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Data Integration to Assess Aquifer Vulnerability Potential to Pollution around Ismailia Canal Using Remote Sensing and Gis Techniques

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***Abstract**: Egypt has been suffering from severe water scarcity problem in recent years.Day-by-day dependence on groundwater is gradually increasing in Egypt due to water scarcity problem.The study area is located around Ismailia Fresh-water Canal in the eastern region of the Nile Delta. It extends from the Ismailia city to El-Asher Men Ramadan city, Egypt.The DRASTIC method has been most commonly and widely used for mapping vulnerability in porous aquifers developed by Aller et al., 1987.In the present study, an attempt has been made to assess the groundwater vulnerability of the unconfined aquifer around Ismailia canal area based on DRASTIC method and ARCGIS. Eight hydrogeological and environmental parameters are used to represent the natural hydrogeologic and environmental settings of the study area i.e. depth to groundwater, net recharge, aquifer media, soil media, topography, impact of the vadose zone, hydraulic conductivity and the land use.*

From the groundwater vulnerability point of view, it is found that the shallow depth to groundwater around Ismailia canal causing that area more vulnerable to pollution especially with its heavily population capacity and presenting the industrial city of El-Asher men Ramdan nearby it located at the western part of the study area. Unfortunately, we found that landfills, agricultural and municipal drains and underground septic tanks are already situated around Ismailia canal. Meanwhile, the northern and southern surrounding areas far from the main course of Ismailia canal have deeper depth to groundwater that causing attenuation for the pollution potential.By the comparison between the depth to groundwater map and water table map of the unconfined aquifer in the study area and the flow directions of the water table map, it can be concluded that the seepage from Ismailia canal to the surrounding areas with losing stream conditions but at some local parts it acts as gaining stream. In general, Ismailia canal could be considered as recharge source for the unconfined aquifer of the study area.the lower values of precipitation in the study area lead to less opportunity to leaching the contaminants in the study area. the Nile silt and mud around the main course of Ismailia canal decrease the intrinsic vulnerability to pollution. On contrary, the surrounding areas have sand, gravelly sand and sand deposits which increase the intrinsic vulnerability to pollution. From the DEM map, it is concluded that the northern parts of the study area and the region around Ismailia canal having more groundwater vulnerability to pollution.In the DRASTIC groundwater vulnerability map five distinct categories are represented: (1) very high vulnerability – red color (distributed nearby and around Ismailia canal) associated with very high risk of contamination, (2) high vulnerability – dark blue color (distributed at the northern part of the map with some localities around Ismailia canal) associated with high risk of contamination, (3) moderate vulnerability – yellow color (distributed at eastern and western parts of the map) associated with moderate risk of contamination, (4) low vulnerability – pale blue color (distributed at the southern portion of the map) associated with low risk of contamination, (5) very low vulnerability – green color (distributed at the far portion of Um-Gidam slopes at the southern area of map) associated with very low risk of contamination. Therefore, the lower depth of groundwater level, the urban and agricultural density increases the groundwater vulnerability in the study area. It shows the positive correlation between the depth to groundwater, urbanization, and agriculture and groundwater contamination. On contrary, the lower depth of groundwater levels, less populated areas and less areas of irrigation represents lower degree of vulnerability. The soil media with gravelly sand sediments exhibit moderate effect on total groundwater vulnerability to pollution. In general, the lower values of precipitation in the study area cause no abrupt effect on the groundwater vulnerability map but the effect of irrigation water is obvious. The topography and impact of vadose zone are also revealed a good correlation with groundwater vulnerability to pollution especially in around Ismailia canal. Fortunately, the lower hydraulic conductivity values around Ismailia canal may be caused attenuation of contaminants. Due to this lower hydraulic conductivity values around Ismailia canal, the total DRASTIC index in this portion is still acceptable depending upon the classification of DRASTIC index developed by Aller et al., 1987.

***Keywords:** Drastic Index, Intrinsic Vulnerability, Groundwater, GIS, Ismailia canal*

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I. Introduction

Egypt has been suffering from severe water scarcity problem in recent years. UN says Egypt will face absolute water scarcity by 2025, while some locations the catastrophe has already arrived. Egypt has only 20 cubic meters per person of internal renewable freshwater resources, therefore the country depends heavily on the Nile River for its main source of water. On the other hand, rising of populations, pollution, environmental degradation, and rapid agricultural, industrial, and municipal development are affecting water availability in the country.Day-by-day dependence on groundwater is gradually increasing in Egypt due to water scarcity problem. Human activities have negative impact on the groundwater quality. This may result in temporary or even permanent loss of the water resource.

Once groundwater has been contaminated, contaminants' fate within the aquifers is uncertain but most of the times long lasting, either because of the intrinsic complexity and site specificity of the soil-water-pollutant interactions, and either because remediation is expensive and time consuming(Foster and Chilton 2003). Thus, pollution prevention and control should be a key component in groundwater management. In recent years, aquifer vulnerability and pollution risk assessment studies aiming at the identification of areas that are more likely to be polluted as a result of human activities, have been used as tools for groundwater pollution prevention and control (Shrestha et al. 2016).

To evaluate the groundwater pollution potential, the groundwater vulnerability techniques have been developed by different authors around the world. Groundwater vulnerability refers to the sensitivity of an aquifer system to deterioration due to an external action. In the last few decades, many techniques have been developed to assess groundwater vulnerability, including index, rating, hybrid, statistical techniques. Groundwater vulnerability is classified into intrinsic vulnerability which considers the inherent geological, hydrological and hydrogeological features of an area, but disregards the nature of the contaminant and the scenario of contamination (Vrba and Zaporozec 1994), and specific vulnerability which considers the properties of a particular pollutant in addition to the inherent vulnerability of an area (Gogu and Dassargues 2000). Existing methods to assess groundwater vulnerability can be classified into three categories: (1) overlay indices methods based on ratings and weights, such as DRASTIC (Aller et al. 1987) and SINTACS (Civita and De Maio 1997); (2) process-based mathematical models such as GLEAMS (Knisel and Davis 2000) and HYDRUS (Šimůnek et al. 2008); and (3) statistical models (Neshat and Pradhan 2015).

The DRASTIC method has been most commonly and widely used for mapping vulnerability in porous aquifers developed by Aller et al., 1987. The intrinsic vulnerability is closely dependent on the hydrogeological settings of the study area (Zwahlen, 2004). The objective of this study was to determine the aquifer vulnerability by integrating the DRASTIC Empirical model with remote sensing and Geographic Information System(GIS) tools. The hydrogeologic parameters were processed and mapped to delineate areas susceptible to contamination producing a groundwater vulnerability map around Ismailia canal, Egypt. This research work will allow the decision makers to better focus groundwater management programs.

The study area:

The study area is located around Ismailia Fresh-water Canal in the eastern region of the Nile Delta. It extends from the Ismailia city to El-Asher Men Ramadan city, Egypt. It lies between longitudes $31^{o}\ 40^{/}$ - $32^{o}\ 15^{/}$ E and latitudes $30^{o}\ 18^{/}$ - $30^{o}\ 40^{/}$ N as shown in Figure (1). It is characterized by semi-arid climate with a precipitation of less than 30 mm per year. The boundaries of the study area include the Suez Canal in the East, El-Asher Men Ramadan Industrial city in the west, El-Salhiya plain in the North, and Um-Gidam slopes in the South.

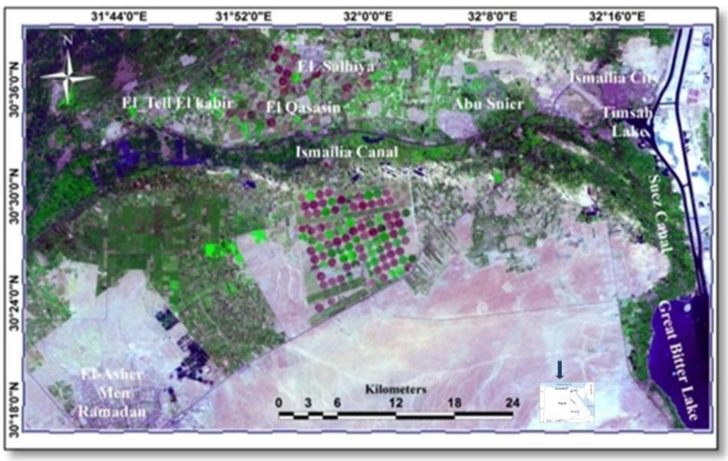

Fig. (1) Location map of study area Geomorphologic and geologic settings:

A lot of previous studies were carried out on geomorphology and geology of the study area. Such works were mentioned in the published works of Barron (1907), Sandford & Arkel (1939), Murry (1951), El-Shazly et al. (1975), El-Ibiary (1981), Said (1981), El-Fawal and Shendi (1991) and El-Fawal (1992). In general, the study area delineated by Wadi El-Tumilat representing an old buried branch of the ancestral Nile River and most of this branch is occupied by Ismailia Fresh-water Canal. Physical and chemical weathering greatly modified the morphology of the land surfaces, especially the physical weathering due to the dominant arid conditions prevailing in the study area. Formation of desert pavement, sand dunes, and accumulation of sand drifts are common features of wind effects during the recent arid conditions in the area north of Ismailia Fresh-water Canal. The sediments of the study area are generally of fluviatile origin but mix towards the east and southeast with fluviomarine sediments. The study area is occupied by agricultural land rest on flood, silty and loamy fine sand soil. The southern boundary of the study area is characterized by elongated and parallel, shallow sand dunes with a number of separate shallow water logged area in between. The subsurface sediments of the study area were represented by two main stratigraphic units; the deeper fluviomarine unit, and the shallow flood plain unit.

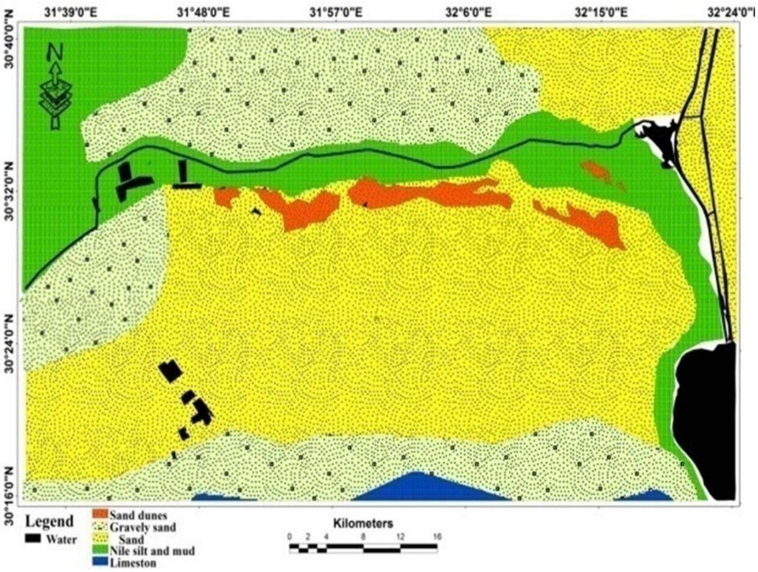

Fig. (2) Geologic map of study area (after Geriesh1994).

Hydrogeologic setting

Geriesh, 1989, and El Shamy and Geriesh, 1989 and 1992 studied the groundwater of the study area. They concluded that, Surface water and groundwater are hydrologically connected systems. The quality and quantity of one is interdependent on the quality and quantity of the other. Understanding the groundwater flow system is very important for protection of surface water bodies (Toth, 1999). The hydrogeological setting of the study area is greatly affected by the Nile sedimentary processes (Said, 1981, Geriesh, 1994 and Afify, 2000). Groundwater around Ismailia Canal occurs in two main aquifer units; the upper permeable unit and the lower highly permeable unit.The upper unit is of Nioltic origin and consists of fine to medium sands with silt and clay caps of sticky characters especially to the east. The eastern part of this unit is formed under lagoon to fluviomarine conditions and is characterized by salty nature due to the high percentage of evaporation (Zoetbrood, 1984). The deposits of the western part of the study area have better hydraulic properties and could be hydrologically connected with the lower aquifer. The thickness of this unit ranges between 5 to 30 meters from west to east successively .The deeper unit represents the main aquifer in the region. It consists of gravelly sand deposits of pure fluviatile origin and attains thickness more than 200 meters. It is composed of pure sand and gravel of high hydraulic properties and low salt contents. Water bearing formations in the study area presents mostly under unconfined conditions, but in some locations semi-confined conditions may exist due to the intercalation of clay lenses. Groundwater flow is almost from west to east and outward of Ismailia canal course. The canal acts as an influent stream in most parts. There are lots of swamps in the low lands due to seepage from Ismailia Canal. The water losses from the canal may reach as maximum as 374 million m^3/year (Geriesh, 1994 and Afify, 2000).The deeper groundwater aquifer is characterized by good hydraulic properties; average transmisivity is about 3000 m^2/d; average hydraulic conductivity is 50 m/d and average specific yield is 0.23.(Geriesh, 1994 and Afify, 2000) stated that, the rate of seepage from Ismailia Canal is about 1m/d, but they referred that, most of the seepage water runs to El Timsah Lake through the adjacent El Mahsama Drain, giving little chance for this water to recharge the main aquifer.

II. Materials and methods

1. *DRASTIC Methodology:*

DRASTIC is an empirical groundwater model that estimates groundwater vulnerability to pollution within aquifer systems based on in situ hydrogeological settings (Aller et al., 1987). Occasionally, DRASTIC can be considered as a Count Point System Model (PCSM) or a parameter weighting and rating method. Rating parameters for each interval are multiplied accordingly with the weight factor and the results are summed up to obtain the final summation. This summation provides a relative measure of groundwater vulnerability degree of one specific area. The intrinsic vulnerability potential of the different areas are compared to each other, and the higher result, the greater susceptibility to pollution for that area or in other words, the higher the intrinsic vulnerability to contamination.

2. *Parameters of the DRASTIC method:*

The most important mappable parameters that control the groundwater pollution potential were determined to be: Depth to water (D), Net Recharge (R), Aquifer Media (A), Soil Media (S), Topography (T), Impact of the vadose zone (I), and Hydraulic Conductivity of the aquifer (C). DRASTIC is an acronym name for the above eight parameters considered in this method. In addition, the Land use (L) is used in this research work as an additional important parameter affecting on the groundwater vulnerability to pollution. Each of the afore mentioned hydrogeologic parameters is assigned a rating from 1 to 10 based on a range of values. The ratings are then multiplied by a relative weight ranging from 1to 5. Weights reflect the relative importance of each parameter in contributing to the overall objective.

Feature	Weight
Depth to water	5
Net recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of voids zone	5
Hydraulic conductivity	3
Landuse/landcover	5

The most significant factors have a weight of 5 while the least significant ones have a weight of 1.
The governing equation for the calculation of the DRASTIC Index (DI) is the following:

$$DI = D_rD_w + R_rR_w + A_r A_w + S_rS_w + T_r T_w + I_rI_w + C_rC_w + L_rL_w \qquad \text{(Eq. 1)}$$

Where, D, R, A, S, T, I, C and L represent the above mentioned hydrogeological parameters, and the subscripts "r" and "w" refer to the corresponding ratings and weights, respectively. The resulting DRASTIC index represents a relative measure of groundwater vulnerability to pollution.
A GIS database is then applied to input data from various sources (e.g. remote sensing). The database can be used to store, manipulate and analyze data in various scale sand formats ((Rahman, 2008, Sener, et al., 2009). After database creation, layers wise data was register with common coordinates system then thematic maps as well as vulnerability map develop (Voudouris, et al., 2010).

3. **Description and preparation of the DRASTIC method parameters**

The depth to water (D) is the distance from the ground surface to thewater table in the unconfined aquifer of the study area. It is a significant data for the input in the DRASTIC method to assess groundwater vulnerability. It determines the depth of the soil material through which a contaminant must travel before reaching the aquifer. Thus, the shallower the water depth, the more vulnerable the aquifer is to pollution. In the present study area, the measurements of depth to water are carried out by using water level Gauge (Electrical sounder) and GPS to measure the ground elevation and geographical coordinates in a number of 30 groundwater monitoring wells distributed in the study area. Then, the depth to water data is used to compute the intrinsic groundwater vulnerability. Using GIS in data processing, raster data format is utilized in each cell that represents the depth to groundwater. For the purpose of demonstration, the water table map of the unconfined aquifer is shown in Figure No. (3).

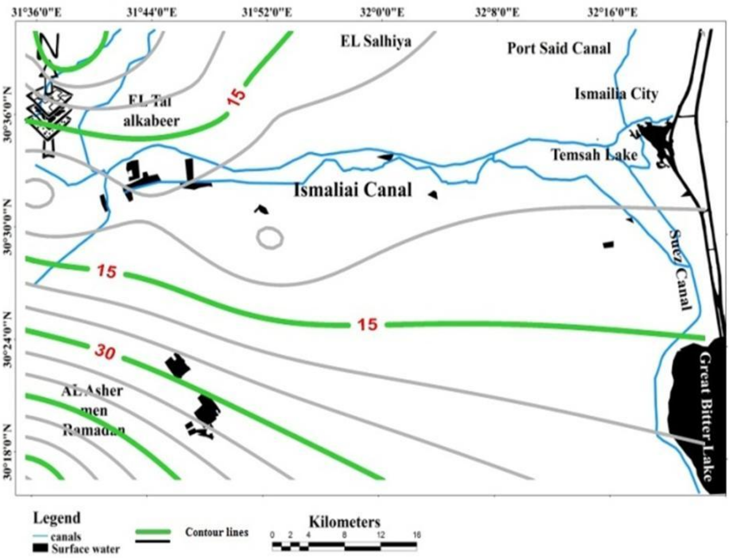

Fig. (3) Showing the depth to water in the study area

Depth to Water Ranges (m)	Rate
0 – 1.52	10
1.52 – 4.57	9
4.57 – 9.14	7
9.14 – 15.24	5
15.24 – 22.86	3
22.86 – 30.48	2
> 30.48	1
Weight(5)	

The net recharge (R) is the amount of recharge water applied on the study area. The recharge water has the ability to carry pollutants to the water table within the aquifer; hence a large recharge value corresponds to a high potential for groundwater vulnerability to pollution .The primary source of recharge is precipitation, which infiltrate sthrough the ground surface and percolates the soil to the water table. The second source is the irrigation water which carries out contaminants through the vadose zone to that aquifer. Net recharge is the total quantity of water per unit area, which applied to the ground surface and infiltrates to reach the unconfined aquifer. Recharge is the principal parameter for leaching and transporting contaminants to the water table. The main sources of recharge in the study area include the precipitation and irrigation. The rainfall data is gathered from a number of 4 meteorological stations distributed in the study area. Therefore, the irrigation water data is collected from the ministry of irrigation, Egypt. Then, the net recharge is computed to determine the DRASTIC index. Using GIS, a shape file of the rainfall stations was obtained and for each station the average long-term rainfall was computed. Thereafter, isohyetal map is constructed for the stations to develop the areas of constant rainfall. Therefore, the map of net recharge including the summation of rainfall and irrigation is constructed (Fig.4).

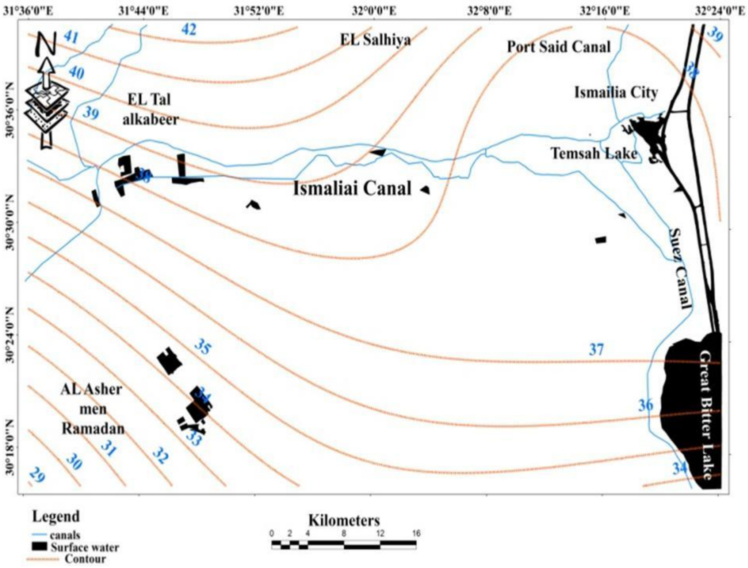

Fig. (4) contour map of the mean annual rainfall of study area.

Rating	Net Recharge Ranges(mm)
1.10	28 – 31
1.22	31 – 34
1.33	34 – 37
1.45	37 – 40
1.57	> 40
Weight(4)	

Aquifer media (A) refers to the geologic materials of water-bearing formation that serves as an aquifer. Grain size of soil (texture) can affect the infiltration rate (Voudouris, Kazakis, Polemio and Kareklas, 2010). The aquifer media ranking map was developed from an interpolation of the lithology of each borehole in the study area. Ratings of each medium represent defined characteristics of each zone. hydrogeologic cross sections and the previous studies (Fig.5).

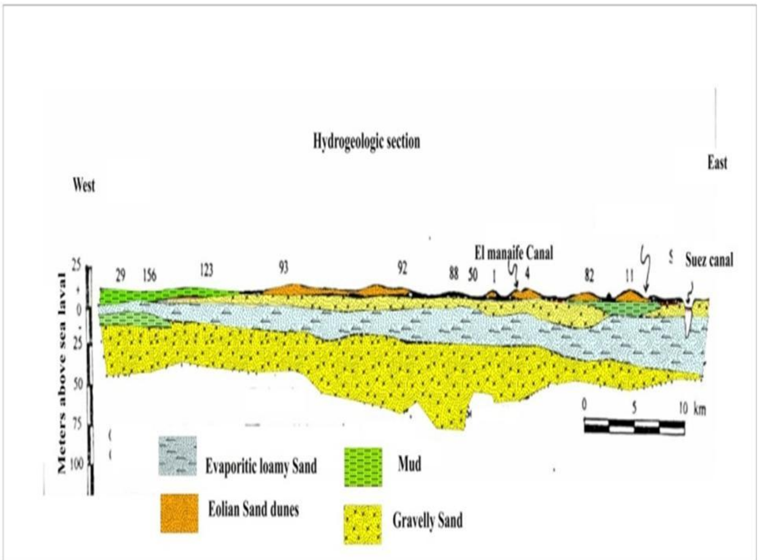

Fig. (5) cross section from west to east in study area (after Geriesh1994).

Rating	Aquifer media Ranges
9	< 30
8	30 – 60

7	60 – 90
6	90 – 120
5	120 – 150
4	> 150
Weight(3)	

Soil media (S) is the top-most soil covering the study area. In general, soil media has a significant impact on the amount of infiltrated water that can reaches to the water table. On contrary, it can attenuate the groundwater pollution depending upon its soil textural characteristics. Soil permeability and media thickness can primarily effect on fate and transport of pollutants. In the present work, the geologic map of the study area is used to determine the soil media parameter values.

Rating	Soil media ranges
10	gravely sand
9	Sand dunes
8	Sand
5	Limestone
2	Silt and mud
Weight (2)	

Topography (T) refers to the slope and the variations of ground elevations of the land surface. It can control if that a pollutant will runoff or remain on the ground surface long enough to infiltrate. Topography also influences on pollutant attenuation. In general, a steeper slope assigns higher groundwater velocity. In the present work, the Digital Elevation Model (DEM) is prepared to construct the topographic map of the study area using remote sensing and GIS (Fig.7). The percent slopes of ground surface are calculated using the aforementioned digital elevation model.

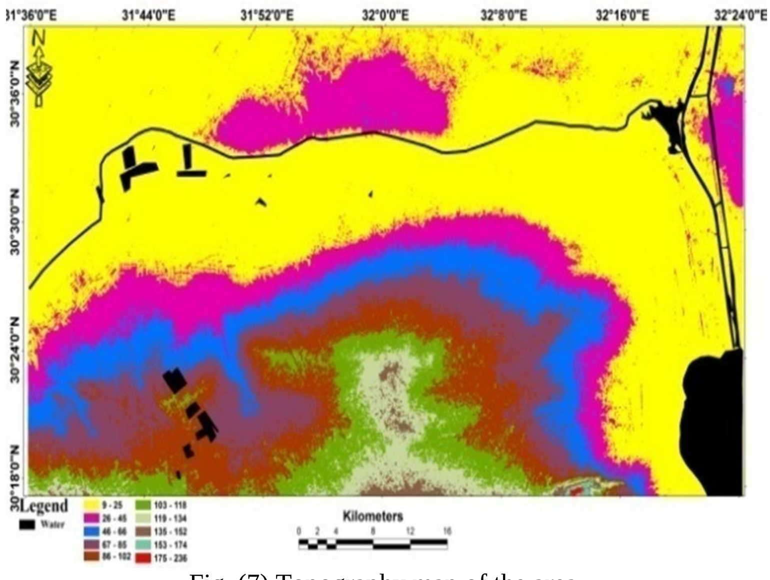

Fig. (7) Topography map of the area.

Rating	Topography ranges
10	0 – 10
9	10 – 20
8	20 – 50
6	50 – 100
4	100 – 150
2	150 – 200
1	> 200
Weight (1)	

Impact of the vadose zone (I) refers to the effect of unsaturated zone that lies above the water table considering the transportation or attenuation of pollutants. Consequently, the soil texture of the vadose zone determines the time of travel of the pollutant through it. In the present work, the impact of the vadose zone is determined using well logs, hydrogeologic cross sections and the previous studies (Fig.8).

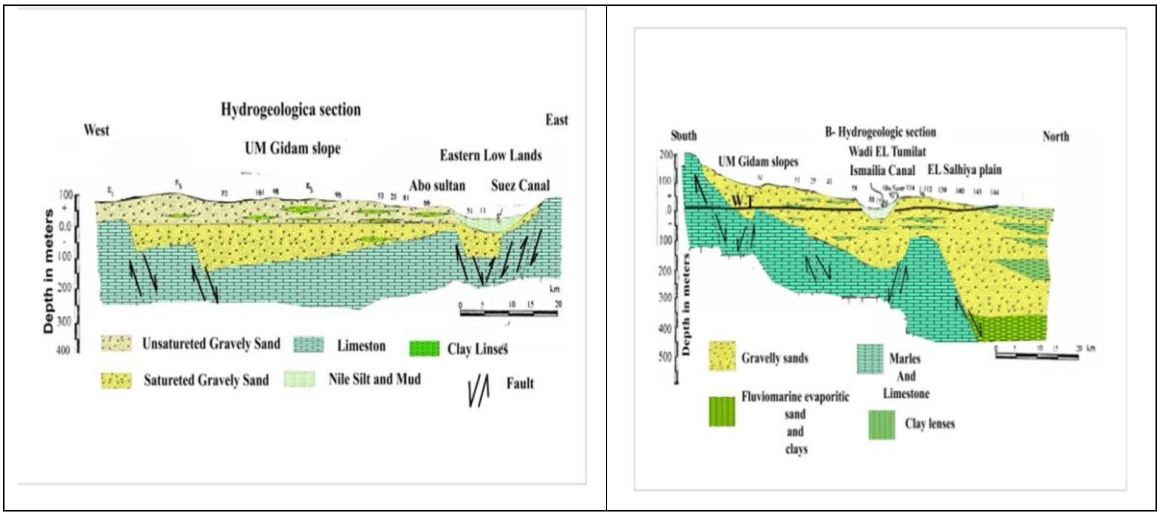

Fig. (8) Cross section of the quaternary aquifer(A)From south to north ,(B)From west to east .showing the vadose zone in study area (after Geriesh1994).

Rating	Vadose zone ranges
8	3 – 8
7	8 – 20
6	20 – 39
5	39 – 58
4	> 58
Weight (5)	

Hydraulic conductivity (C) of the aquifer refers to the ability of aquifer to transmit water or the rate at which water flows through the aquifer. In general, the higher the conductivity is, the faster the velocity of groundwater flow will be and the contaminant will spread out through the aquifer more quickly. In the present work, the hydraulic conductivity values are collected from the previous hydraulic conductivity measurements that carried out by constant and falling-head permeameters and pumping tests. The aforementioned hydraulic conductivity measurements are published by different authors in the study area. Then, the ratings and weights of that parameter are assigned depending upon the above measurements.

Geologic unit	K (m/s)*10^{-6}	Rating
Gravelly Sand	10000	10
Sand dunes	1000	10
Sand	329	10
Limestone	100	6
Silt and Mud	6.6	2
Weight(3)		

Land use (L) refers to the different municipal, industrial, agricultural, and etc. uses on the study area. The land use parameter is a modified parameter developed by many authors worldwide. In the modified DRASTIC, the GIS coverage is all in raster format and values for each overlay are summed in ArcView GIS according to the pixel value of each area that resulted from multiplying the rating with its appropriate DRASTIC weight. In the present work, the land use map (Fig.10) is constructed in the study area.

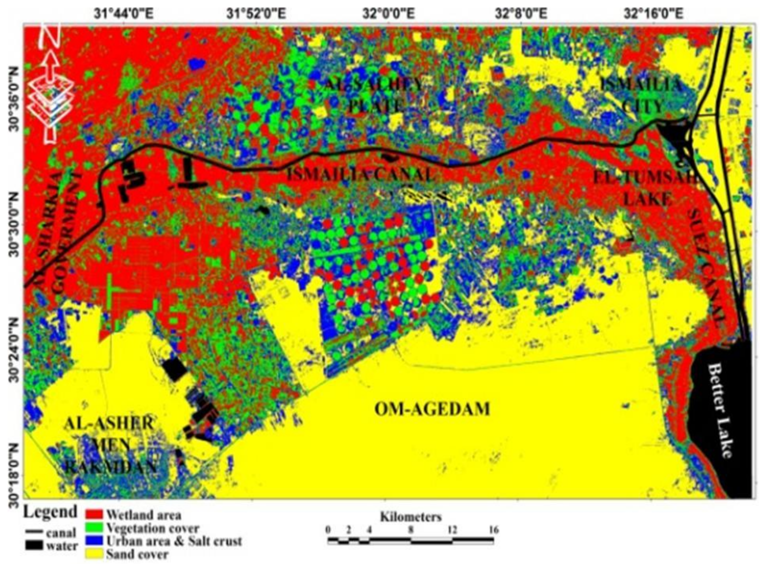

Fig. (10) Landuse\Landcover map of the study area.

Landuse ranges	Rating
Urban	8
Wetlands	6
Vegetation cover	4
Sand cover	2
Weight (5)	

III. Results and discussion

In the present study, the DRASTIC method is applied on the unconfined aquifer of the study area. Consequently, the thematic map of each parameter, then the groundwater vulnerability map is developed to assess groundwater vulnerability to pollution. In the following, groundwater vulnerability results for each parameter are discussed for the study area.

Measurements of depth to groundwater at monitoring wells throughout the study area is used for construction of depth to groundwater map of the unconfined aquifer around Ismailia Canal (Fig. 3). Ismailia canal was already drilled in the Wadi El-Tumilat that is old buried branch of Nile River. The depth to groundwater values range from 5m to 75m in the unconfined aquifer of the study area. These values gradually increase towards the northern and southern parts of the study area. On contrary, these values decrease towards around Ismailia canal at the middle part of the study area. Consequently, it is concluded that the depth to groundwater follows the variations of topography in the unconfined aquifer of the study area. Due to the wide agricultural activities and reclamation projects in the study area, a lot of pumping wells are drilled that cause discharge from the aquifer. From the groundwater vulnerability point of view, it is found that the shallow depth to groundwater around Ismailia canal causing that area more vulnerable to pollution especially with its heavily population capacity and presenting the industrial city of El-Asher men Ramadan nearby it located at the western part of the study area. Unfortunately, we found that landfills, agricultural and municipal drains and underground septic tanks are already situated around Ismailia canal. Meanwhile, the northern and southern surrounding areas far from the main course of Ismailia canal have deeper depth to groundwater that causing attenuation for the pollution potential. In addition, the water table map of the unconfined aquifer in the study area is constructed (Fig.11) to show the distribution of equipotential lines and groundwater flow directions. It is revealed that the values of equipotential lines increase toward Ismailia canal.

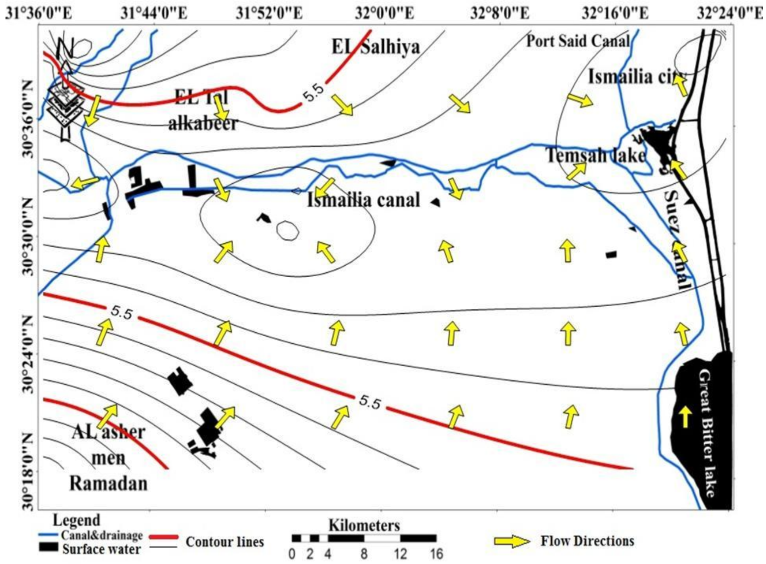

Fig. (11). Distribution of equipotential lines and groundwater flow directions.

By the comparison between the depth to groundwater map and water table map of the unconfinedaquifer in the study area and the flow directions of the water table map, it can be concluded that the seepage from Ismailia canal to the surrounding areas with losing stream conditions but at some local parts it acts as gaining stream. In general, Ismailia canal could be considered as recharge source for the unconfined aquifer of the study area.

The study area has arid climate conditions varying from 31mm to 41mm. In general, the isohyetal lines slightly increase toward the northeastern direction. The irrigation rate is (395) mm annually that is important factor especially for DRASTIC index. However, the lower values of precipitation in the study area lead to less opportunity to leaching the contaminants in the study area.

The distribution of soil media is shown in Figure (6). The Nile silt and mud covers the main course of Ismailia canal. In the northern part of the study area, the sand covers this part except the western portion which is covered by the gravelly sand. In the southern part of the study area, the gravelly sand covers most of this part with small portions of sand dune and sand sediments. Fortunately, the Nile silt and mud around the main course of Ismailia canal decrease the intrinsic vulnerability to pollution. On contrary, the surrounding areas have sand, gravelly sand and sand deposits which increase the intrinsic vulnerability to pollution.

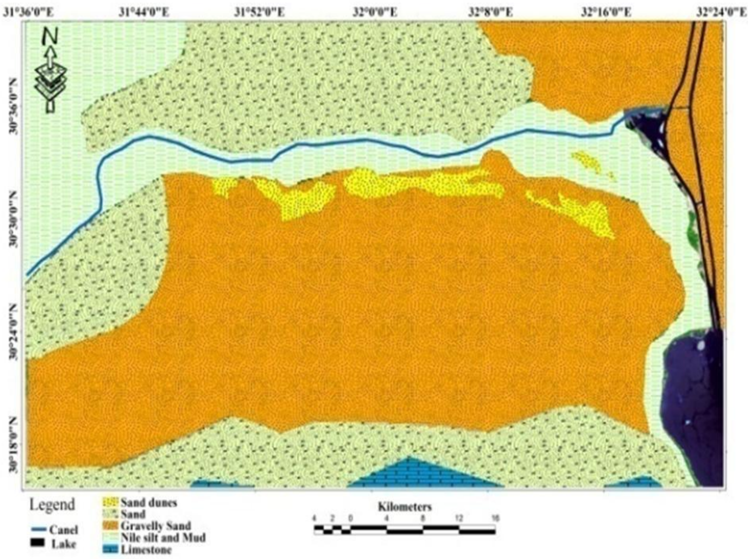

Fig. (6) Soil map of the area (after Geriesh1994).

The digital elevation model (DEM) is prepared in the study area (Fig.7). The ground elevations range from 9m to 236m above mean sea level (a.m.s.l.). Most of northern part of the study area and around Ismailia canal shows lower ground elevations varying between 9m to 26m (a.m.s.l.). In the southern part of the study area including Um-Gidam slopes, it shows higher ground elevations varying between 26m and 236m (a.m.s.l.). Consequently, the slope percent is higher in the southern part than the northern part of the study area. The slope percent is calculated by using ARCGIS software to determine the rating of the topography in the groundwater vulnerability map. From the DEM map, it is concluded that the northern parts of the study area and the region around Ismailia canal having more groundwater vulnerability to pollution.

Two hydrogeologic cross sections are used to represent the impact of the vadose zone (Fig.8). The first section is north-south direction normal to the Ismailia canal. The second section is east-west direction parallel to the Ismailia canal. From the above aforementioned hydrogeologic cross sections, the unsaturated gravelly sand is represented the vadose zone in the study area. Consequently, it has higher intrinsic vulnerability potential to pollution especially at the region nearby Ismailia canal due to its textural characteristics.

The hydraulic conductivity values are widely varied depending upon the type geologic materials. In the DRASTIC method developed by Aller et al. 1987, the unit of hydraulic conductivity should be converted from meter/second (m/s) to Gal/Day/ft^2 (GPD/ft^2).The hydraulic conductivity values (Fig.9) exhibits lower values nearby and around Ismailia canal reflecting the attenuation behavior of geologic rocks against the contaminants in this part of the study area. On contrary, the hydraulic conductivity values exhibits higher values in the northern and southern parts of the study area reflecting the leaching behavior of geologic rocks to the contaminants in this part of the study area.

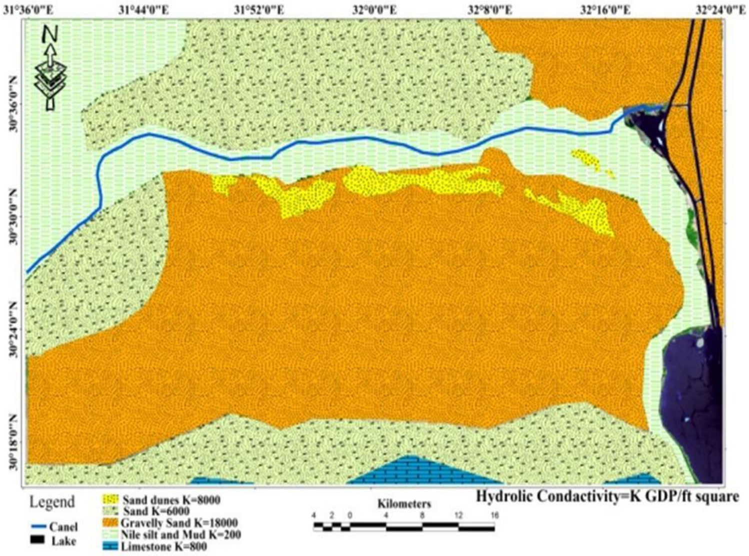

Fig. (9) Hydraulic conductivity map of study area.

The land use mapused to Monitoring and analysis of the recent landcover dynamics through the integration of remote sensing and GIS could provide base information for documenting water pollution. satellite image taken . Image enhancements and classifications were applied to changes in the available image. The results confirmed Increase pollution opportunities in 2017. The main objective of this study are specifying factors controlling water pollution problem using remote sensing and GIS, in addition, suggest solutions mitigating this problem using DRASTIC techniques and Integration with maps of land use/land cover. The non-manageable agricultural expansion, excess irrigation water and deficiency of Sewage system, In addition to urban expansion are the most important factors producing water pollution .Figure (10) illustrates the contrast in land use/ land cover distribution in 2017.

Groundwater vulnerability of the DRASTIC model:

Considering DRASTIC method, the ratings and weights of the DRASTIC parameters are determined. The final computed values for DRASTIC index provide numerical range for groundwater vulnerability potential to pollution. Then, the groundwater vulnerability map is prepared that has been shown in Figure (12). In the study area, the DRASTIC index value degree varied from 1 to 108 divided into five categories; (1) very low vulnerability (1-28), (2) low vulnerability (29-42), (3) Moderate vulnerability (43-57), (4) high vulnerability (58-75), and very high vulnerability (77-108). Based on intrinsic vulnerability, appropriate colors are selected to each category. In the DRASTIC groundwater vulnerability map five distinct categories are represented: (1) very high vulnerability – red color (distributed nearby and around Ismailia canal) associated with very high risk of contamination, (2) high vulnerability – dark blue color (distributed at the northern part of the map with some localities around Ismailia canal) associated with high risk of contamination, (3) moderate vulnerability – yellow color (distributed at eastern and western parts of the map) associated with moderate risk of contamination, (4) low vulnerability – pale blue color (distributed at the southern portion of the map) associated with low risk of contamination, (5) very low vulnerability – green color (distributed at the far portion of Um-Gidam slopes at the southern area of map) associated with very low risk of contamination. Therefore, the lower depth of groundwater level, the urban and agricultural density increases the groundwater vulnerability in the study area. It shows the positive correlation between the depth to groundwater, urbanization, and agriculture and groundwater contamination. On contrary, the lower depth of groundwater levels, less populated areas and less areas of irrigation represents lower degree of vulnerability. The soil media with gravelly sand sediments exhibit moderate effect on total groundwater vulnerability to pollution. In general, the lower values of precipitation in the study area cause no abrupt effect on the groundwater vulnerability map but the effect of irrigation water is obvious. The topography and impact of vadose zone are also revealed a good correlation with groundwater vulnerability to pollution especially in around Ismailia canal. Fortunately, the lower hydraulic conductivity values around Ismailia canal may be caused attenuation of contaminants. Due to this lower hydraulic conductivity values around Ismailia canal, the total DRASTIC index in this portion is still acceptable depending upon the classification of DRASTIC index developed by Aller et al., 1987.

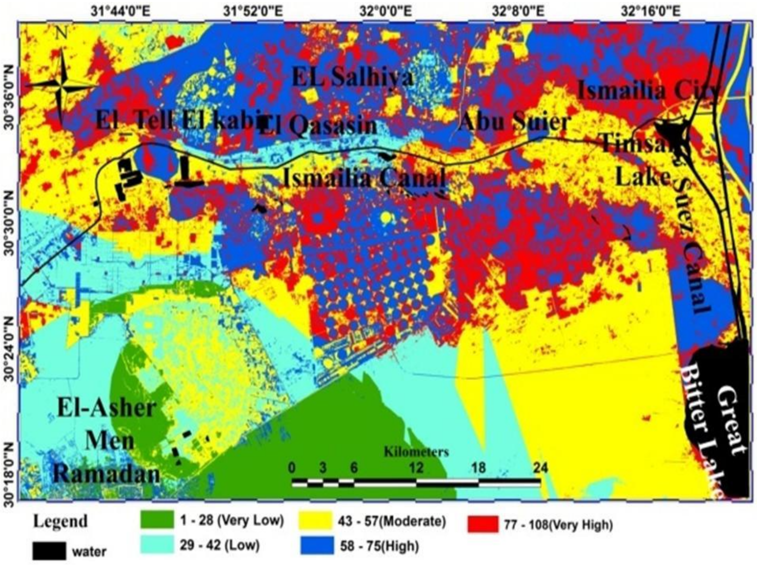

Fig. (12) Integrated ground water vulnerability map of study area.

IV. Conclusions

In the present study, an attempt has been made to assess the groundwater vulnerability of the unconfined aquifer around Ismailia canal area based on DRASTIC method and ARCGIS. Eight hydrogeological and environmental parameters are used to represent the natural hydrogeologic and environmental settings of the study area i.e. depth to groundwater, net recharge, aquifer media, soil media, topography, impact of the vadose zone, hydraulic conductivity and the land use. From the groundwater vulnerability point of view, it is found that the shallow depth to groundwater around Ismailia canal causing that area more vulnerable to pollution especially with its heavily population capacity and presenting the industrial city of El-Asher men Ramadan nearby it located at the western part of the study area. Unfortunately, we found that landfills, agricultural and municipal drains and underground septic tanks are already situated around Ismailia canal. Meanwhile, the northern and southern surrounding areas far from the main course of Ismailia canal have deeper depth to groundwater that causing attenuation for the pollution potential. By the comparison between the depth to groundwater map and water table map of the unconfined aquifer in the study area and the flow directions of the water table map, it can be concluded that the seepage from Ismailia canal to the surrounding areas with losing stream conditions but at some local parts it acts as gaining stream. In general, Ismailia canal could be considered as recharge source for the unconfined aquifer of the study area. the lower values of precipitation in the study area lead to less opportunity to leaching the contaminants in the study area. the Nile silt and mud around the main course of Ismailia canal decrease the intrinsic vulnerability to pollution. On contrary, the surrounding areas have sand, gravelly sand and sand deposits which increase the intrinsic vulnerability to pollution. From the DEM map, it is concluded that the northern parts of the study area and the region around Ismailia canal having more groundwater vulnerability to pollution. In the DRASTIC groundwater vulnerability map five distinct categories are represented: (1) very high vulnerability – red color (distributed nearby and around Ismailia canal) associated with very high risk of contamination, (2) high vulnerability – dark blue color (distributed at the northern part of the map with some localities around Ismailia canal) associated with high risk of contamination, (3) moderate vulnerability – yellow color (distributed at eastern and western parts of the map) associated with moderate risk of contamination, (4) low vulnerability – pale blue color (distributed at the southern portion of the map) associated with low risk of contamination, (5) very low vulnerability – green color (distributed at the far portion of Um-Gidam slopes at the southern area of map) associated with very low risk of contamination. Therefore, the lower depth of groundwater level, the urban and agricultural density increases the groundwater vulnerability in the study area. It shows the positive correlation between the depth to groundwater, urbanization, and agriculture and groundwater contamination. On contrary, the lower depth of groundwater levels, less populated areas and less areas of irrigation represents lower degree of vulnerability. The soil media with gravelly sand sediments exhibit moderate effect on total groundwater vulnerability to pollution. In general, the lower values of precipitation in the study area cause no abrupt effect on the groundwater vulnerability map but the effect of irrigation water is obvious. The topography and impact of vadose zone are also revealed a good correlation with groundwater vulnerability to pollution especially in around Ismailia canal. Fortunately, the lower hydraulic conductivity values around Ismailia canal may be caused attenuation of contaminants. Due to this lower hydraulic conductivity values around Ismailia canal, the total DRASTIC index in this portion is still acceptable depending upon the classification of DRASTIC index developed by Aller et al., 1987.

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