, where gas movements are restricted by compacted soil covers, and areas of low pressure, where the gas can move freely. This variation in pressure causes the gas to move around the landfill, in a process known as convection [31]. When more gas is produced, the pressure inside the landfill becomes higher than the atmospheric pressure and it moves out into the atmosphere. Finally, gas migrates to areas of low resistance, which is how well gases and liquids flow through connected spaces and pores in waste and soil. Gas rather moves through dry, sandy soils with high permeability, than moist clay with low permeability [31]. These gases cause bad odors inside and outside the landfills. In a semi-arid climatic region, the landfill waste stays relatively dry and generates gas so slowly that an active gas collection system cannot be supported in some cases. However, the produced methane gas has to be treated or eliminated either through collection or by using oxidation process using alternative final cover to passively eliminate methane as it moves slowly up through the cover.

In Jordan, the Mafraq Landfill which is known also as the Al-Husaineyat landfill, has an area of 180,000 m^2, a volume capacity of 400,000 m^3, and a landfilling capacity of 60 years (1986 - 2046) [32], Fig. (**5**) shows the location of the landfill. The landfill is located 25 km from the eastern part of the city and receives a total of 134 tons of waste per day from the city of Mafraq and 64 villages in the surrounding

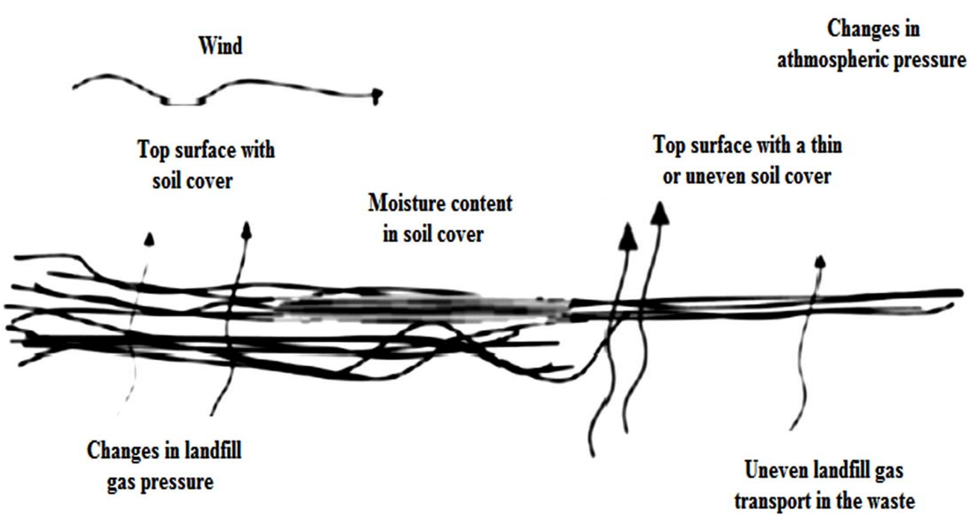

Fig. (4). Different variables that influence the flow of landfill gas through the landfill surface [30].

region [33]. The different types of waste deposited on the landfill are residential, commercial, institutional, and municipal. The waste is collected by trash trucks and weighted at the entrance of the landfill. The landfill has been preliminary excavated in order to form a pit for receiving the trash; the waste is directly deposited on the surface ground. After disposal on the site, teams of about 15-30 human scavengers are employed to sort the trash. They sort the trash manually into the following categories: plastic, cardboard/paper, metallic waste, and aluminum waste. The remaining waste is then piled on by trucks for final deposition. Mafraq landfill is located in an open area and exposed to wind, the prevailing winds in the area is the North West and South East; this wind contribute in the accumulation of gases in the landfill, which can carry to the residential areas if these winds southwesterly. Odors are noticed outside the landfill and from the nearest residential area which is located 7 km far from the northeast of the landfill, the odors are expected to be increased as the landfill is expanding. According to the landfill monitoring records the average TVOC,s measured inside the landfill around 500 ppb, ammonia 8-15 ppm and the methane gas was 0.5 mg/m^3, which is within European standards [34] for working environment.

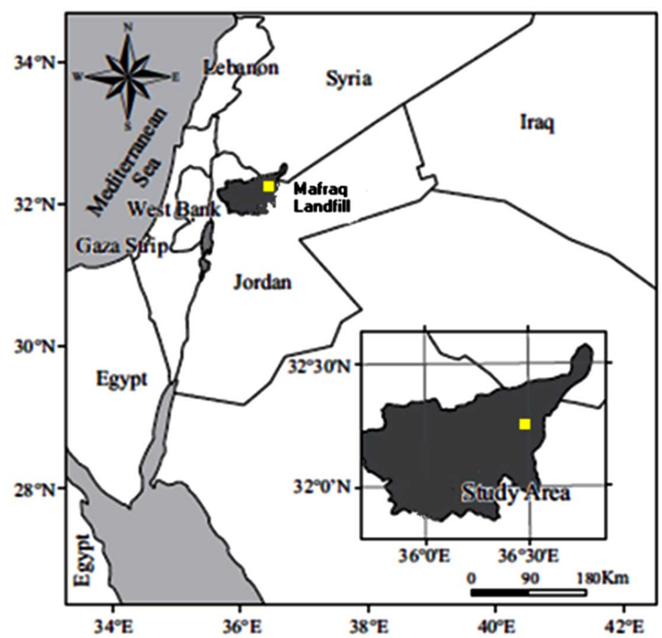

Fig. (5). Mafraq Landfill Location.

4.2. Climate Change Impacts

Climate change is not only a major global environmental problem, but also an issue of great concern to developing country like Jordan [35]. Over the last 20 years significant reductions in the average rainfall have been noticed, and the rains are not as predictable as they were. In addition, the number of days with extreme high temperatures and days with extreme low temperatures are rising, more heat means losing more of our energy resources. In the year 2000, GHG emissions to the atmosphere from the waste sector totaled 2713 GgCO_2 equivalents(CO_2 eq) at 13.5% of Jordan's total GHG emission which is about 20.14 million tons of CO_2 eq of GHGs [6, 36]. Most of the emissions originated from disposal of domestic solid waste which accounted for 12.5% (2515 Gg CO_2 eq) of the total GHG emissions, while wastewater handling accounted for 1% (199 Gg CO_2 eq) of the total GHG emissions. The largest contributor to methane emissions is the waste sector. Methane emissions generated from domestic solid waste landfills and wastewater accounted for 91.6% and 3.6% of the total methane emissions; respectively. The energy sector contributed 4.7% of the total methane emissions. The contribution of agriculture sector to methane emissions was negligible [6], see Fig. (**6**).

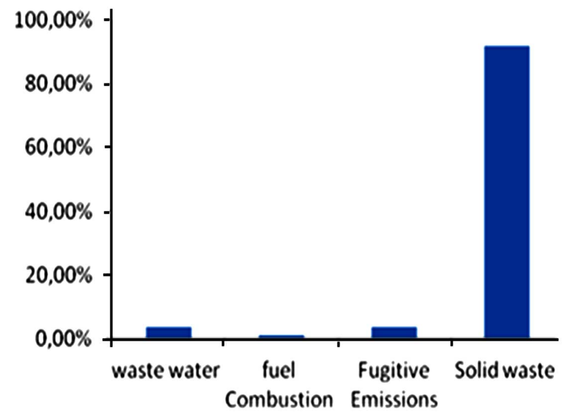

Fig. (6). Methane Emissions by sector [6].

Jordan is not contributing to more than 0.05% to the world total GHG emissions. This relatively small contribution of GHGs does not correspond to the projected impacts of climate change over the country [37], and will continue to be severely impacted [38]. One opportunity for Jordan is the CDM agreement that allows developed countries payments for GHG emissions reductions to developing countries [39]; these payments will encourage and increase worldwide rates of landfill methane recovery; effective mitigation through reducing GHG concentrations in the atmosphere is the significant technique for climate change problems [40]. In Jordan, scientific proof of a relation to climate change could not be seen yet. Also [41] in there study to investigate the relation between the development of precipitation in Jordan and the global phenomena of climate change; they found no evidence of a visible trend in the average increase or decrease of precipitation, still there appears to be a clear reduction of temperature range. However, sufficient data generation and analysis cannot be achieved in Jordan simply because of limited meteorological infrastructure and limited data resources.

4.3. Groundwater Impacts

Groundwater in Jordan is of two types, renewable and non-renewable fossil water distributed among 12 basins as shown in Fig. (**7**). It plays a central role in Jordan where it represents 55-60% of the available water resources, equaling 850 million cubic meter annually (MCM/a) [42-45]. The country is facing a future of very limited water resources, it has among the lowest renewable water resources in the world on a per capital basis [6, 46]. In urban areas, there are many possible sources for groundwater contamination, including

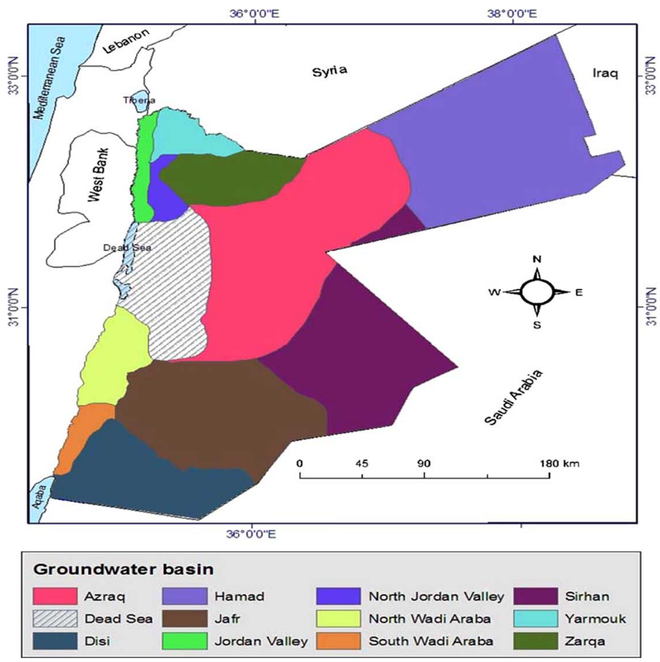

Fig. (7). Groundwater basins in Jordan.

landfills, septic tanks and cesspools, domestic and industrial effluents, leaky sewage system and gasoline stations [6, 26, 47, 48]. Areas near landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachate direct mitigation [49]. Leaching of pollutants from landfills may result in groundwater contamination, especially when it comes to uncontrolled landfills with the absence of lining and monitoring systems of the waste received. The generation and the chemical characteristics of leachate in arid climate countries depends upon the MSW characteristics, moisture content, capillary action, water content of subsurface soil and ambient temperature [50]. Generation of leachate from municipal solid waste landfill in arid regions was neglected on the assumption that minimal leachate could be formed in the absence of precipitation. Many studies, on the other hand, have identified potential of contamination due to uncontrolled landfilling, e.g. [23, 26, 27, 47, 49, 51, 52]. Groundwater contamination is generally irreversible once it is contaminated; it is difficult to restore the original quality [53]. It has been found that the water held in the surface soils by capillary action can infiltrate through the solid waste. Therefore, the leachate will migrate toward the water table beneath the landfill, contaminating the soil and the aquifer system in arid region. In Jordan, groundwater quality has been deteriorating by point and non-point pollution source including domestic agricultural and industrial uses and become an increasing problem in recent year. During the last 20 years, many evidences for groundwater contamination have been presented especially in northern part of Jordan [52]. Additionally [54], a gradual increase of element concentrations has been reported in the groundwater wells around the Akaider landfill starting from 1985. Nitrate concentrations rose dramatically, doubling more than ten times in ten years; this indicates that the previously unsaturated zone had become saturated with polluted water. Also [47, 55] affirm that the Yarmouk basin is contaminated with high nitrate concentration, exceeding the maximum acceptable concentration for drinking water standard, which was identified previously by [56] where they found high concentration of HCO^-_3 and NO^-_3 of 307 and 51 mg/l, respectively in groundwater in the northern areas of Jordan. Another study by [57] showed high nitrate concentrations in groundwater at Amman-Zarqa basin; it ranged from 10 to 330 mg/l, and increased from the year 2001 to 2006. About 92% of the samples have NO^-_3 concentration more than 20 mg/l; which is the allowable limit in drinking water standards. The effect of uncontrolled landfilling practices from Al-Husaineyat landfill site on the water quality in the surrounding area has been investigated by the author; the landfill is located over Amman-Zarqa basin, the basin extends from Jebel Arab in Syria in the northeast. It covers a total area of 4,586 km^2, with about 4,074 km^2 in Jordan and 512 km^2 in Syria. The annual average precipitation is around 600 mm in Jebel Arab, 400 mm in western Amman, and less than 100 mm towards the desert [58, 59]. The Amman–Zarqa aquifers have the highest groundwater recharge in Jordan; 88 (MCM/a). This represents about 30% of the nation's renewable groundwater resources (275 MCM/a). The main groundwater system in the basin is composed of the Basalt and the Amman (B_2) and Wadi Es-Sir (A_7), which are located in the northeastern highlands extending north to the Syrian border and southwest to the outskirts of Amman. The A_7 formation consists of massive bedded limestone containing chert nodules in the upper part, which is overlain by the B_2 Formation. The B_2 Formation is composed of cyclical deposits of chalk, phosphate, silicified phosphate, limestone and chert. The main recharge zones are located over outcropping areas extending from the Ajlun Dome northward to Irbid and eastward to Mafraq. It is also recharged by underlying aquifers. The thickness of this aquifer ranges from under 10 meters to around 500 meters in the Azraq basin. The water quality from the aquifer is in general good, with TDS values ranging from 500 to 1000 mg/l. The high permeability and large extension of the aquifer makes it an important groundwater resource in the area, in the study water samples were collected, physical and chemical parameters were estimated for selected wells within an area of 2 km from the landfill site and the impact on the ground water flow direction was covered. The result showed that the landfill constitute a serious threat to the local aquifers, see Figs. (**8**, **9**). Ion concentrations analyzed were in accordance with world health organization (WHO) guideline values and according to Jordanian Drinking Water Standards (JDWS) 286/2008, except for the fluoride and the chloride concentrations. The guideline value for chloride is set to 200-300 mg/L [60]; the values in well 4 were of 330 mg/L. The guideline value for fluoride is set to 1.5 mg/L whereas it was 14, 3.8, 1.2, and 0.5 for wells 1, 2, 3, and 4 respectively. From Fig. (**9**), the electric conductivity (EC) was 1230, 948,870 and 635 μS/cm for wells 1,2,3 and 4 respectively. According to EC classification for irrigation purposes [61], wells 1,2, and 3 classified as having slight to moderate degrees of restriction on use whereas the well 4 classified as having no restriction. The pH 8.2,7.9,7.8 and 8.3 were almost neutral for all the well fields for wells 1,2,3 and 4 respectively. Biological contamination was monitored; the Total Coliform Counts (TCC) in well 1 and well 2 was

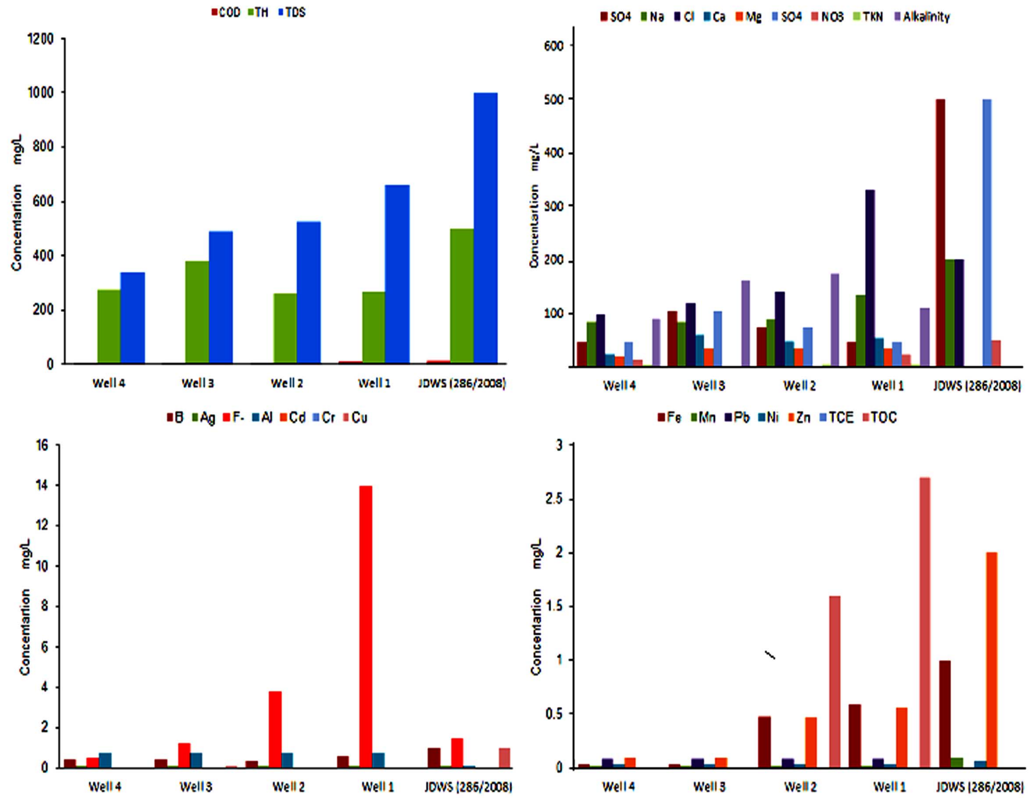

Fig. (8). Chemical analysis for different wells in Mafraq area.

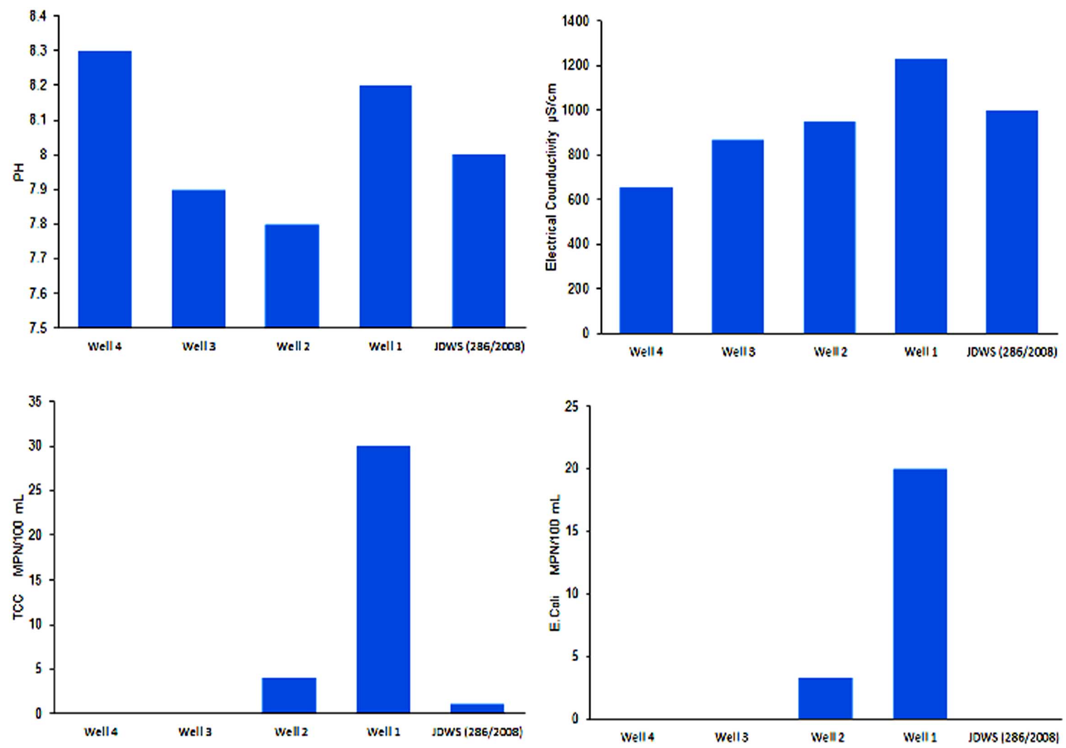

Fig. (9). Physical and Biological analysis for different wells in Mafraq area.

30 and 4.1 MPN/100 mL respectively. Also the Escherichia coli (*E. coli*) was found to be 20 and 3.3 MPN/100 mL respectively. Groundwater should be free from any trace of biological contaminant according to (JDWS) 286/2008. See Fig. (**10**) a map providing locations of wells 1- 4 with reference to the landfill.

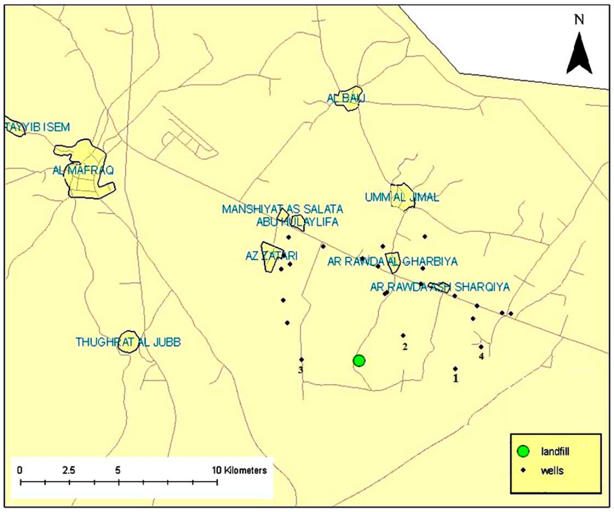

Fig. (10). Map providing locations of wells 1- 4 with reference to Mafraq landfill.

5. DISCUSSION AND CONCLUSION

The current situation of landfills in Jordan does not fulfill the required national and international conditions for environmental precautions; the weak financial status of municipalities and common services councils (CSC) which is responsible for managing dumpsites and landfill in the country stand against getting modern solid waste collection and successful landfill operations. Landfill should be operated to a standard, which protects human health and the environment. Where landfill standards have not reached the minimum for protection of health, it is recommended that action should be taken immediately. However, the improvement of the landfills has to be done gradually according to the country's condition and its financial and technical abilities. Landfill gas and leachate generation are concerns for the practices of waste disposal in the landfills; measures are essential in order to minimize negative environment impacts of solid waste in Jordan. The following immediate improvements can be done to minimize these environmental and socio-economic impacts.

5.1. Long Term Remedial Measures

1. Landfill should be designed, located and operated based on national, international guidelines, environmental impact analyses (EIA), and environmental friendly which take into consideration the accurate climate date precipitation, evaporation, temperature, and wind direction beside the location from residential areas and the groundwater level. It must also be recognized that good engineering and management of a landfill can be used to maintain a perennial water deficit within the landfill by maximizing runoff and minimizing infiltration into the waste. Authorities must make provision for future landfill needs by allocating suitable land in their long-term strategies [62]. The Establishment of environmental friendly landfills is also consistent with country strategy planning and Ministry of Municipal and Rural Affairs strategy [6].
2. Operational standards (guidelines) for landfill practices needed to provide the requirements for environmentally sound design and operation which considers all site specific conditions (especially climatic data, hydrologic and geologic factors).
3. Avoid the co-disposal of waste water from septic tanks into the landfill body to minimize the leachate generated and groundwater contamination [6].
4. Responsible authorities should provide the basic facilities needed for sorting and source separation of waste; in a survey conducted by the author in 2010 around 1000 Jordanian citizens were surveyed, from the study the respondent hold a positive attitude and willing for source separation if the authority provides the necessary tools [63].
5. Landfill economic feasibility of gas recovery, processing, and utilization in Jordan has been reported by many researches [9, 12, 17, 64]. Landfill gas control and collection system should be implemented for more efficient utilization and to prevent the gas accumulation even where the case is not economically feasible.
6. Increase the knowledge and awareness between residences for the importance of waste sorting and source separation and it is beneficial effect on social, economic and environmental aspects [65].
7. Declare and organizing the scavenger work through merging them formally in the system, Scavenging has been recognized recently in Jordan as an effective way for managing waste whereas it reduces the cost of formal waste management systems as it reduces the quantity of waste for collection [16, 65-67]
8. Encourage the private sector to invest in all forms of waste recycling and management projects [39].
9. Reducing the quantity of the biodegradable waste that is landfilled which is considered with encouraging landfill methane recovery the major strategies for reducing the methane emissions, by implementing special standards starting with industries, companies and big waste generators [68].
10. Establishing environmental friendly landfills which are consistent with country strategy planning and Ministry of Municipal and Rural Affairs strategy [6].

5.2. Short Term Remedial Measures

1. Ensure that daily covers are practiced. Leachate problem could be minimized by limiting the water getting into the landfill through surface water diversion to ensure that no water can enter the landfill and also to ensure a low water table within the landfill by frequent pumping that should be coupled with the daily soil cover. A low-permeability cover affects the water content of the landfill [25].
2. Improvement of access road.
3. Constructing the basic infrastructure, fencing and weighbridge.
4. Stop open burning inside landfills.
5. Establishing surface drainage system for limiting the infiltration of the water through the landfill cover by

providing impermeable cover and surface water diversion for ensuring that less water will enter the landfill body.

6. Raising the awareness and competences of the employees.
7. Construction of leachate collection and gas venting facilities.
8. Ensure that no disposal of hazardous and medical waste takes place; it is important that only municipal waste is disposed in landfill, and no industrial or hazardous waste. Therefore, waste should be sorted and sites should be carefully selected to especially avoid negative impacts on groundwater resources.

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CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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