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Siting of Landfills for Hazardous Waste in Iraq from a Geological Perspective

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Abstract

Iraq has been involved with two major wars in 1991 and 2003 (Gulf war I and II), which resulted in leaving large amounts of wrecked tanks, vehicles, weapons and ammunition. A considerable amount of the military waste contains depleted uranium (DU), which is a by-product of the enrichment of natural uranium for nuclear reactor-grade or nuclear weapons-grade uranium. DU used during the second Gulf war is more than 1100 to 2000 tons. This has serious effects on humans in Iraq and the environment. There is no national or international program for cleaning Iraq of DU wastes. To protect humans and the environment, three locations for disposals were suggested according to the geological conditions. These locations fulfill the requirements so that radioactive waste does not affect human life and the environment. To use these sites there should be proper design for the landfills so that it can perform for long period of time.

Keywords: Landfill, Hazardous Waste, depleted uranium (DU), geological factor for siting, Iraq.

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1. Introduction

Waste is generated in different forms due to human activities and animals. Parts of the waste is considered hazardous to the human and environment. This problem is more serious in third world countries where 80% of the world population live [1, 2] and financial resources are lacking. Waste related diseases cause the loss of 10% of each person's production life [1]. For this reason, it is very important to avoid solid waste hazards through proper legislations and laws (see UN conference in Stockholm, 1972; Earth Summit in Rio de Janeiro, 1992, in [3]) to ensure sustainable development and management of waste.

On international level, USA and Canada produce more waste than other countries followed by Western Europe, Japan and Korea, Australia and New Zealand [4]. Hazardous waste production reached 150 million tons in the year 2000 [4].

Hazardous waste includes radioactive waste, which is produced by nuclear power plants, industry, hospitals, research organizations and military nuclear tests and weapons [5]. In 2008, the Global radioactive waste inventory reported by International Atomic Energy Agency as storage was 15.6 million cubic meters of long and high-level waste and 1800 million cubic meters of waste from uranium mining and milling operations [6].

Iraq is located in the northeastern part of the Middle East covering an area of 437,072 square kilometers with a total population of about 32 million (Figure 1). The main population density is on the banks of the Tigris and Euphrates Rivers. Iraq passed through many destructive wars in 1991 and 2003. During these wars, massive amounts of new weapons and sophisticated manufactured nuclear weapons were used, called depleted uranium (DU). DU effects human health because it is organ tropic and becomes integrated in organs such as skeletal tissues and accumulates in the kidney, reproductive system, brain and lung with verified genotoxic, mutagenic alterations [7,8,9,10,11,12,13,14,15,16,17,18].

Figure 1: Location map of Iraq.

In this paper, three sites were selected depending mainly on geological factors and considering the remoteness from infrastructures and living centers; such as cities, towns, villages etc. The three selected candidate sites are the best sites for the isolation of DU in Iraq, to protect humans' life and the environment. The methodology of siting is discussed, besides their designs to assure best isolation and prevent contamination of the groundwater, and the surrounding environment.

2. DU in Iraq

The quantity of DU used in Iraq during the second Gulf war in 2003 was more than five times as many DU bombs and shells as the total number used during the first Gulf war in1991[19]. In 2003, it was estimated that 1100 to 2200 tons of DU was used which are 400 to 800 more powerful than the ones used in the first Gulf war. [20] reported that the quantities of DU used in Iraq can be summed up to consist of at least 2000 metric tons.

DU contaminated sites spread from north to south of Iraq (Figure 2) [21]. The only three governorates that was not hit by DU weapons are the Kurdistan Region Governorates (Dohuk, Erbil and Sulaiymaniyah). In addition, the sites of the Iraqi Atomic Energy Commission were also bombed during the military operations (Figure 3) [19, 22, 23]. In these sites, there were tons of uranium in the form of "yellow cake" as well as by-products from processing activities in addition to radioactive waste stored in barrels, In addition, about 200 barrels of isotopes and radioactive materials as well as yellow uranium oxides were all spilled on the ground at the Iraqi Energy Authority headquarter center. Wind can carry these toxic materials over long distances. Furthermore, there were insects in breeding labs used as biological insecticides and these flies were released by the looters [20]. It seems that no place is not contaminated in Iraq according to [24]. The Iraqi Ministry of Environment of Iraq (MOEN) published a report summarizing the radioactive wastes in Iraq (Table 1) [25].

Figure 2: Contaminated sites in Iraq with DU [21].

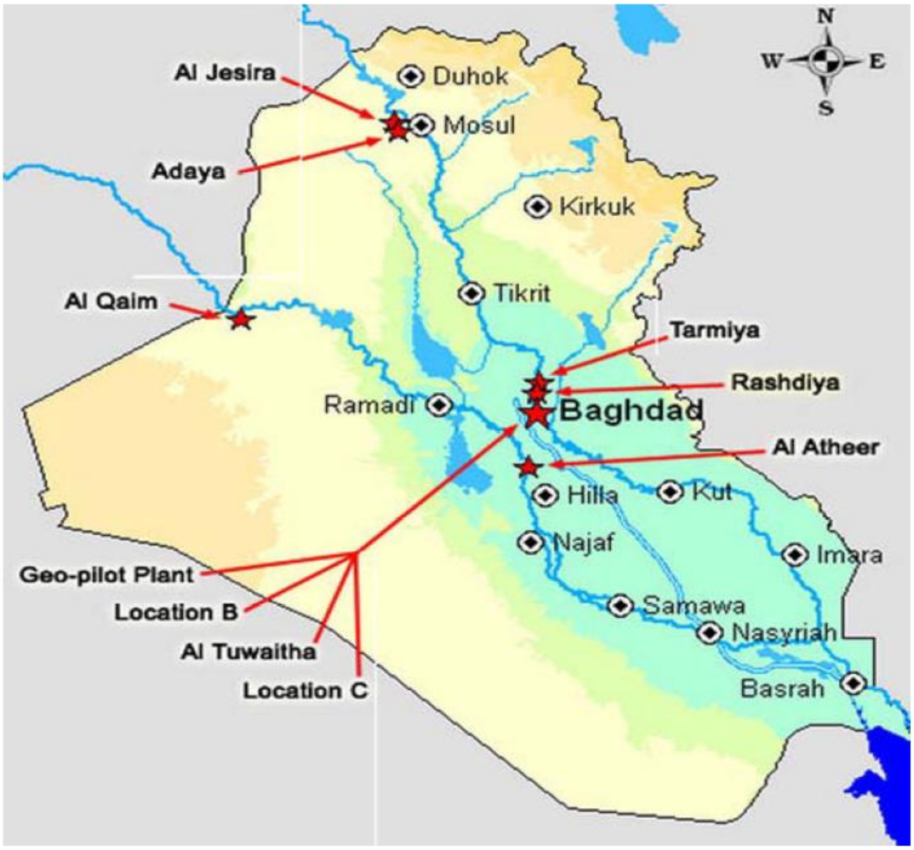

Figure 3: Locations of nuclear facilities in Iraq

(http://www-ns.iaea.org/images/rw/iraq/map-images/map_01.jpg)

Table 1: Preliminary data on radioactive contamination in Iraq including DU [25].

Radioactive contamination	Quantity (ton)
Solid	500
Liquid	270
Scrap and soil	Unspecified

As a consequence, there are plenty of victims within the American soldiers who participated in the Gulf war. Bollyn [26] reported in 2004 that about every third veteran from the first Gulf war and 179,310 veterans of 59,561 from the second one was discharged, are receiving disability compensation and another 24,763 cases are pending due to DU effect. In Iraq, 140,000 cancer cases were reported after 2003 war due to the toxic weapons used where 2000 tons of DU expenditure were used [27,28]. In addition, many grossly deformed children born in areas such as southern Iraq where tons of DU have contaminated the environment and local population and even babies whose fathers served in the 1991 Gulf war are 50 percent more likely to have physical abnormalities; and 40 percent increased risk of miscarriage among women whose partners served in the war was found [26]. The amount of DU weapons used in the southern of Iraq (Basrah) is sufficient to cause 500,000 victims which might lead to death [27]. Lorimore [29] reported that physical abnormality is increasing after the Gulf war. Severe leukemia cases were reported also in Iraq [24]. The battered remnants of the Iraqi wars are radioactively contaminated and are still radioactive. Residues are found in farm fields, along roads, near residential areas (Figure 4) and the soil is also contaminated. Soils were removed and piled by bulldozers and dump trucks and then transported to disposal sites. During this operation, fine dust was spread and inundating hundreds of square kilometers [20]. In certain areas, the battleground was covered with piles of sand and bombed-out building debris which was trucked into the site and spread out over the combat areas. This cover-up was careless and incomplete, leaving radioactive kinetic penetrators, wrecked tanks and heaps of spent and unused ammunition exposed. Several of the damaged tanks, cars and artillery components were moved to the “tank graveyards” in Auweirj and to occupied airports.

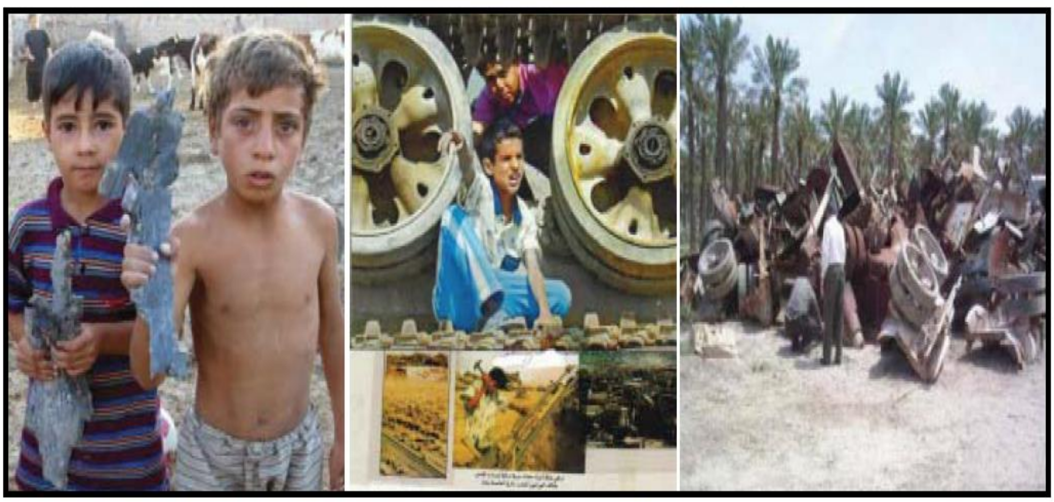

Figure 4: Military scrap yards in Iraq.

3. Suggested Locations of the Three Landfills

The process of selecting appropriate deep repositories for nuclear waste and spent fuel is now under way in several countries. The basic concept is to locate a large, stable geologic formation to dump the waste in an artificial storage dug for this special purpose.

The goal is to permanently isolate nuclear waste and military materials contaminated with depleted uranium from the human environment. Many people remain uncomfortable with the immediate stewardship cessation of this disposal system, suggesting perpetual management and monitoring would be more prudent.

The proposed land-based waste disposal method disposes of nuclear waste in a subduction zone accessed from land and therefore is not prohibited by international agreement. This method has been described as the most viable means of disposing of radioactive waste [30] and as the state-of-the-art as of 2001 in nuclear waste disposal technology [31].

During last century many efforts were carried out by some governmental offices to select relevant sites for damping of polluted materials. Among them is candidate sites in Al-Anbar Governorate [32].

3.1 Factors Controlling Siting of the Three Landfills

The following factors were used in the siting of the three landfills in the western, southern and northwestern parts of Iraq.

- Lithology: The best rocks which serve as excellent container to the dumped wastes are those which are: 1) impermeable, 2) not porous, 3) massive or very thickly bedded, 4) not fractured, 5) not karstified, and 6) not folded. However, it is almost impossible to find such rocks to be used as the base for the landfill. Therefore, the chosen sites include the most of the mentioned factors; otherwise, the landfills should be lined either with natural impervious rock; like clay or with synthetic impervious material.
- Karstification: Karstification is a well-known phenomenon in soluble rocks like limestone and gypsum. It is the processes of solution and infiltration by water, mainly chemical but also mechanical, whereby the surface features and subterranean drainage network of a karstland are developed to form a karst topography, including such surface features as dolines, karren, and mogotes and such subsurface features as caves and shafts. However, not all limestone beds are karstified. The karstification depends on many factors. All karstified areas should be avoided as much as possible. Otherwise, the landfills should be lined either with natural impervious rock; like clay or with synthetic impervious material.
- Surface Water Bodies: These include rivers, lakes, streams and large dry valleys. The selected site should be at least 5 km far from water body to assure that surface water will not be contaminated.
- Inhabitation: This includes all cities, towns, villages and other sites which is populated; like military camps, industrial sites, planted sites. The selected

site should be at least 5 km far from such areas, taking in consideration the main wind direction. The anti-wind direction is more preferable.

- Transportation: This includes all types of paved roads, main unpaved roads, and rail roads. The selected site should be at least 5 km far from such transportation facilities.
- Tectonic Features: The tectonic features like faults (different types and extensions), fold axes, shear zones … etc. should be avoided when possible. When active faulting indications occur then must be avoided.
- Economic Deposits: The selected site should devoid any economic deposit; whatever the type and amount is, since the utilization of the deposit will not be possible.
- Geological Hazards: The selected site should devoid any type of geological hazards, like landslides (all types), sand dunes, depressions, sabkhas, liquefaction.
- Groundwater: The depth of the groundwater should be below the chosen impermeable rocks in the selected sites in order to assure that the groundwater will be not contaminated if dispersion take place in the site.

3.2 Selections of the three Landfills (Sites)

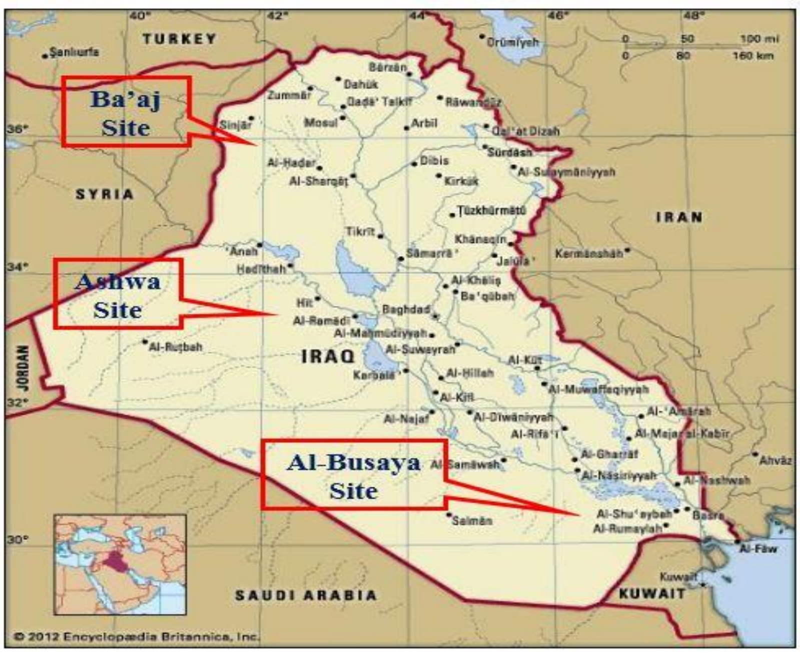

Figure 5: Tentative location of the three selected sites

3.2.1 Western Desert (Ashwa Site)

This site is located in the Iraqi Western Desert, west of Ramadi city by about 70 km, north of the Express way No. 1 (Figure 5). The site area is almost flat dissected by wide and shallow valleys which drain to the Euphrates River. The exposed rocks belong to the Nfayil Formation [34] (Figure 6). The formation consists of three cycles, each cycle consists of thick (4 – 8 m) green marl and thin (1. – 3 m) limestone [35]. The green marl will act as a sealant for any leaching from the damped waste.

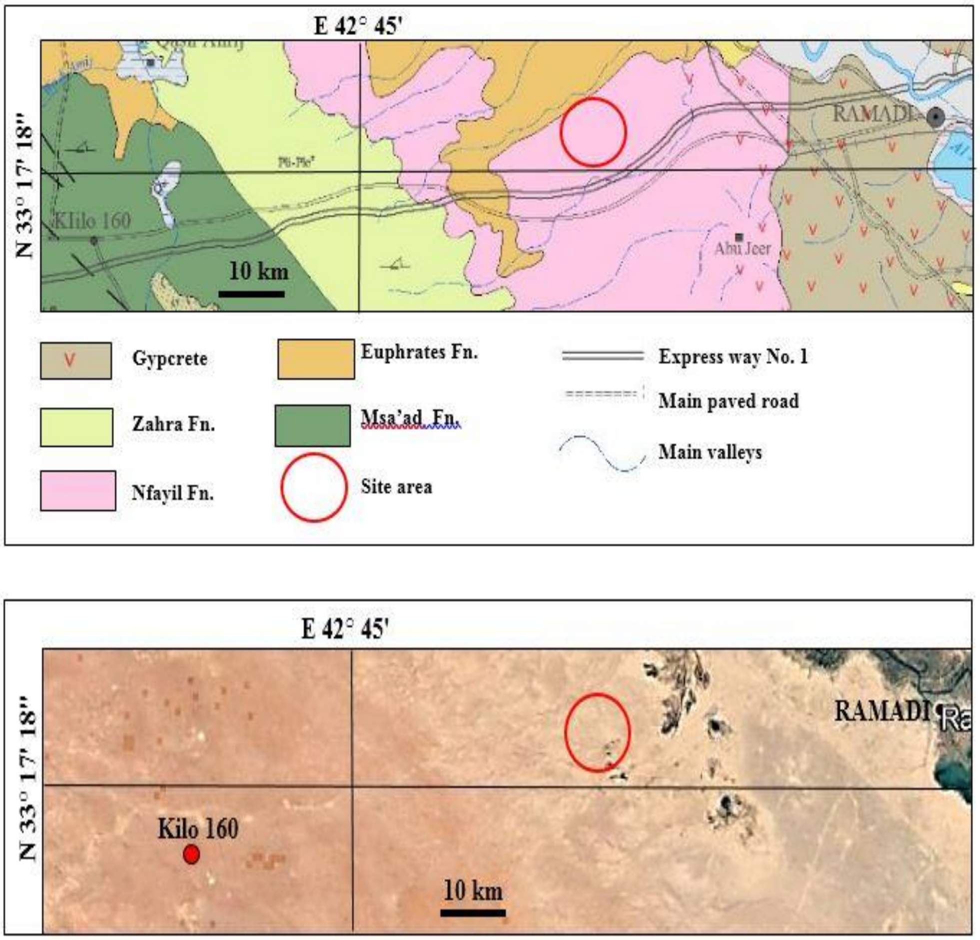

Figure 6: The location of Ashwa site.
Top (Geological map, Bottom) Satellite image (The coordinates of the center of the candidate site N 33^0 23' 15.90'' E 42^0 39' 24.10'').

3.2.2 Al-Jazira Site

This site is located in Al-Jazira area west of Mosul city by about 120 km (Figure 5). The site area is almost flat dissected by narrow and shallow valleys which drain to local karst depressions. The exposed rocks belong to the Injana Formation [34] (Figure 7). The formation consists of cyclic sediments; each cycle consists of sandstone alternated with claystone with different thicknesses [35]. The claystone beds will act as a sealant for any leaching from the damped waste in it.

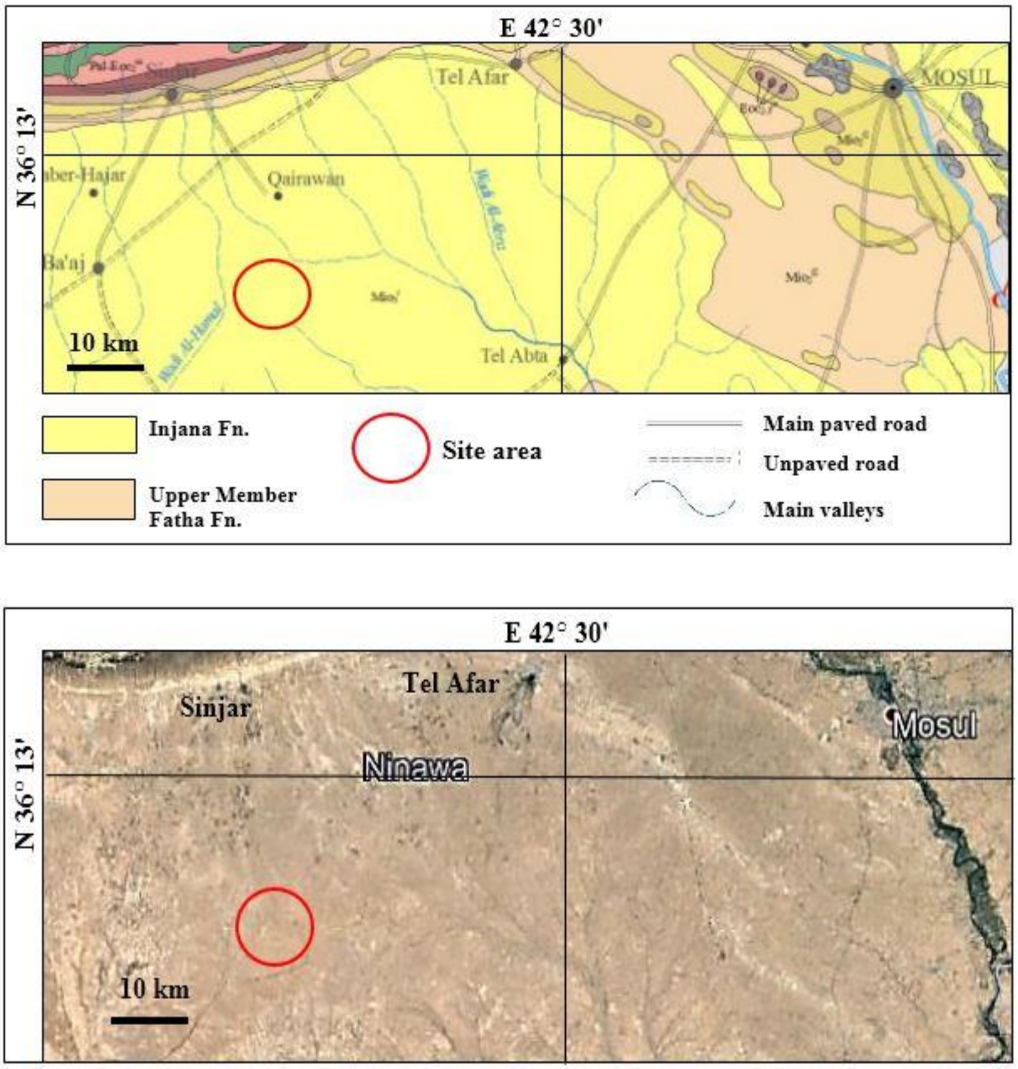

Figure 7: The location of Al-Jazira site.
Top (Geological map, Bottom) Satellite image (The coordinates of the center of the candidate site N 35^0 59' 55.75'' E 41^0 56' 59.58'').

3.2.3 Southern Desert (Al-Busaya Site)

This site is located in the Iraqi Southern Desert, about 80 km south of Nasiriya city (Figure 5). The site area is flat dissected by wide and shallow valleys which drain to the Euphrates River. The exposed rocks belong to the Nfayil Formation [34] (Figure 8). The formation consists of three cycles, each cycle consists of thick (4 – 8 m) green marl and thin (1 – 3 m) limestone [35]. The green marl will act as a sealant for any leaching from the damped waste in it.

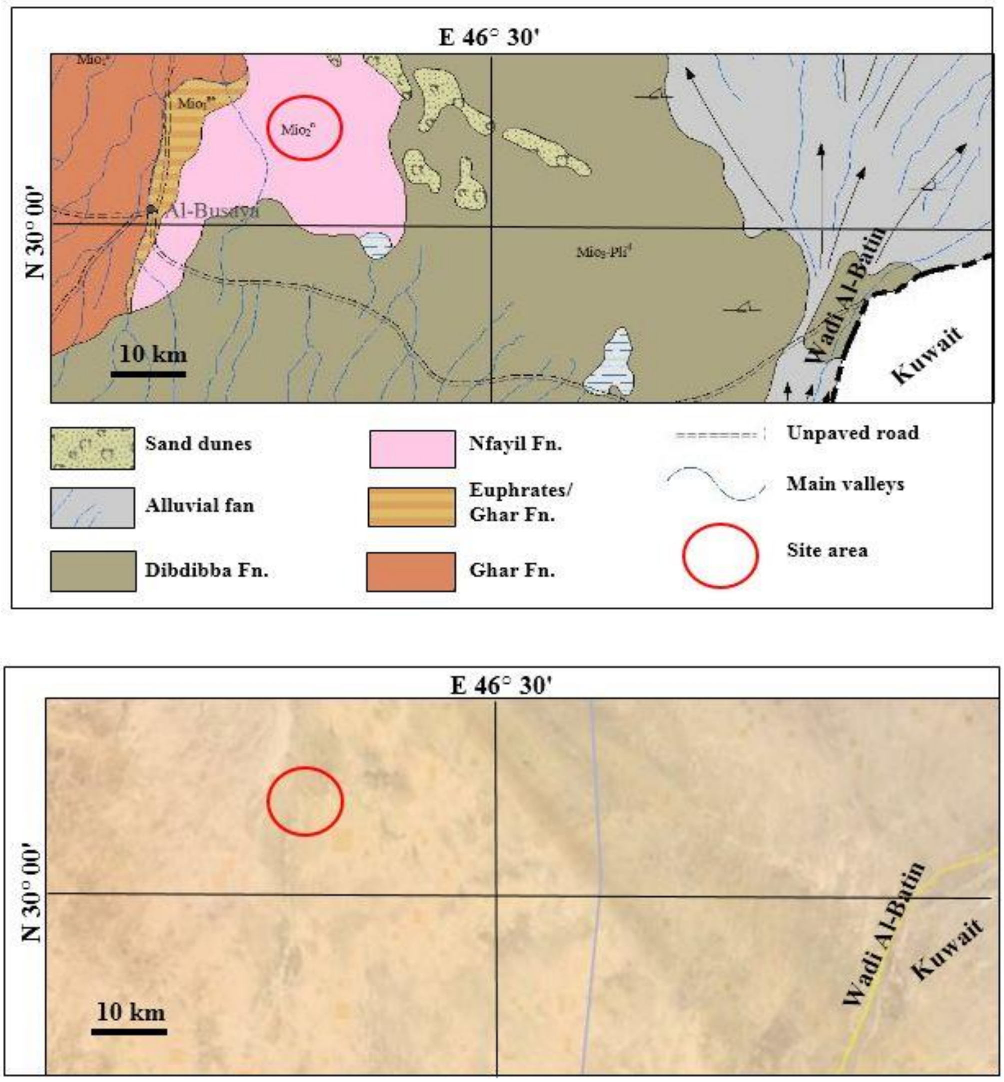

Figure 8: The location of Al-Bussaya site.
Top (Geological map, Bottom) Satellite image .The coordinates of the center of the candidate site N 30^0 05' 22.27'' E 46^0 10' 09.64''.

4. Discussion

In order to protect the humans in Iraq and its environment, it is very important to locate the most suitable site from the geological perspective. After locating the site, proper design for the landfill is to be adopted.

4.1 Procedure of the Siting

The mentioned three sites were selected following the aforementioned eight factors. The procedure of the siting was based on avoiding the unsuitable factors and/ or their parameters. The details are assigned in Table 2.

Table 2: Status of the siting factors in the three selected sites.

No.	Factor	Parameter	SITES		
			Ashwa	Al-Jazira	Al-Busaya
1	Lithology	Permeability	–	+ / –	–
		Porosity	–	+ / –	–
		Bedding	+ / –	+ / –	+ / –
		Fractures	–	–	–
		Karstification	–	–	–
		Folding	–	–	–
2	Karstification		–	–	–
3	Surface Water		–	–	–
4	Inhabitation		–	–	–
5	Transportation		–	–	–
6	Tectonic features		–	–	–
7	Economic deposit		–	–	–
8	Geological Hazards		–	–	–
9	Groundwater		–	–	–
– Negative (does not exist), + / – Between negative and positive					

It is clear from Table 2 that the three sites include bedded rocks; however, the presence of green marl in Ashwa and Al-Busaya sites and claystone in Al-Jazira site will decrease the effect of the bedding on the efficiency of the site as leaching to deeper beds is concerned.

The presence of the sandstone beds in Al-Jazira site will increase the permeability and porosity of the rocks in the sites. Although the sandstone beds are interbedded with claystone beds, but lining of the site by impervious natural or synthetic material is highly recommended.

In Al-Jazira site, the Injana Formation is underlain by the Fatha Formation which includes gypsum layers that are highly karstified. Therefore, the thickness of the Injana Formation should be checked before locating of the site. The number of the cycles in the Injana Formation should not be less than (4 – 5) cycles to provide acceptable thickness of the claystone layers; accordingly, will decrease the possibility of leaching from the site to deeper layers.

4.2 Suggested Design for the landfill

Landfills for DU – contaminated waste should last in its performance for tens of thousands of years. In such landfills, clay is a very important component. The suggested clay to be used is that recommended by EU for isolating mercury-rich waste and solidified pesticides [36]. It implied mixing of smectitic clay and solid waste in weight proportions down to 1:20. However, the facilities for mixing would imply expensive industrial-scale operations and simpler techniques are asked for, like sandwich-type placement of DU-contaminated sandy/silty soil with ammunition and disseminated larger objects mixed in, and interchangeably placed clay layers (Figure 9). The clay, obtained by dredging in rivers or by excavation using large shovels maneuvered by masts, should have a low water content when placed on the disposal site, which requires spreading out on the ground for drying in the sun as the south-European clay manufacturers frequently do. This is suggested as the cheapest way to store the waste. For more details about the design of such landfills see [23].

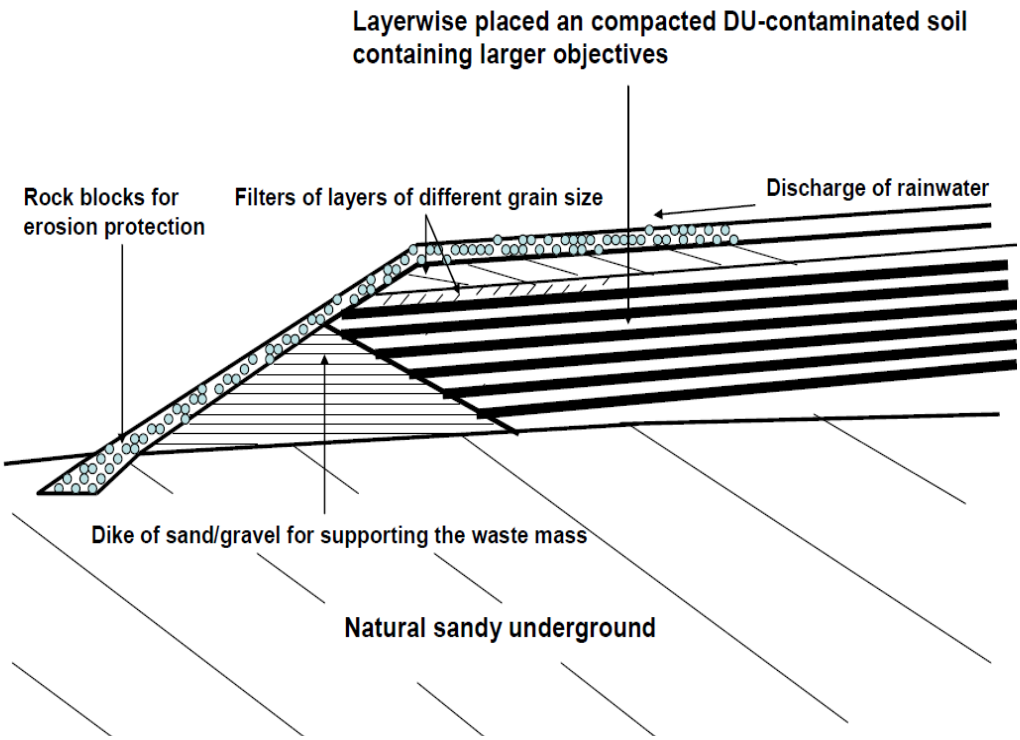

Figure 9: Schematic section of landfill of DU-contaminated soil and solid waste objects.

5. Conclusion

During the first Gulf war in 1991in Iraq, the amount of depleted uranium used in the weapons were about 300 tons and during the second Gulf war in 2003, about 1000 to 2000 tons of DU were used. The waste of the remnants of the DU weapons represent high threat to humans in Iraq and its environment. To clean up the contaminated waste it should be buried in a safe place. To do so, the geological, hydrological and climatic conditions makes the deserts in Iraq as very good candidate sites for such landfills. Through study of these conditions suggests that the southern, western and northern deserts in Iraq can serve this purpose. Details of the geology of these sites were investigated. These are Ashwa Site in the Western Desert, Al-Busaya Site in the Southern Desert and Al-Jazira Site. In addition, basic principles for the design of the required landfills is given to ensure its performance for long period of time.

References

[1] Pearce, D. and Walker, C. (1996). Sustainable development, In: Baily, R., Ed., Water and Environmental Management, Amazon Company, UK.

[2] Jackson, B. (1996). International institutions. In: Baily, R., Ed., Water and Environmental Management in Developing countries.

[3] Aldiab, S. (2000). The gap between planning and execution of environmental policies in Jordan: A case study of Jordan valley. M.A. Thesis, Al al-Bayt University, Jordan.

[4] Chandak, S.P. (2010). Trends in solid waste management: Issues, challenges and opportunities. International Consultative Meeting on Expanding Waste Management Services in Developing Countries, Tokyo, 18-19 March 2010.

[5] Abdel Rahman, R. (2012). Eds. Radioactive waste. Tech Publishing, Croatia, 219.

[6] IAEA (International Atomic Energy Agency) (2008). Estimation of Global Inventories of Radioactive Waste and Other Radioactive Materials, Report number IAEA-TECDOC-591, 43p. https://www-pub.iaea.org/MTCD/Publications/PDF/te_1591_web.pdf

[7] ICBUW, (2008). International Coalition to Ban Uranium Weapons, European Parliament passes far reaching DU resolution in landslide vote, http://www.bandepleteduranium.org/en/ /181.html

[8] Durakvic, A. (2003). Undiagnosed Illnesses and Radioactive Warfare, Croatian Medical Journal, 44(5), 520-532.

[9] Durakovic, A., Dietz, L. and Zimmerman I. (2003). Evaluation of the carcinogenic risk of depleted uranium in the lungs of Gulf War veterans. In: Hansen HH, Demer B, editors. Proceedings of the 10th World Congress on Lung Cancer, 10-14 Aug 2003; Vancouver, Canada. London: Elsevier; 2003. p. S252 P-634.

[10] Miller, A.C., Brooks, K., Stewart, M., Anderson, B., Shi, L., McClain, D. et al. (2003). Genomic instability in human osteoblast cells after exposure to depleted uranium: delayed lethality and micronuclei formation. J Environ Radioact; V. 64:247-59.

[11] L'Azou, B., Henge-Napoli, M.H., Minaro, L., Mirto, H., Barrouillet, M.P. and Cambar, J. (2002). Effects of cadmium and uranium on some in vitro renal targets. Cell Biol Toxicol; V.18:329-40.

[12] Arfsten, D.P., Still, K.R. and Ritchie, G.D. (2001). A review of the effects of uranium and depleted uranium exposure on reproduction and fetal development. Toxicol Ind Health;V17: 180-91.

[13] Gu, G., Zhu, S., Wang, L. and Yang, S. (2001). Irradiation of 235 uranium on the growth, behavior and some biochemical changes of brain in neonatal rats (in Chinese). Wei Sheng Yan Jiu; V 30:257-9.

[14] Pellmar, T.C., Keyser, D.O., Emery, C., Hogan, J.B. (1999). Electrophysiological changes in hippocampal slices isolated from rats embedded with depleted uranium fragments. Neurotoxicology; V. 20:785-92.

[15] Kennedy, C.H., Mitchell, C.E., Fukushima, N.H., Neft, R.E. and Lechner, J.F. (1996). Induction of genomic instability in normal human bronchial epithelial cells by 238Pu alphaparticles.Carcinogenesis;V.17:1671-6.

[16] Lehnert, B.E., Goodwin, E.H. and Deshpande, A. (1997). Extracellular factor(s) following exposure to alpha particles can cause sister chromatid exchanges in normal human cells. Cancer Res;V. 57:2164-71.

[17] Kadhim, M.A., Macdonald, D.A., Goodhead, D.T., Lorimore, S.A., Marsden, S.J. and Wright E.G. (1992). Transmission of chromosomal instability after plutonium alpha-particle irradiation, Nature, V. 355:738-40.

[18] Kadhim, M.A., Lorimore, S.A., Hepburn, M.D., Goodhead, D.T., Buckle, V.J. and Wright, E.G. (1994). Alpha-particle-induced chromosomal instability in human bone marrow cells. Lancet; V. 344:987-8.

[19] Al-Ansari, N., Knutsson, S. and Pusch, R. (2014). The environmental implications of depleted uranium in Iraq and the principles of isolating it, Waste Management 2014 conference, 12-14 May, 2014, Ancona, Italy, 367-376.

[20] Weyman, T., Abu Khasib to Al Ah’qaf (2003). Iraq Gulf War II, Field Investigations report, Uranium Medical Research Centre, http://www.umrc.net/os/downloads/Iraq_report_1.doc

[21] Chulov, M. (2010). Iraq littered with high levels of nuclear and dioxin contamination, The Guardian, 22 January 2010. https://www.theguardian.com/world/2010/jan/22/iraq-nuclear-contaminated-sites

[22] Al-Ansari, N.A., Pusch, R., and Knutsson, S. (2013). Suggested Landfill Sites for Hazardous Waste in Iraq, J. Natural Science, V. 5, 4,463-477.

[23] Al-Taie, L., Al-Ansari, N.A., Knutsson, S. and Pusch, R. (2013). Hazardous Wastes Problems in Iraq: Suggestions for an Environmental Solution. J. Earth Sciences and Geotechnical Eng., V.3, 3, 81-91

[24] Hall, I.W. (2006). Depleted Uranium for Dummies. http://www.notinkansas.us/du_3.html

[25] Ministry of Environment of Iraq (MOEN) (2007). Report on the environmental fact in 2007 (published in Arabic). http://www.moen.gov.iq/waq3.html

[26] Bollyn, C. (2004). The real dirty bombs: Depleted uranium. http://www.erichufschmid.net/TFC/Bollyn-Uranium-Iraq-Vets.html

[27] Ross, S. (2008). We are living through another Hiroshima. Iraqi doctor says, uruknet.info, informazione dal medio oriente information from Middle East. http://www.uruknet.de/?p=m42361&hd=&size=1&1=e

[28] Press TV (2010). Radioactive US weapons taking toll in Iraq, http://www.presstv.ir/detail.aspx?id=104356&sectionid=351020201

[29] Lorimore, S.A. and Wright, E.G. (2003). Radiation-induced genomic instability and bystander effect: Related inflammatory-type responses to radiation-induced stress and injury? A review. International Journal of Radiation Biology, 79, 15-25.

[30] Jack, T. and Robertson, J. (2008). Utah Nuclear Waste Summary Archived at the Wayback Machine Center for Public Policy & Administration, University of Utah.

[31] Rao, K. R. (2001). "Radioactive waste: The problem and its management (PDF). Current Science, Vol. 81, No. 12. Archived from the original on 16 December 2008.

[32] Ma'ala, K.A., Mahmoud, S.S., Hamza, N.M., Al-Kadhimi, J.A. and Sissakian, V.K. (2001). Siting of Candidate sites for Damping Industrial Waste in Rutba, Jandili, Traifawi, Abu Mindhar, Al-Anbar Governorate. Iraq Geological Survey Library Report No. 2684 (in Arabic).

[33] EPA (Environmental Protection Agency), 2002. A Lexicon of Cave and Karst Terminology with Special Reference to Environmental Karst Hydrology Office of Research and Development, Washington, D.C. 20460.

[34] Sissakian, V.K. and Fouad, S.F. (2012). Geological map of Iraq, scale 1:1000000, 4th edition. Iraq Geological Survey Publications, Baghdad, Iraq.

[35] Sissakian, V.K., Mahdi, A.I., Amin, R.M. and Mohammed, B.S. (1997). The Nfayil Formation. A new lithostratigraphic unit in Iraq. Iraqi Bulletin of Geology and Mining, Vol. 30, No. 1.

[36] Popov, V., and Pusch, R. (2006). Disposal of Hazardous Waste in Underground Mines. WIT Press (ISBN:1-85312-750-7).