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Research Article

Hydrogeochemical Indicators for Radioactive Waste Disposal Site Survey to the East of Nile Delta, Egypt

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Abstract

The present work introduces a hydrogeochemical indicator for surveying the area to the east of Nile Delta in Egypt, to select, screen out and rank potential sites for radioactive waste disposal facility. The index and overlay methodology exemplified by DUPIT index, has been applied to determine the susceptibility of groundwater contamination through unsaturated zone reach. This provides a basis for classifying the study area into subareas and mapping them according to their suitability for hosting radioactive waste disposal facility, from hydrogeochemical point of view. The environmental isotopes (oxygen-18, deuterium, tritium and carbon-14) have been used for verifying the results of waste disposal siting survey. The transit time of chosen six radionuclides (T, C-14, Co-60, Tc-99, Ni-59 and Sr- 90) through the unsaturated zone reach, has been calculated, based on simple hydrological / pollutant retardation model. A considerable consistency exists between the calculated radioisotopes transit times and the corresponding waste disposal suitability index. A high adoptability has been proven for using the employed indicator methodology for siting survey of radioactive waste disposal facility.

Keywords:*Hydrogeochemical indicators, radioactive waste disposal, transit times, DUPIT, Egypt.*

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1. Introduction

Radioactive waste is generated from the production of nuclear energy and from the use of radioactive materials in industrial applications, research and medicine. The importance of safe management of radioactive waste for the protection of human health and the environment has long been recognized and considerable experience has been gained in this field.

In Egypt, radioactive waste is usually generated from the use of radioactive materials in various activities; medicine, research, industry, two research reactors and the radioisotope production facility. Consequently, a wide range of radionuclides elements and concentrations with variety of physical and chemical forms is generated. According to the Nuclear Law, all radioactive wastes are collected from the different places and activities (except NORM and Tailing) and transported to the Hot Laboratories Center (Atomic Energy Authority) for waste management.

The current work aims at selection of suitable sites for radioactive waste disposal facilities by surveying in the south eastern part of Nile Delta. Relevant hydrogeochemical indicators have been determined for that. An index and overlay methodology (DUPIT) has been used for defining the groundwater pollution susceptibility and ranking up selected sites according to their potentiality to host radioactive waste disposal sites from the hydrogeological point of view.

1.1Physical Setting of the study area

The area under investigation lies in the south eastern part of Nile Delta to the north east of Cairo. It covers a surface area of about 2550 km2, between latitudes 30° 05' & 30° 30' N and longitudes 31° 10' & 31° 30' E. It is bordered from north by Ismailia Canal and from south by Cairo-Ismailia Desert road figure (1).

The area of study may be divided into two parts separated by Ismalia Canal; the first part located to the west and northwest of Ismalia Canal (old cultivated lands), while the second part is located to east and southeast of the canal (the desert area). This desert area is characterized by mild to moderate topography (Salah, 2005), the land slopes to the north and west and the surface is dissected by a network of wadies that terminate towards the north and west directions. The surface of the area is covered by different types of soils; some are of sandy clay nature (near the old cultivated land), others are of sands and gravels (between Belbis and El-Asher) and the rest are of calcareous nature (South El-Asher).

The study area is mainly covered by Tertiary and Quaternary sediments; the exposed section varies in thickness and shows an increase toward the Nile Delta recording more than l000 m. The top portion of this Section is mainly sand and clay facies, whereas the lower

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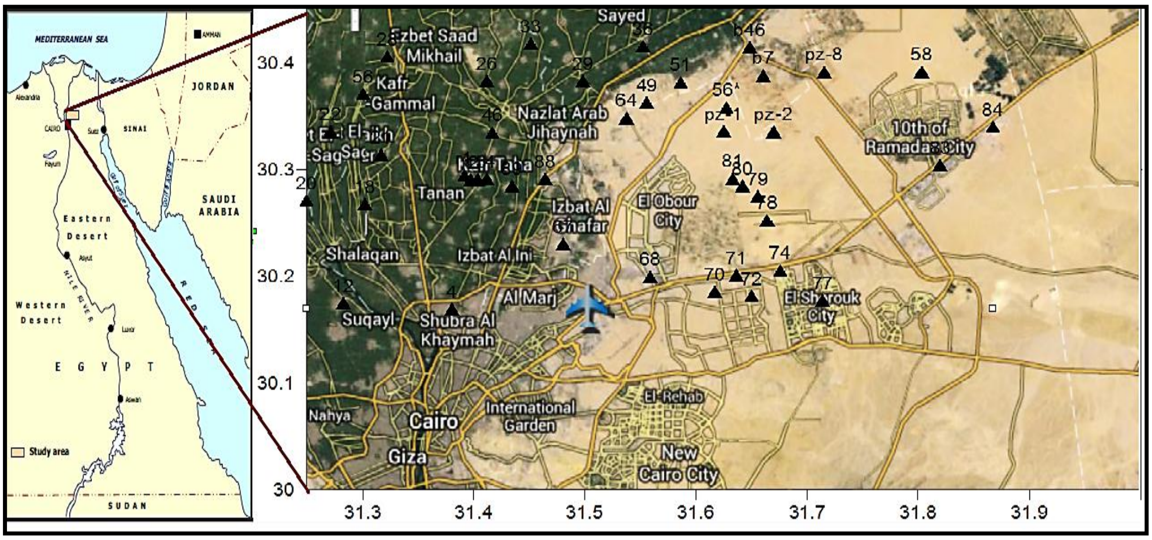


Figure (1): Location map of the study area showing selected boreholes

portion is dominated by carbonate facies .The Tertiary carbonates are underlain by Cretaceous limestone and dolomite, that are strongly dissected by a complex system of faults striking, mostly, E-W., figure (2) shows a generalized stratigraphic column of the different rock units in the study area.

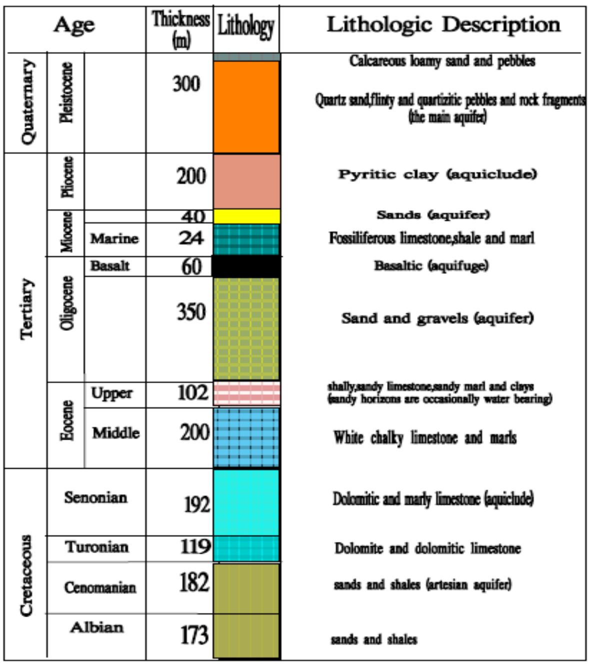


Figure (2): A generalized stratigraphic column of the study area (Ahmed, 2008).

2. Material and Methods

The primary objective of waste disposal site selection process is to identify prima-facie potential sites out of several candidate sites which are primarily chosen from big region based on their prominent features, surrounding establishments, proximity to drinking water sources, habitation and usageetc. The potential sites are then subjected to knock out criteria in order to single out potential sites for carrying out detailed Environmental Impact Assessment Studies.

In general, the most important environmental factors considered during the selection procedure are related to the susceptibility of regional groundwater to contamination. Factors such as the depth to groundwater table, the availability of impervious layers which could naturally minimize the risk of contamination, the type and conductivity of the underlying aquifer, the land use/cover patterns and the site topography are among the many that must be taken into account in the site selection procedure. The analysis of the vulnerability of groundwater to pollution has been an important research area in the last decades. Several models including DRASTIC (Aller et al. 1987), GOD (Foster 1987, 1998), SINTACS (Civita 1994) and CALOD (Edet 2004) are developed to assess the susceptibility of aquifers to pollution. Recently, only a few researchers have started to use the vulnerability maps developed by using methods similar to DRASTIC in evaluating the suitability of alternative disposal sites throughout the world (Ibe et al. 2001; Lee 2003). In accordance with that, this paper is intended to use one of the vulnerability indexes of groundwater contamination, (DUPIT index) for screening and comparing the appropriateness of waste disposal sites.

2.1Theory

The proposed DUPIT index is formed by the combination of: (1) **Depth** to groundwater table, (2) **Upper** layer lithology, (3) **Permeability** of unsaturated zone, (4) **Impermeable** layer thickness and (5) **Topographic** slope. Each of these parameters is given a weighing coefficient (Table 1) from 1 to 5 such that the most and the least important factors in solid waste disposal site selection are given the highest (5) and lowest (1) points respectively. In addition to the weighing coefficients, the technique assigns rating coefficients for each parameter as shown in Table 1. The proposed DUPIT index is then calculated asillustrated in figure (3):

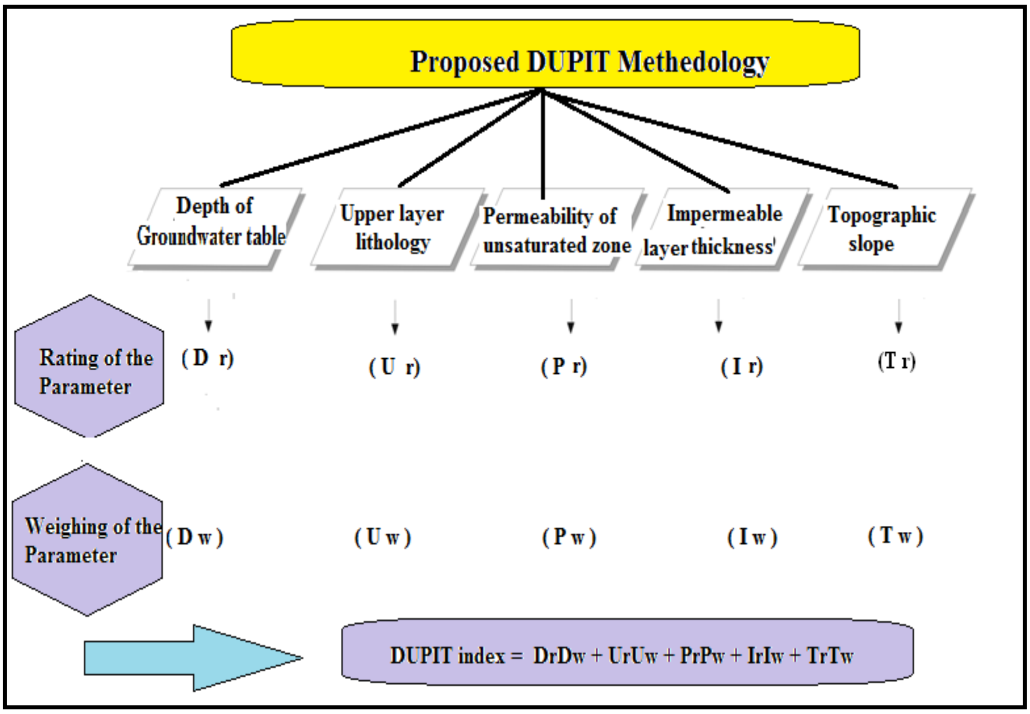


Figure (3): Illustrative figure of the DUPIT methodology.

Table (1):DUPIT index parameters and their classification (Simsek, 2006)

Factor	**Weight**	**Range**	**Rating**	**Suitability**
Depth to groundwater table	5	<5	1	Very Low
		5-15	2	Low
		15-30	3	Medium
		30-50	4	High
		> 50	5	Very High
Upper layer lithology	4	Fractured Rocks	1	Very Low
		Sand and Gravel	2	Low
		Silty Sand, clayey and silty	3	Medium
		Silty and clayey sand	4	High
		clay, schists and flysch,	5	Very High
Permeability of unsaturted zone(m/s)	3	>1.0E-2	1	Very Low
		1.0E-2 - 1.0E-3	2	Low
		1.0E-3 - 1.0E-5	3	Medium
		1.0E-5 - 1.0E-7	4	High
		<1.0E-7	5	Very High
Impermeable thickness(m)	2	<3	1	Very Low
		3-6	2	Low
		6-12	3	Medium
		12-24	4	High
		>24	5	Very High
Topographic Slope(^{o})	1	>60	1	Very Low
		40-60	2	Low
		20-40	3	Medium
		10-20	4	High
		<10	5	Very High

Table (2):DUPIT index and its suitability(Simsek, 2006).

DUPIT Index	Suitability
<22	Very Low
22-36	Low
37-51	Medium
52-67	High
>67	Very High

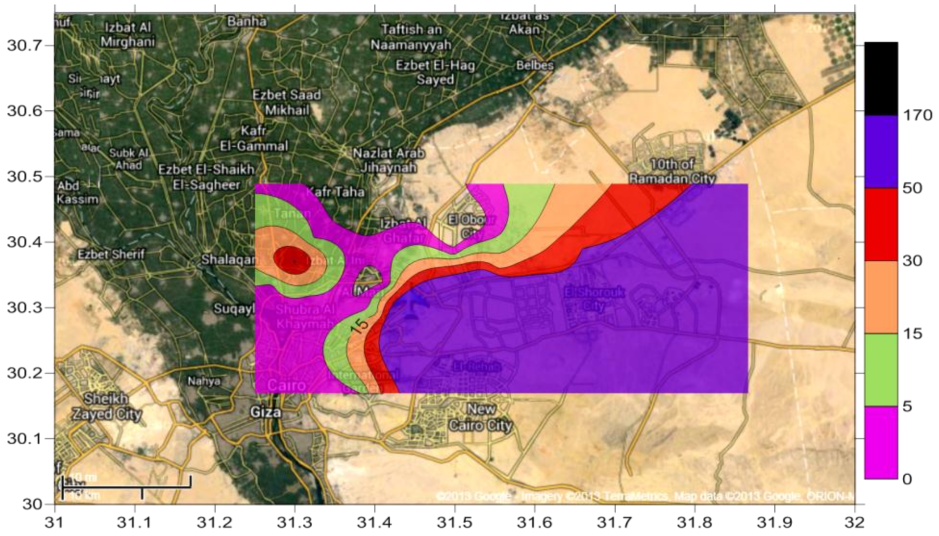


Figure (4): Depth to groundwater of the study area.

Where **Dr and Dw** , **Ur and Uw**,**Pr and Pw, Ir and Iw, Tr and Tw** are the rating factor and weighing coefficient for depth to groundwater, upper layer lithology, unsaturated zone permeability, impermeable layer thickness, topography slope factor, respectively .

2.2 Calculation

2.2.1 Data preparation

The database used in this study is created by utilizing the data obtained from the 42 boreholes -shown in figure (1)- obtained from previous work (Salah, 2005). Grid files have been created for each parameter and transformed into index grids using the Surfer computer program. A discussion of the data preparation, analysis and interpretation are described as follow:

- *Depth to groundwater table*

The distance between the ground surface and the water table is an important parameter in assessing the risk of groundwater contamination via surface pollutants. It is generally accepted that as the time required for a surface contaminant to reach the groundwater gets higher as the distance to water table becomes larger. Although the travel time is also a function of other parameters including the hydraulic conductivity of the domain between the surface and the water table, this generalization usually holds true.

The Quaternary aquifer has shallow water table in the old cultivated lands where the depth to groundwater table varies from 1.1 m to 7 m. while in the desert land, the depth to water increases gradually due to east and south, it varies between 5.1m near Ismalia Canal and 73 m due east and 67.5m north tenth of Ramadan City as shown in figure (3).

- *Upper layer lithology*

The highly desired lithologic units in waste site selection process consist of massive and consolidated impervious rocks that do not contain any cracks. The impervious clays are one of the ideal materials for waste disposal sites when observed in continuous, thick layers. In contrast, the porous and pervious materials such as sand and gravel contain and transmit significant amounts of groundwater similar to the rocks with fractures and cracks; and hence, must be avoided for waste disposal areas. The Quaternary sediments in the study area occupy the northern and western portions. These are mainly composed of deltaic deposits (silt, clay and very fine sand), fluviatile deposits (fine to medium sand) and old deltaic deposits (mainly sand and gravel with occasional clay lenses). The Tertiary deposits are well exposed on the surface of the middle and southern portions of the study area; the oldest rocks are composed mainly of limestone and shaley sandy limestone of Eocene times and Oligocene volcanic basalts, which are scattered north and south of Cairo-Ismalia Highway and at Abu Zaable area. The Miocene deposits widely distributed in southern parts of the study area are differentiated into non-marine deposits (mainly formed of sands and gravels) which are exposed at the vicinity of Cairo-Ismalia Highway and marine deposits (formed of sandy limestone, sands, clay, marle and limesone). A generalized stratigraphic column of the study area (El-Mahmoudi, 2008) is shown in figure (2).

- *The permeability of the unsaturated zone*

The permeability of the unsaturated zone is important parameter in waste disposal site selection as it has a direct influence on the contaminant transport between the ground surface and the water table. While the contaminants are rapidly transported to lower layers with the infiltrating precipitation in high permeability regions, they slowly migrate downwards in low permeability layers. In the case of disposal sites located on fractured rocks and high permeability sand and gravel zones, the highly contaminated leachate is observed to travel downwards rapidly with the infiltrating precipitation, (Simsek 2002). Samples of the Quaternary and Miocene aquifers have medium to high permeability, where average permeability ranges from 244×10^{-6} m/s to 1797.6×10^{-6} m/s and from 318×10^{-6} m/s to 1961.6×10^{-6} m/s in the Quaternary and Miocene aquifers respectively.

- *Impermeable layer thickness*

The impervious geological barriers are important criteria used in solid waste site selection procedure. They provide

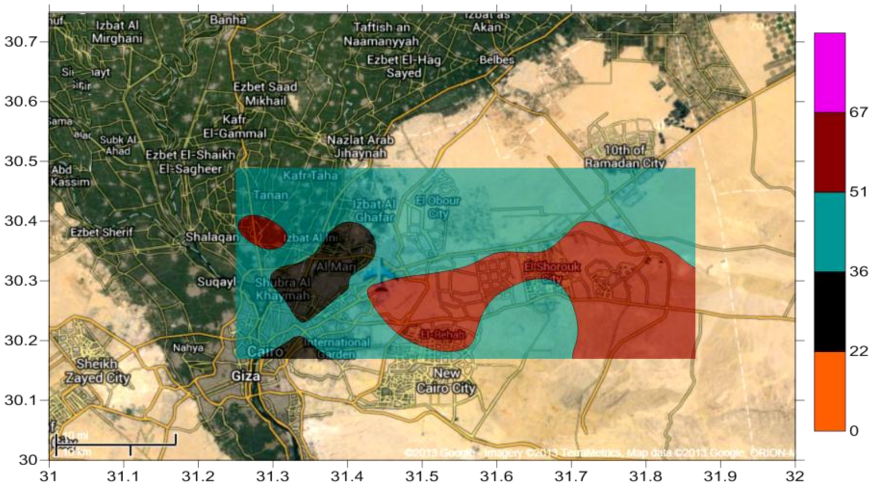


Figure (5): The DUPIT suitability index map of the study area.

Table (3): Dupit index results from proposed data.

Data No	**x**	**y**	**rd**	**wd**	**ru**	**wu**	**r i**	**wi**	**rt**	**wt**	**r p**	**wp**	**DUPIT index**
1	31.38	30.17	1	5	3	4	2	2	5	1	2	3	32
2	31.28	30.18	1	5	3	4	2	2	5	1	2	3	32
3	31.30	30.27	1	5	3	4	3	2	5	1	2	3	34
4	31.25	30.27	1	5	5	4	4	2	5	1	2	3	44
5	31.32	30.31	1	5	4	4	2	2	5	1	2	3	36
6	31.27	30.34	1	5	4	4	2	2	5	1	2	3	36
7	31.41	30.38	1	5	4	4	3	2	5	1	2	3	38
8	31.32	30.41	1	5	4	4	3	2	5	1	2	3	38
9	31.50	30.38	1	5	5	4	3	2	5	1	2	3	42
10	31.45	30.42	1	5	3	4	3	2	5	1	2	3	34
11	31.55	30.42	1	5	3	4	3	2	5	1	2	3	34
12	31.54	30.49	1	5	3	4	3	2	5	1	2	3	34
13	31.42	30.33	1	5	2	4	3	2	5	1	2	3	30
14	31.56	30.36	3	5	3	4	4	2	5	1	2	3	46
15	31.59	30.38	3	5	3	4	4	2	5	1	2	3	46
16	31.30	30.37	5	5	3	4	3	2	5	1	2	3	54
17	31.63	30.36	4	5	2	4	3	2	5	1	2	3	45
18	31.80	30.39	5	5	2	4	2	2	5	1	2	3	48
19	31.54	30.35	5	5	2	4	2	2	5	1	2	3	48
20	31.48	30.23	5	5	2	4	5	2	5	1	2	3	54
21	31.56	30.20	5	5	2	4	4	2	5	1	2	3	52
22	31.62	30.19	5	5	2	4	1	2	5	1	2	3	46
23	31.64	30.20	5	5	2	4	1	2	5	1	2	3	46
24	31.65	30.18	5	5	2	4	2	2	5	1	2	3	48
25	31.68	30.21	5	5	2	4	2	2	5	1	2	3	48
26	31.71	30.18	5	5	2	4	4	2	5	1	2	3	52
27	31.66	30.25	5	5	2	4	2	2	5	1	2	3	48
28	31.66	30.28	5	5	2	4	2	2	5	1	2	3	48
29	31.64	30.28	5	5	2	4	2	2	5	1	2	3	48
30	31.63	30.29	5	5	2	4	3	2	5	1	2	3	50
31	31.82	30.30	5	5	3	4	4	2	5	1	2	3	56
32	31.87	30.34	5	5	2	4	2	2	5	1	2	3	48
33	31.46	30.29	5	5	2	4	5	2	5	1	2	3	54
34	31.43	30.28	5	5	2	4	5	2	5	1	2	3	54
35	31.66	30.39	5	5	2	4	2	2	5	1	2	3	48
36	31.39	30.29	2	5	2	4	2	2	5	1	2	3	33
37	31.40	30.29	2	5	2	4	2	2	5	1	2	3	33
38	31.40	30.29	2	5	2	4	4	2	5	1	2	3	37
39	31.41	30.29	4	5	2	4	3	2	5	1	2	3	45
40	31.63	30.34	5	5	3	4	3	2	5	1	2	3	54
41	31.67	30.34	5	5	2	4	4	2	5	1	2	3	52
42	31.72	30.39	5	5	3	4	4	2	5	1	2	3	56

extra environmental safety without additional costs. In general, geological units with permeability values less than 10^{-7} m/s are considered to be impervious (Terzaghi et al. 1996). It is, however, important to note that the impervious layer must have a minimum thickness of 5 m for it to be a geologically significant barrier unit (Dorn and Tantiwanit 2001). In the old cultivated lands, the Quaternary aquifer is capped by semipermeable sandy clay layer of thickness ranging from 5m to 14m. The Eocene aquifer is mainly composed of fractured limestone and sandstone with clay intercalations, while the Oligocene aquifer is mainly composed of sands and gravels with occasional thin streaks of clay and it is always capped by basaltic sheets (11m thick) of late Oligocene and early Miocene times.

- *Topographic slope*

The waste disposal facilities must be constructed in low topography areas with fine slopes. High topography areas reduce the stability of the side slopes and increase the risk of landslides. Moreover, the leachate formation and movement is observed to be higher in high topography disposal facilities (Crawford and Smith 1985; Bagch 1994).

The study area is occupied by a central plateau decreasing gradually in elevation northward and westward. The topographic contours increase gradually toward the south forming ridges that extend in a nearly E-W trend. However, two main topographically lows are shown intervening the above mentioned ridges. One of them lies in the study area (Heliopolis depression), while the other lies southward (El-Dakruri depression).

3. Results and Discussion

The suitability map of waste disposal, figure (5), has been obtained by evaluation of the computed DUPIT index values according to the five categories given in Table(2). The areas of computed index value between 52 and 67 demonstrate high suitability for waste disposal facilities. These areas are located to the middle and eastern part of the domain of interest, especially at Tenth of Ramadan city, El-Obour city and some desert areas near Cairo-Ismalia Desert Road. The areas with a DUPIT index value of 37–51 are considered to be moderately suitable for a solid waste disposal site are located in the northern sections demonstrating a suitable alternative for the disposal site since it has relatively low permeability and depths to groundwater table values and a mildly sloping topography. Some parts of Belbis Al-Asher Desert Road at of the domain of interest have DUPIT index between 22 and 36 demonstrating low suitability for solid waste disposal sites, these areas generally have low scores from the most important parameters including depth to groundwater and upper layer lithology; such sites are generally considered to be not suitable for waste disposal areas unless no better alternative is available in the vicinity.

The above analysis of DUPIT model is developed as a screening level tool that results in the identification of a few candidate sites that would then be examined in the site characterization stage to minimize all the associated contamination risks and environmental pollution. Those candidate sites have scores of 52-67 and 36—51 reflecting high and moderate suitability for the waste disposal facility.

3.1 Verification of DUPIT Methodology

3.1.1Isotopes Verification

The data of environmental isotopic analysis; oxygen-18, deuterium, tritium and carbon-14 that have been conducted on the groundwater of the study area, (Faten, 2009), are used in the present study to validate the results of DUPIT methodology. A scatterplots of O-18, tritium and carbon-14 on one side and DUPIT index on the other side are shown in figures (6, 7, and 8). The patterns indicated in these figures show a considerable comply between DUPIT parameters and isotopic composition where , the high DUPIT values which correspond to high waste disposal suitability are generally attached to low O18, low tritium, and low carbon 14 values that point out to retarded groundwater flow.

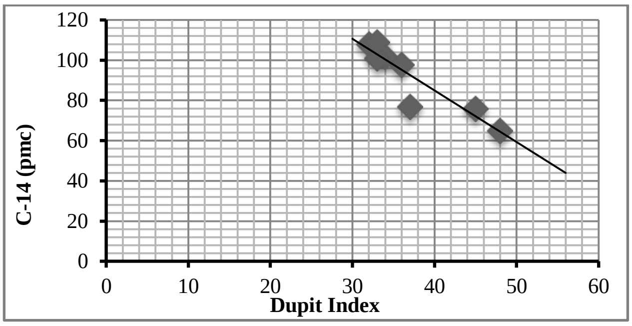


Figure (6): C-14 vs DUPIT index

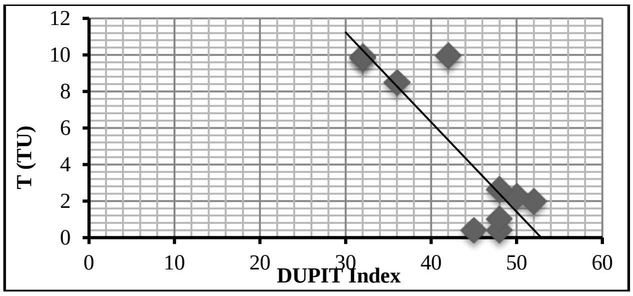


Figure (7): T vs DUPIT index.

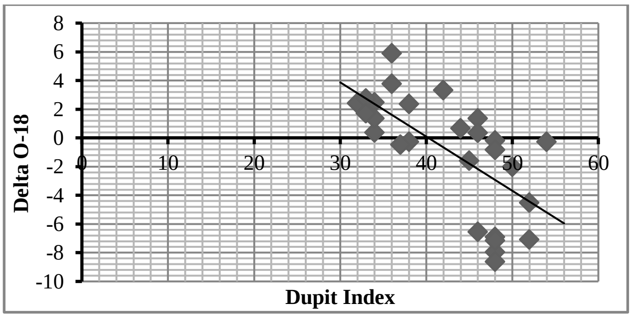


Figure (8): O-18 vs DUPIT index.

3.1.2 Mathematical Model Verification

The impacts of planned discharges of radionuclides to the environment are assessed by means of mathematical models that approximate the transfer of radionuclides through the compartments of the environment. These models can be used as tools to evaluate the effectiveness of counter measures applied to reduce the impacts of accidental releases of radionuclides and to predict the future impact of releases from underground waste repositories. In all these applications, the reliability of the predictions of the models depends on the quality of the data used to represent radionuclide transfer through the environment. Ideally, such data should be obtained by measurements made in the environment being assessed. However, this is often impracticable or overly costly, and thus there is heavy reliance on data obtained from the literature. Often such data can provide an estimate of the radiological impact of a planned release to satisfy regulatory requirements (TRS-IAEA, 2010).

To examine the degree to which the groundwater vulnerability index can be used for waste disposal site screening and selection, the transit time of radionuclides through unsaturated zone to reach groundwater table has been calculated based on simple hydrological / pollutant adsorption retardation model (IAEA, 2003). The model considers the different parameters that affect the migration of radioisotopes in the soil and unsaturated zone including: thickness of unsaturated zone, radionuclide's seepage velocity as a function of groundwater velocity and effective porosity and radionuclide retardation factor which is a function of soil density, effective porosity and radionuclide distribution coefficient which describes the relative transport speed of the contaminant to the water existing in the pores (EPA, 1996). The following equations represent the underground transport of radionuclides under equilibrium condition:

$$T = \frac{X_u R_d}{U_u}$$

$$U_u = \frac{v_u}{\theta}$$

$$R_d = 1 + \rho \frac{K_d}{\theta}$$

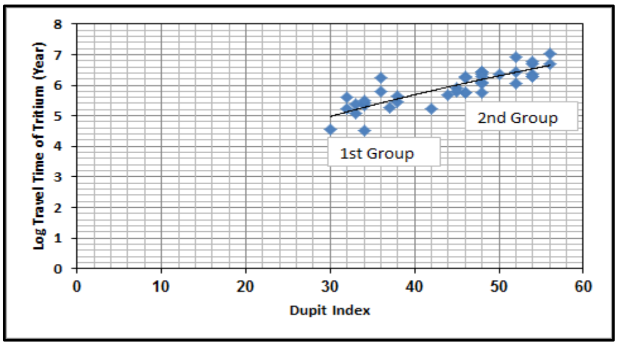
Where: U_u velocity of radionuclide in unsaturated and saturated zone [L/T], Ɵ is the effective porosity of the zone. R_d is the retardation coefficient of radionuclide within the soil, dimensionless. ρ is the density of the soil in [M/L^3], K_d is the distribution coefficient of the radionuclide in [L^3/M].

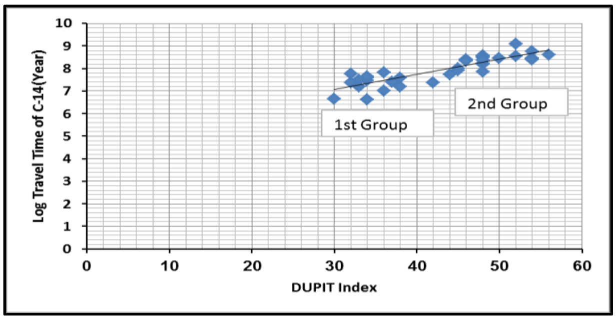
The indicated model is applied on a six radionuclides (T, C-14, Co-60, Tc-99, Ni-59 and Sr-90), those common radionuclides were selected to be with a variety of half-life and distribution coefficient (EPA, 1996; Yu, 1993) in homogeneous distribution mixture buried in a vault waste disposal structure during the controlled and continuous release of radionuclides to the environment from a waste facility.

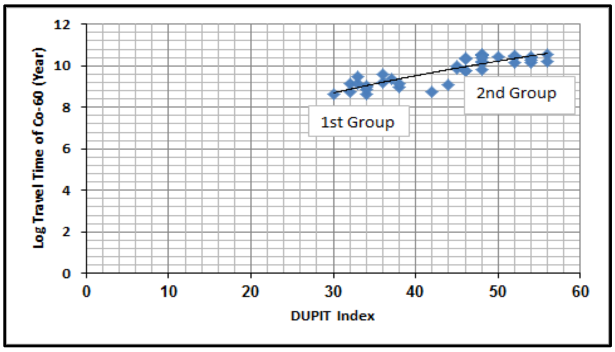
The transit times calculated for the relevant radioisotopes that could leach out from radioactive waste disposal facility through unsaturated zone to reach groundwater, have been scatter plotted against the DUPIT index values, figure (9). Two major groups can be recognized in these patterns. The 1st group includes the samples of lowest DUPIT index (30 to 40, high vulnerable), which have lowest transit times, reflecting the non suitability for waste disposal siting. The 2nd group shows somewhat increase of DUPIT index (42 – 58), complying with the increase of transit times, reflecting medium to high suitability for waste disposal.

Conclusion

Three hydrogeochemical indicators (DUPIT vulnerability index, environmental isotopes, and transit times of relevant radionuclides) have been used complimentarily for surveying the area to the East of Nile Delta, to select potential sites for radioactive waste disposal. The study area has been classified into subareas that are mapped according to their suitability for hosting radioactive waste and susceptibility of groundwater contamination through unsaturated zone reach. A considerable consistency exists between the calculated radioisotopes transit times through unsaturated zone and the corresponding vulnerability index. A high adoptability has been proven has been proven for using the employed DUPIT index for site survey of radioactive waste disposal facility.







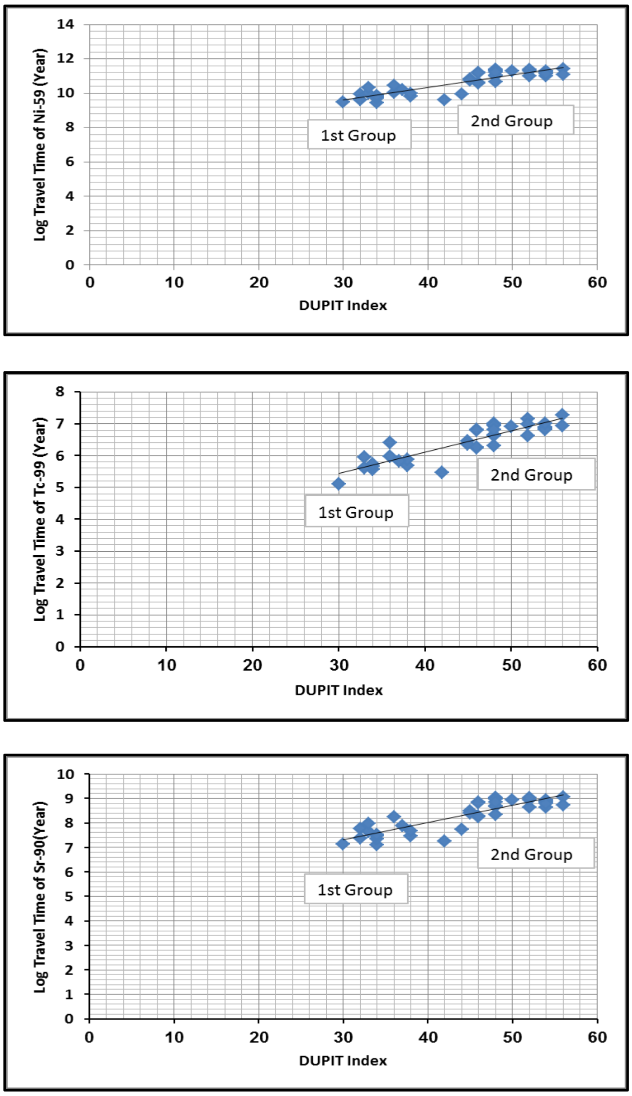


Figure (9): Travel Time of different radioactive isotopes vs DUPIT index.

References

Ahmed S., El-Arabi H. and Saber M. (2008); Groundwater exploration with schlumberger soundings at Cairo-Bilbeis district, east Nile Delta, Egypt.The Seventh Annual U.A.E. University Research Conference.

Aller L, Bennett T, Lehr JH, Petty RJ, Hackett G (1987); DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeological settings. Prepared for the US Environmental Protection Agency, Office of Research and Development, EPA-600/2-87-035.National Water Well Association, Dublin, OH.

Bagch.A (1994); Design, construction and monitoring of landfills, 2nd edn. Wiley, New York, NY.

Yu C, Loureiro C, Cheng J, Jones LG, Wang YY, Chia YP, and Faillace E, (1993); collection handbook to support modeling impacts of radioactive material in soil, Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Illinois.

Civita M (1994); Vulnerability maps of aquifers subjected to pollution: theory and practice. PitagoraEditrice, Bologna (in Italian)

Crawford JF, Smith PG (1985); Landfill technology.Butterworths, London.

Documenting ground-water modeling at sites contaminated with radioactive substances, EPA 540-R-96-003-PB96-963302, January 1996.Dorhofer G, Siebert

H (1998); The search for landfill sites requirements and implementation in Lower Saxony, Germany. Environ Geol 35:55–65 (DOI: 10.1007/s002540050292)

Dorn M, Tantiwanit W (2001); New methods for searching for waste disposal sites in the Chiang Mai–Lamphun basin, Northern Thailand. Environ Geol 40:507–517 (DOI: 10.1007/s002540000187)

Edet AE (2004); Vulnerability evaluation of a coastal plain sand aquifer with a case example from Calabar, southeastern Nigeria. Environ Geol 45:1062–1070 (DOI: 10.1007/s00254-004-0964-9)

Ekpo BO, Ibok UJ, Umoh ND (2000); Geochemical evaluation of suitability of sites for hazardous waste disposal: a case study of recent and old waste-disposal sites in Calabar Municipality, SE Nigeria. Environ Geol 39:1286–1294 (DOI: 10.1007/s002540000114)

El-Shazly E M, Abdul-El- Hadi M A, Meshref W M, Soliman A b, Ammar A A, Morsy M.A, El-Rakaiby M M, Assy E and Kamal A F (1975b); Geological and geophysical investigation of the suez canal zone .Remote Sensing Research Project: Academy of Scientific Research and technology , Cairo, Egypt.1-25 pp.

ESRI (1999); Getting to know ArcView GIS, 3rd edn. ESRI Press, Redlands, CA

Foster SSD (1987); Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In: Duijvanbooden W, van Waegeningh HG (eds) Vulnerability of soil and groundwater to pollution. Proceedings and Information No. 38 of the International Conference held in the Netherlands, TNO Committee on Hydrological Research, Delft, The Netherlands

Foster SSD (1998); Groundwater recharge and pollution vulnerability of British aquifers: a critical overview. Geological Society Special Publication, No:130, London

Gogu R C, Dassargues A, (2000); Sensitivity analysis for the EPIK method of vulnerability assessment in a small karstic aquifer, Southern Belgium: Hydrogeology Journal, 8(3), 337-345.

Ibe KM, Nwankwor GI, Onyekuru SO (2001); Assessment of groundwater vulnerability and its application to the development of protection strategy for the water supply aquifer in Owerri, southeastern Nigeria. Environ Monit Assess 67:323–360 (DOI: 10.1023/A:1006358030562)

International Atomic Energy Agency, (2003), “Derivation of Activity Limits for the Disposal of Radioactive Waste in Near Surface Disposal Facilities,” IAEA-TECDOC-1380.

Technical Reports Series No. 472 Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments (2010).

Lee S (2003); Evaluation of waste disposal site using the DRASTIC system in Southern Korea. Environ. Geol. 44:654–664 (DOI: 10.1007/s00254-003-0803-4)

Lodwik, W A, Monson W, Svoboda L, (1990); Attribute error and sensitivity analysis of maps operation in geographical information systems – suitability analysis: International Journal of Geographic Information Systems, 4, 413-428.

Rao KS (1997); Site selection for a landfill.Narosa Publishing House, New Delhi

Sakiyan J, Yazicigil H (2004); Sustainable development and management of an aquifer system in western Turkey.Hydrogeol J 12:66–80 (DOI: 10.1007/s10040-003-0315-z)

Salah A W, (2005); " Hydrogeological Studies and Application of the Environmental Isotopes Techniques on the Northeast Greater Cairo Area, Egypt.", Ph.D., Department of Geology, Faculty of Science, Ain Shams University.

Schreck P, (1998); Environmental impact of uncontrolled waste disposal in mining and industrial areas in Central Germany. Environ Geol 35:66–72 (DOI: 10.1007/s002540050293)

Simsek C (2002); The hydrogeological investigations for the site selection of the landfill area of the Torbalı Plain. PhD Thesis, The Graduate School of Natural and Applied Science, DokuzEylul University, Izmir

Simsek C, Karaca Z, Gemici U, Gunduz O (2005); The assessment of the impacts of marble waste site on the water and sediment quality in a river system. Fresenius Environ Bull (in press)

Simsek C, Kincal C, Gunduz O(2006); A solid waste disposal site selection procedure based on groundwater vulnerability mapping, Volume 49, Issue 4, pp 620-633.

Terzaghi K, Peck RB, Mesri G (1996); Soil mechanics in engineering practice, 3rd edn. Wiley, New York, NY.

Torbali Municipality (2002); Saibler landfill site environmental impact assessment report, Torbali, Izmir (in Turkish)

Understanding variation in Partition coefficient, K_d, values, (2004) United States Office of Air and Radiation EPA, 402-R-04-002C.