Groundwater Quality and Vulnerability Assessment in the New Reclamation Areas, Assuit Governorate, West Nile River, Egypt

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Abstract*:* Groundwater vulnerability assessment to delineate areas that are more susceptible to contamination from anthropogenic sources has become an important element for sensible resource management and land use planning. Reclamation processes at western part of Assuit Governorate have created many hydrogeological and environmental problems such as an increase of groundwater salinity, soil deterioration and water logging on the new cultivated land. This paper attempts to evaluate the groundwater quality for drinking and agricultural purposes and produce groundwater vulnerability maps using geographic information system (GIS). For irrigation purposes about 75% of water samples are unsuitable for MR (Magnesium Ratio) indicating unfavorable effects on crop yield and an increase in soil alkalinity. Calculating Kelly's Index (KI) indicating 42% of water samples have (KI>1) shows an excess of sodium.Vulnerability maps were produced by applying the Generic and Agricultural models according to DRASTIC charter. The resulting maps revealed that the potential for polluting groundwater with agricultural chemicals is greater than with Generic DRASTIC index pollutants due to extensive agricultural activities. Also, there are some groundwater samples were polluted with nitrate, iron and manganese. There is a trend of decreasing in both nitrate and manganese concentrations from East to West, i.e., the degree of pollution, decrease as we get far from the old cultivated lands (from Pleistocene aquifer to Eocene aquifer) and vice versa of iron.
[Abdel-Hameed M. El-Aassar, Rasha A. Hussien, Saad Y. Ghoubachi. **Groundwater Quality and Vulnerability Assessment in the New Reclamation Areas, Assuit Governorate, West Nile River, Egypt.** *J Am Sci* 2016;12(11):1-23]. ISSN 1545-1003 (print); ISSN 2375-7264 (online). http://www.jofamericanscience.org. 1. doi:10.7537/marsjas121116.01.

Key words: Groundwater Quality Index / Vulnerability/ DRASTIC Method/ Assuit Governorate

1. Introduction

Egypt faces many challenges regarding water resources due to overpopulation and increasing of water demand. The limitation of the cultivable lands in the narrow Nile Valley and Delta urged the successive governments to draw various programs for land reclamation in desert areas. The new land reclamation depends mainly on available and renewable water resources (AHT Group AG, 2009). The agriculture in Egypt depends mainly on the Nile surface water system, but in the newly reclaimed areas, groundwater is the main source of water used for agriculture. In Assuit Governorate, the groundwater in desert fringe areas is used, not only for agriculture purposes, but also for the establishment of new settlement cities. The problem of how to accommodate large and growing water requirements is further complicated by pollution from all sources; agricultural, domestic and industrial- which limits how both fresh and wastewater can be used without adverse economic, environmental, and health implications (IWRM II, 2010). The assessment of the environmental fate and behavior of the constituents that have the potential to leach from waste disposal, and other similar sites is of immense interest to environmentalists. Such assessments require knowledge of the various environmental, chemical and hydrogeological parameters. These parameters exhibit large uncertainties due to the limited number of observations and the natural heterogeneity of the underlying geologic formations. The concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against anthropogenic and natural impacts, and that the degree of vulnerability is a function of the hydrogeological conditions and the prevailing patterns of waste disposal systems. The degree of vulnerability is expressed by means of maps and analytical models which show that the protection provided by the natural environment varies at different locations (Ibe. *el al.,* 2001). It is clearly an urgent need for rapid reconnaissance techniques that allow an assessment of groundwater vulnerability over large areas, despite the fact that there may be only limited secondary data. Groundwater vulnerability mapping is based on the idea that some land areas are more vulnerable to groundwater contamination than others (Piscopo, 2001) and basic vulnerability indices have been developed extensively for planning purposes in many areas of the world (Carter *el al.,* 1987), (NRA, 1994).

west the Nile course, it occupies an area extending from the northern edge of Sohag Governorate to the southern edge of El-Minia Governorate. It is bounded between latitudes 26˚ 45`and 27˚ 30`N and between longitudes 30˚ 30` and 31˚ 30`E Fig 1. The area of study covers an area of about 2300 Km^2. The ground elevation ranges from 29 to 615 m above mean sea level (amsl) from south to north, respectively. The Nile tends to occupy the eastern side of its valley, so that the cultivated lands to the west of the river are generally much wider than those lands to the east. Reclamation processes at the desert fringes of Assuit have created many hydrogeological and environmental problems such as the increase of groundwater salinity, soil deterioration and water-logging on the low lying old cultivated lands. Also, the pollution of the groundwater by nitrate and some heavy metals, especially at the public water wells used for human drinking causes many of the public health issues.

2.1 Climatic conditions

In general, the climate of the study area is arid. It is hot, dry and rainless in summer. On the other hand, it is mild with rare rainfall in winter. The climatic data Table 1. indicates that the average maximum monthly temperature is 37.4^o C during June, whereas the average minimum value is 5.5^o C during January. Rain is scarce and occurring only in winter in the form of scattered showers and a high evaporation rate. The average annual precipitation reaches 7 mm and mostly restricted to November-December period. Relatively heavy rainfall showers take place only occasionally over a short duration. It was recorded occasionally in November, 1994 where rainfall intensity reached 24 and 13 mm in two hours, causing great damage to Drunka Village, West of Assuit city (Ashmawy and Nassim, 1998). The maximum monthly evaporation rate is 21.84 mm/day during June and the minimum value is 5.99 mm/day during December (El Meligy, 2004).

2.2 Geological setting

Based on the geological map, as shown in Fig 2. the surface geology is built up of different rock units.

1- Eocene rocks:

The Eocene rocks are differentiated into the Lower and Middle. The Lower Eocene rocks are represented by Thebes Group. This Group is divided into Serai and Drunk Formations. They occupy the southern portion of the study area. They are composed of thinly-bedded fossiliferous chalkly limestone beds with nodular limestone interbeds (Shileby, 2000). On the other hand, the Middle Eocene sediments cover most of the surface area of the northern portion of the study area. They can be distinguished from base to top into the following formations:

Since the concept of vulnerability to the contamination was introduced by (Albinet and Margat, 1970) many methods have been proposed for vulnerability mapping of aquifers, including DRASTIC (Aller. *el al.,* 1987) GOD (Foster, 1987), AVI (Van Stempoort, *el al.,* 1993) SINTACTS (Civita, 1994) EPIK (Doerfliger, *el al.,* 1999) and PI (Goldscheider, *el al.,* 2000). The above acronyms normally stand for the factors that are considered for vulnerability assessment. The conventional methods (i.e. DRASTIC, AVI, GOD, SINTACS) are able to distinguish degrees of vulnerability in porous aquifers at regional scales where different lithologies exist, while the EPIK and PI methods were specifically developed for the assessment of vulnerability in karstic areas (Secunda, *el al.,* 1998, Al-Adamat, *el al.,* 2003, Gogu, *el al.,* 2003, Babiker, *el al.,* 2005). One of the most widely used models to assess groundwater vulnerability to a wide range of potential contaminants is DRASTIC (Evans and Mayers,1990, Rundquist, *et al.,*1991, Fritch, et al., 2000 and Piscopo,2001). This method uses seven parameters including climatic, geological, and hydrogeological conditions controlling the seepage of pollutant substances to groundwater. The DRASTIC method was developed for use in areas over 0.4 km^2, and assumes a generic contaminant, with the mobility of water, that travels vertically downward towards the groundwater system by direct recharge (Aller, et al., 1987). In this model, spatial data sets on ***D***epth to groundwater ***R***echarge by rainfall, ***A***quifer type, ***S***oil properties, ***T***opography, ***I***mpact of the vadose zone and the hydraulic ***C***onductivity of the aquifer are combined (Navulur and Engel 1998). Because of the higher number of parameters included in the DRASTIC model, it could be expected to obtain a greater degree of accuracy in the vulnerability maps. DRASTIC is a numerical rating scheme, which was developed by the US EPA, for evaluating the potential for groundwater contamination at a specific site given its hydrogeological setting (Knox *el al.,* 1993).

There are two objectives of this work; the first objective is to evaluate groundwater quality whereupon can determine its suitability for different uses and sustainable development through studying the water quality. The second is to concern with the exploring the impact of extensive agricultural land use activity and excess tapping groundwater in the new reclamation areas at West Nile River in Assuit governorate with regard to groundwater vulnerability to pollution through using the DRASTIC model within a GIS environment.

2. Site Description

Assuit Governorate stretches for about 120 km along the Nile banks. It lies in the Nile Valley east and

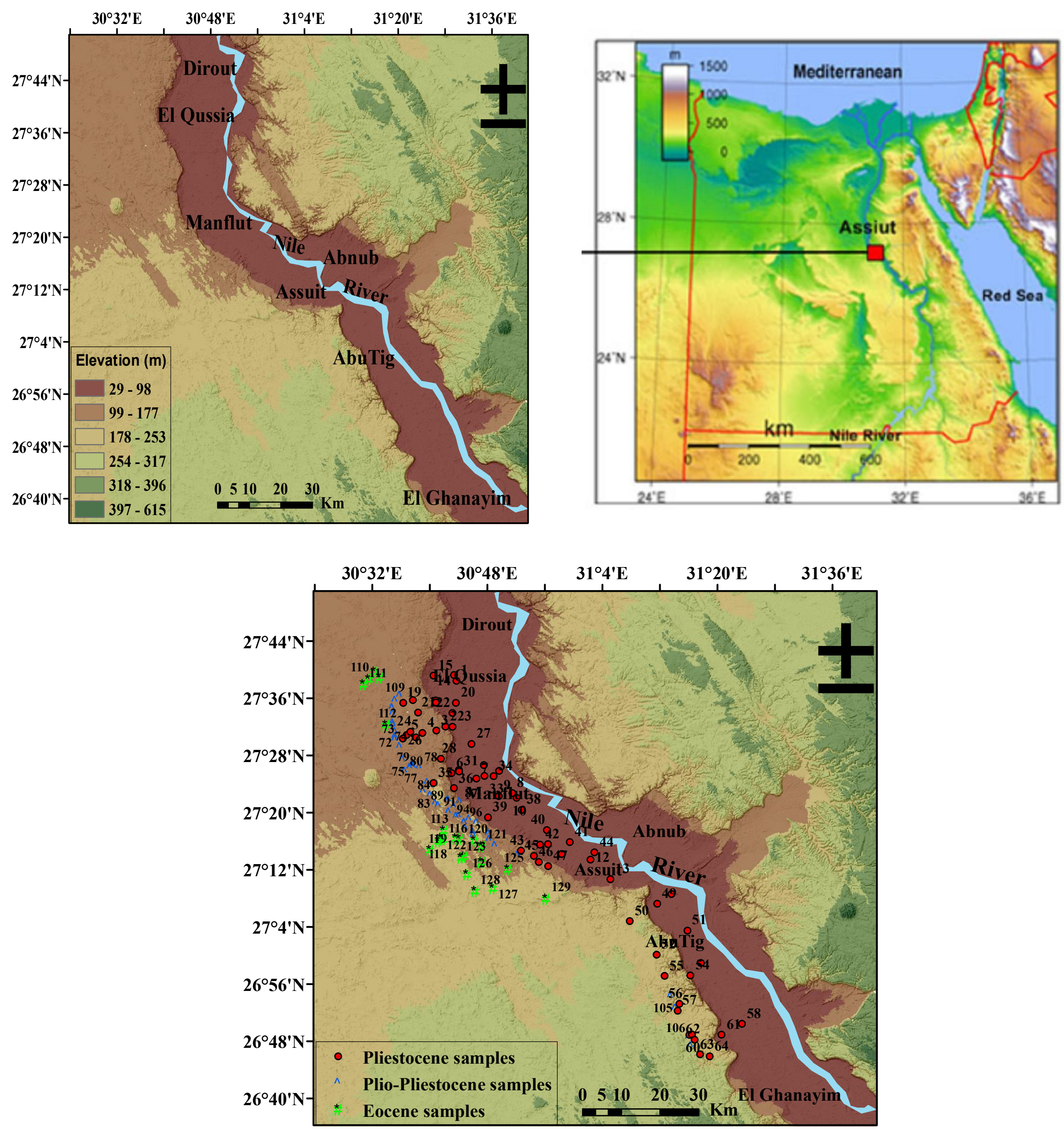


Fig1. Digital Elevation Model (DEM) and location of the collected groundwater samples of Assuit Governorate

Table 1. Mean values of climatic elements of Assuit Governorate

Month	Max. Temp. (◦C)	Min. Temp. (◦C)	Precipitation (mm/month)	Evaporation (mm/year)
Jan.	19.4	5.5	0.4	6.39
Feb.	21.6	6.5	0.18	8.52
Mar.	25.6	10.1	0.07	11.83
Apr.	31.6	14.9	0.07	16.14
May.	35.3	18.9	0.07	19.92
Jun.	37.4	21.4	0	21.84
Jul.	36.8	22.2	0	19.47
Aug.	36.3	21.9	0	17.74
Sep.	34.2	19.6	0	16.01
Oct.	31.3	16.8	0.01	12.44
Nov.	25.5	11.4	0.01	8.23
Dec.	21	7.2	0.12	5.99
Mean	29.6	14.7	0.08	13.71

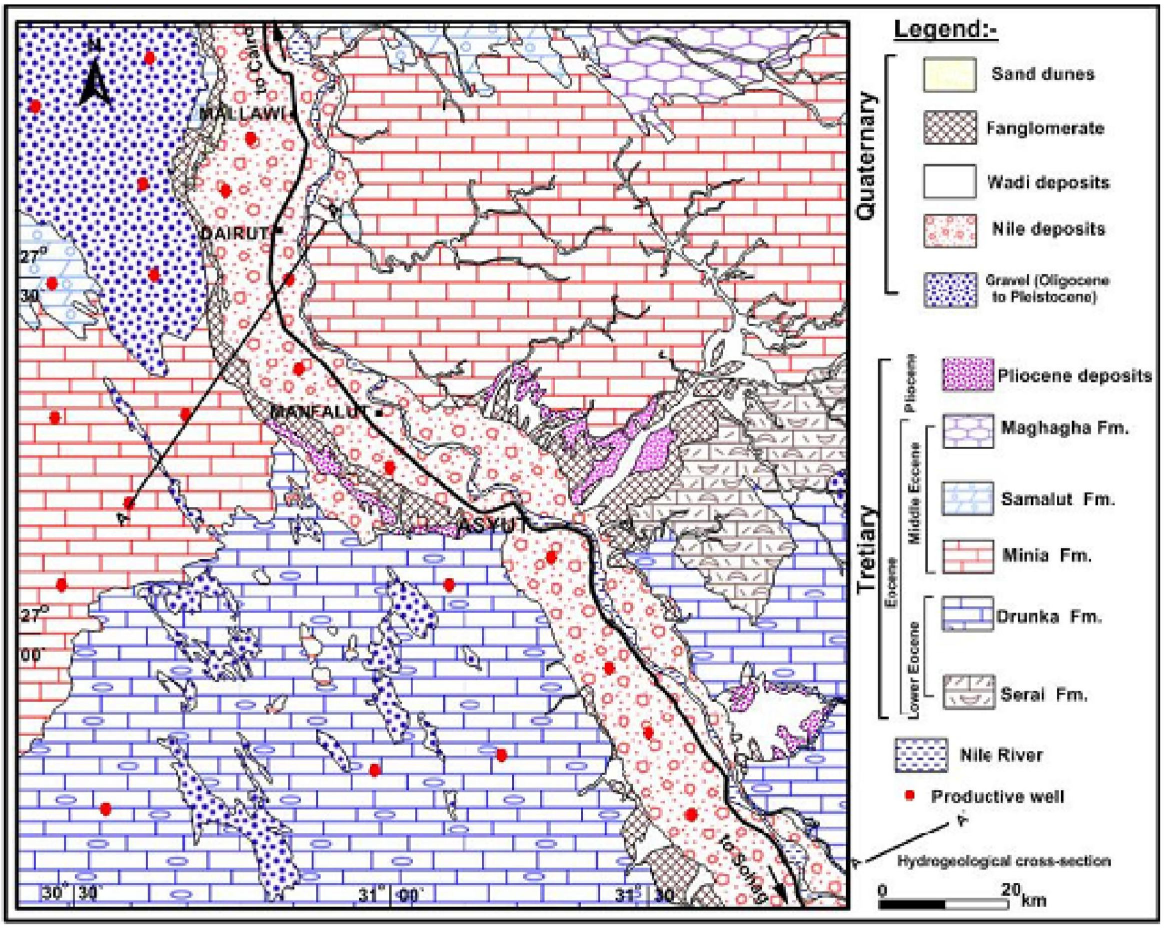


Fig 2. Geological map of the study area (modified after Conoco, 1987)

It is exposed on the surface in the northern portion of the study area and overlies the Samalut Formation. It is composed of marly limestone with chalky limestone interbeds with few clay intercalations. The rocks of the concerned formation are highly fossiliferous with Pelecypods and Gasrtopods species.

The Pliocene deposits are exposed only as small patches on the surface and consists mainly of gravel and sand. It represents a water bearing formation. Quaternary sediments are represented by gravel plains (Pleistocene) and alluvial deposits (Holocene). The Quaternary sediments represent the water bearing formation.

2.3 Hydrogeological conditions

The data collected from well logging and composite logs of drilling wells, rock samples of the new observation wells and the aquifer hydraulic parameters, chemical analyses and the hydrogeological cross section were analyzed. The results indicated that there are two main aquifer systems in the study area; the Quaternary granular aquifer system and the Eocene carbonate aquifer system as described below Fig 3.

a- Drunka Formation:

It was introduced by (El Naggar, 1970). It belongs to Lower Eocene age and composed of porous and cavernous limestones. The maximum thickness of the Drunka Formation attains 134 m (El Naggar, 1970). Its base is unexposed and underlies the Minia Formation.

b- Minia Formation:

This formation was first introduced by (Said, 1962). It directly overlies the Thebes Formation and underlies the Mokattam Formation. It occupies the majority northern portion of the study area. It composed of grayish white, bedded to massive limestone and marly limestone rich in alveolines with thin intercalations of dolomitic and sandy limestone. This formation represents the water bearing formation.

c-Samalut Formation

It occupies the northern portion of the study area. It underlies the Maghagha Formation and overlies the Minai Formation. It consists mainly of snow white to greyish white limestone crowded with Nummulite gizahensis. This formation represents the main water bearing formation in the study area.

d-Maghagha Formation

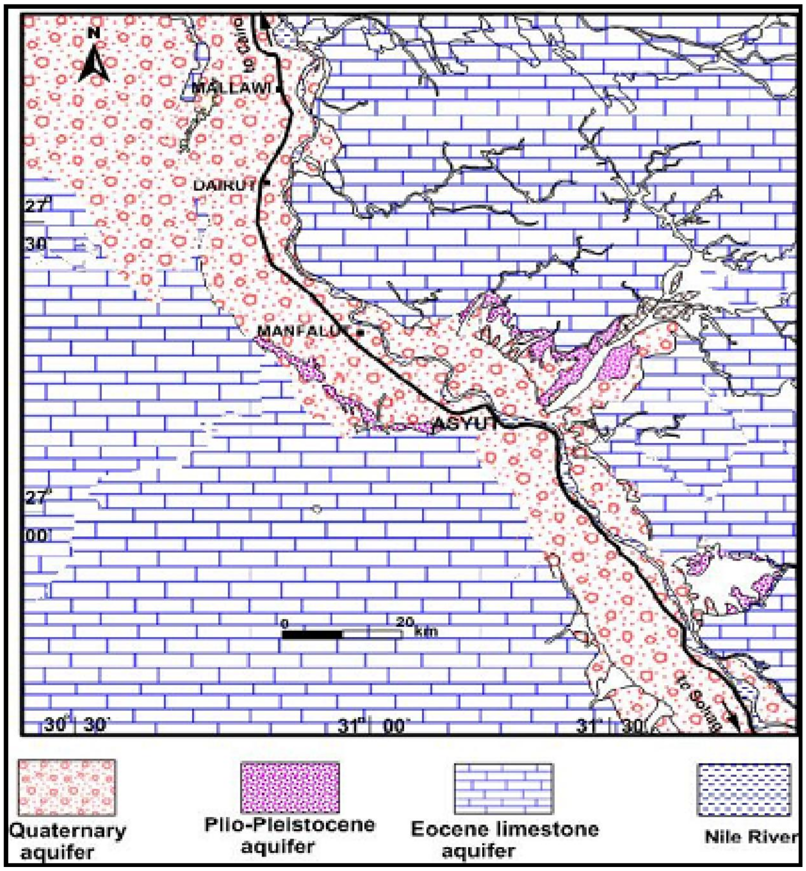


Fig 3. Areal distribution of the different aquifers in the study area

connected, where these aquifers are contacted with each other due to the fault displacement Fig 4. The depth to the Pleistocene water varies from 3 to 20m in the flood plain area of the Nile Valley. Depth to water generally increases from areas adjacent to the old cultivated lands in the Nile Valley to those adjacent to the Eocene tablelands. This coincided with the surface relief and the boundary conditions governing the groundwater flow in the area (Tamer *el al.,* 1989). The salinity of the investigated aquifer ranges from 182 ppm to 996 ppm indicating fresh water quality. Except few numbers of wells have high salinity ranging between 1350 ppm to 5657 ppm located close to the western desert fringes indicating brackish to saline water quality.

2- Plio-Pleistocene aquifer:

The Plio- Pleistocene aquifer is represented by a narrow strip at the Western Desert fringes occupying the area between the old cultivated lands and the western limestone plateau (see, Fig. 3). It is composed of fine-grained sand, silt and sandstone with thick marine dark clays of the Kom El Shelul Formation occupying the bottom of the valley (El-Sayed, 1993). The fluvial sequence of this formation contains water of good quality, while the lower marine sequence of

According to RIGW-A (1994), the Pleistocene and Plio-Pleistocene aquifers are classified as inter-granular aquifers of different potentialities, whereas the Eocene aquifer is classified as a fractured aquifer. Recently, some wells are drilled on the western plateau tapping from the Eocene aquifer.

1- The Quaternary aquifer:

It acts as an important aquifer, the groundwater exists under unconfined conditions. The Quaternary aquifer is continuously recharged by the infiltration of the return flow after irrigation as well as from the seepage of surface water in the main canals. According to the hydrogeological investigation made by the Research Institute of Ground Water (RIGW-B, 1994), the thickness of this aquifer varies from less than 30m near the edges of the Eocene plateaus to about 300 m at the central parts of the Nile valley. The transmissivity of this aquifer ranges from 66 m^2/day to 564 m^2/day. Transmissivity of the concerned aquifer is in the order of 4000 m^2/day. The high transmissivity of this aquifer is attributed to this aquifer composed of gravelly to coaser sand. The general direction of groundwater flow is northward (Mousa *el al.,* 1994, Abu El Ella 1997, Gomaa, 2003 and El Meligy, 2004). The Quaternary and Eocene aquifers are hydraulically

0.002 and 0.054 with a mean value of 0.034 (Tamer *el al.,* 1989). Furthermore, the actual amount of water stored at this aquifer is estimated to be 2.4 x 10^8 m^3 (Shaker, 1999). The total dissolved salts of the Plio-Pleistocene aquifer varies from 260 ppm to 3302 ppm.

the Kom El Shelul Formation may cause salinization of the wells tapping it. The thickness of this aquifer ranges between few meters close to limestone plateau to more than 80 m near the flood plain. The transmissivity of this aquifer varies from 400 to 1600 m^2/day and the storage coefficient (S) ranges between

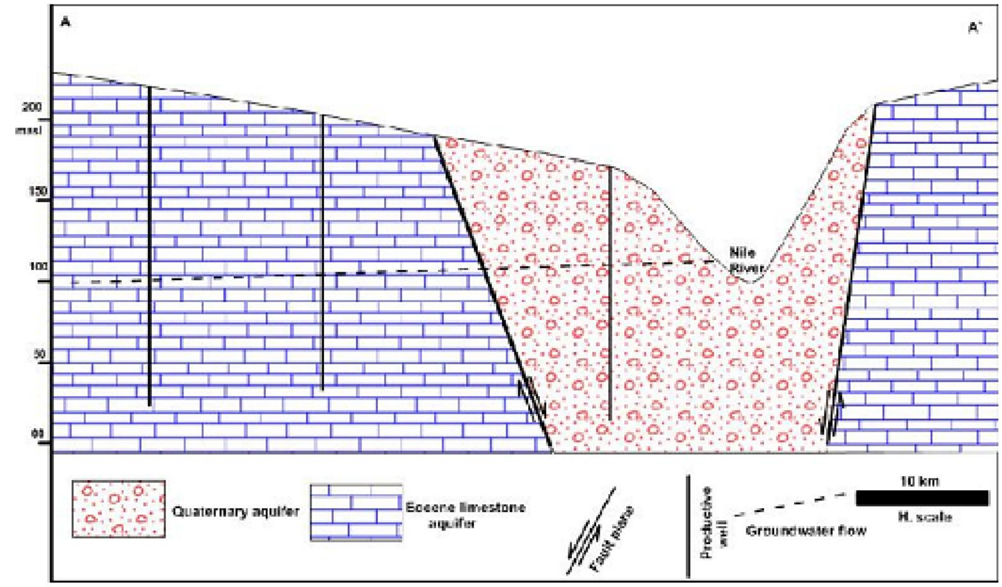


Fig 4. Hydrogeological cross-section in the study area

Eocene, the Palio-Pleistocene and the Pleistocene aquifer, respectively.

3.2 Description of the DRASTIC Vulnerability Assessment

In this work, DRASTIC model was selected based on the following considerations. DRASTIC uses a relatively large number of parameters (seven parameters) to calculate the vulnerability index, which ensures the best representation of the hydrogeological setting. The numerical ratings and weights are well defined and are used worldwide. This makes the model suitable for producing comparable regional-scale maps of aquifer vulnerability, so that appropriate land-based management actions and policies can be developed to minimize future contamination. This model employs a numerical ranking system that assigns relative weights to various parameters that help in the evaluation of relative groundwater vulnerability to contamination. The DRASTIC seven parameters referring to the components required by the system and making up the acronym can be summarized in Table 2.

Each DRASTIC parameter is subsequently classified into ranges (for continuous variables) or into significant media types (for thematic data) which have an impact on pollution potential Tables 3 and 4. A rating protocol was developed for each parameter in a scale of 1 to 10, based on their relative effect on the

3- Eocene aquifer:

The Eocene limestone aquifer is composed of fractured carbonate rocks of Samalut, Minia and Drunka Formations. While the Samalut aquifer represents the main aquifer due to this aquifer is highly fractured and voids. This aquifer underlies both the Quaternary and Plio-Pleistocene aquifer and overlies the Nubia sandstone (Pre-Cenomanian) aquifer. The transmissivity of Eocene limestone aquifer varies from 18.3 m^2/day to 1758 m^2/day. The great variation is attributed to the difference in fracture intensity in the Eocene limestone aquifer. The groundwater salinity of this aquifer ranges between 229 ppm to 907 ppm indicating fresh water quality.

3. Methodology

3.1 water samples:

The present work depends on the chemical analysis results of 129 groundwater samples that were collected from the study area (Ibrahim, 2013) and analyzed according to (ASTM, 2002). These analyses included the concentration measurements of major, minor and trace elements to study water quality and assess the water pollution. The collected samples represented the three aquifers in the study area as 22, 43 and 64 groundwater samples tapped from the second is for the agricultural chemicals. Agricultural DRASTIC was specifically designed to address the important processes offsetting the fate and transport of agricultural chemicals in the soil. Assigned weights for the generic case indicate that depth to groundwater, the impact of vadose-zone media and net recharge are the most influential factors in the groundwater contamination process. This is also true for the agricultural set in addition to the soil media, which is considered to play more active role in the transmission of agricultural chemicals to the groundwater.

aquifer vulnerability, and assigns higher ratings to situations deemed to have higher pollution potential. This rating is scaled by DRASTIC weighting factors ranging between 1 (least significant) and 5 (most significant) reflecting their relative importance assigned to the parameters. Two sets of weights were proposed by the DRASTIC founding group; the difference between the two indexes is in the assignment of relative weights for the seven DRASTIC factors. For each parameter there are two weights. The first is for the application of DRASTIC to generic municipal and industrial pollutants, whereas the

Table 2. The DRASTIC model parameters

Factor	Description	Generic weight	Agricultural weight
Depth to water	Represents the depth from the ground surface to the water table, deeper water table levels imply lesser chance for contamination to occur.	5	5
Net Recharge	Represents the amount of water that penetrates the ground surface and reaches the water table, recharge water represents the vehicle for transporting pollutants	4	4
Aquifer media	Refers to the saturated zone material properties. It controls the pollutant attenuation processes.	3	3
Soil media	Represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward.	2	5
Topography	Refers to the slope of the land surface, it dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone.	1	3
Impact of vadose zone	Is defined as the unsaturated zone material, it controls the passage and attenuation of the contaminated material to the saturated zone.	5	4
Hydraulic Conductivity	Indicates the ability of the aquifer to transmit water, hence determines the rate of flow of contaminated material within the groundwater system.	3	2

Table 3. DRASTIC standard ranges and rating for DRASTIC factors that can be measured directly

Depth to water (D)		**Recharge (R)**		**Topography (T)**		**Hydraulic Conductivity (C)**	
Range (m)	Rating	Range (mm)	Rating	Range (%)	Rating	Range (m/d)	Rating
0-1.5	10	0-51	1	0-2	10	0-4.1	1
1.5- 4.6	9	51-102	3	2-6	9	4.1-12.2	2
4.6-9.1	7	102-178	6	6-12	5	12.2-28.5	4
9.1-15.2	5	178-254	8	12-18	3	28.5-40.7	6
15.2-22.5	3	>254	9	>18	1	40.7-81.5	8
22.5-30	2					>81.5	10
>30	1						

Table 4. DRASTIC standard rating value that cannot be measured directly

Aquifer media (A)		Soil type (S)		Impact of Vados Zone (I)	
Range	Rating	Range	Rating	Range	Rating
Massive shale	2	Thin or absent	10	Confining layer	1
Metamorphic/Igneous	3	Gravel	10	Silt/Clay	3
Weathered Metamorphic/Igneous	4	Sand	9	Shale	3
Glacial Till	5	Peat	8	Metamorphic/Igneous	4
Bedded Sandstone, Limestone and shale	6	Shrinking and/or Aggregated clay	7	Limestone	6
Massive Sandstone	6	Sandy loam	6	Sandstone	6
Massive Limestone	6	Loam	5	Bedded limestone, Sandstone, Shale	6
Sand and Gravel	8	Silty loam	4	Sand and Gravel with significant Silt and Clay	6
Basalt	9	Clay Loam	3	Sand and Gravel	8
Karst Limestone	10	Muck	2	Basalt	9
		Non-shrinking/ Non-aggregated clay	1	Karst Limestone	10

respectively, and can be used to rank a site's vulnerability to groundwater contamination. The resulting DRASTIC index represents a relative measure of groundwater vulnerability. The higher the DRASTIC index number, the higher is the susceptibility for groundwater pollution. A site with a low DRASTIC index is not free from groundwater contamination, but it is less susceptible to contamination compared with the sites with high DRASTIC indices.

4. Results and discussions

Physical and chemical parameters for the collected water samples of the three study area aquifers including statistical measures, such as Min, Max., and the average of EC, pH, TDS, cations, anions and some of different pollutants such as SiO_2, NO_3, Fe, Mn and Zn are reported as shown in Table 5.

The model yields a numerical index that is derived from the ratings and weights assigned to the seven model parameters. The DRASTIC Index (DI) is then computed applying a linear combination of all parameters according to the following equation:

$DI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$ (1)

Where D, R, A, S, T, I and C represent the seven hydrogeological parameters and the subscripts r and w designates the rating value (1-10) and the weight value for a given parameter, respectively.

The DRASTIC system allows the user to show areas more likely to be susceptible to groundwater contamination relative to others and offers a cost-effective screening process to set priorities for groundwater protection and monitoring efforts. The DRASTIC index score is relative, with no specific units. DRASTIC index values can range from 26 to 226 and 29 to 256 for the generic and agricultural sets,

Table 5. Physical and chemical parameters for the collected samples of the study area

Aquifer	Pleistocene			Plio- Pleistocene			Eocene			Study area		
Factor	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
EC	334.	9330	1237	265	5880	1939	265	5880	1939	265	9330	1377.3
pH	7.58	8.62	8.05	7.11	8.61	7.88	7.11	8.61	7.88	7.11	8.62	7.98
TDS	182.	5657	693.6	260.8	8205	1423.3	260.	8205.8	1423.3	182.3	8205	871.2
Ca	3.66	193.	43.26	11.04	294.	96.38	11.0	294.4	96.38	3.66	294	59.07
Mg	8.94	290.	43.26	8.94	310.	72.28	8.94	310.7	72.28	4.47	310	48.58
Na	24.6	1439	145	12.24	2448	301.37	12.2	2448.3	301.37	12.24	2448	184.55
K	1.82	32.8	8.93	1.82	391	26.11	1.82	391	26.11	1.82	391	14.33
CO_3	0	81.6	20.71	0	31.6	13.06	0	31.68	13.06	0	81.6	18.58
HCO_3	99.5	639.	266	111	365.	223	111.	365.02	223	28.06	639	239.51
SO_4	7	1894	15358	10	2932	407.05	10	2932.3	407.05	7	2932	210.1
Cl	21.1	1640	145.5	35.8	2268	407.27	35.8	2268.4	407.27	15.1	2268	221.43
SiO_2	0	2.97	0.66	0.57	32.4	12.06	2.19	26.5	14	0	46.4	17.88
NO_3	0	83.9	12.03	0.31	79.9	11.23	0.06	66.29	14.78	0	83.2	11.38
Fe	0	2.97	0.66	0.01	4.37	0.566	0.04	6.612	0.877	0	6.61	0.632
Mn	.004	1.36	0.451	0.006	1.08	0.3698	.005	0.437	0.107	0.0044	1.36	0.383
Zn	0	4.51	0.393	0.003	4.51	0.3722	.001	0.3783	0.12	0	4.51	0.308

weight (wi) based on their perceived effects on primary health. The maximum weight is 5. It has been assigned to both TDS and nitrate due to their major importance and impact on water quality assessment. On the other hand, the Potassium is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment.

- *Step two*: calculation of the relative weight (Wi) of each parameter using the following equation:
- *Step three*: quality rating scale (qi) was calculated for each parameter using the following equations.

(1)

$$Wi = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

$$qi = \frac{C_i}{S_i} \times 100$$

The WHO standard for each parameter and its weight (wi) as well as its relative weight (Wi) were shown in Table 6.

It is obvious that, there are some groundwater samples were polluted with nitrate, iron and manganese. Also, there is a trend of decreasing in both nitrate and manganese concentrations from East to West, i.e., the degree of pollution, decrease as we get far from the old cultivated lands (from Pleistocene aquifer to Eocene aquifer) and vice versa of iron. Since the old cultivated lands around the Nile are intensively irrigated, higher concentration of nitrate in groundwater can be resulted from the agricultural activities and fertilizer applications. This means that the Eocene aquifer is the least polluted aquifer in the study area. So, it is very important to study the water quality and evaluate the groundwater for drinking and irrigation purposes.

4.1 Water Quality Index (WQI)

Water Quality Index (WQI) is considered as an important tool that used to determine the suitability of the groundwater for drinking purposes. WQI is a very useful for communicating the information on the overall quality of water. The WHO standards for drinking purposes have been considered for calculation of WQI. To estimate the water quality index, there are three steps that can be shown as follows:

- *Step one*: assigning the 10 parameters (pH, TDS, Ca, Mg, Na, K, HCO_3, Cl, SO_4 and NO_3) as a

Table 6. WHO standards, weight and relative weight of each parameter that effect on water quality index

Parameter	WHO (2011) standard	weight (wi)	Relative weight (Wi)
PH	8.5	3	0.103
TDS	1000 ppm	5	0.172
Ca	75 ppm	2	0.068
Mg	100 ppm	2	0.068
Na	250 ppm	3	0.103
K	12 ppm	1	0.034
HCO_3	500 ppm	2	0.068
Cl	250 ppm	3	0.103
SO_4	250 ppm	3	0.103
NO_3	45	5	0.172
		$\sum$(wi)= 29	$\sum$Wi= 0.994

The calculated WQI values are usually classified into five categories: Excellent, good, poor, very poor and unfit for human consumption, as shown in Table 7.

Table 7. Water classification according to WQI values

WQI Range	Types of water
<50	Excellent water
50- 100	Good water
100.1-200	Poor water
200.1-300	Very poor water
>300	Unfit for drinking

By calculation the WQI of the collected samples for the three aquifers in the study area, the classification of samples of each aquifer, according to WQI range can be presented in Table 8.

Table 8. classification of the collected groundwater samples in the study area.

Aquifer	Total No.	Excellent		Good		Poor		Very poor		Unfit	
		No.	(%)	No.	(%)	No.	(%)	No.	(%)	No.	(%)
Pleistocene	64	44	68.75	15	23.43	2	3.125	2	3.12	1	1.56
Plio-Pleistocene	43	12	27.90	14	32.55	12	27.90	4	9.30	1	2.32
Eocene	22	16	72.72	6	27.27	0	0	0	0	0	0
Study area	129	72	55.81	35	27.13	14	10.85	6	4.65	2	1.55

(WQI) calculations for groundwater samples reveal that 69%, 28% and 73% are excellent for human consumption for Pleistocene, Plio-Pleistocene and Eocene aquifers respectively. While, about 9% of the samples are very poor for human consumption in the Plio-Pleistocene aquifer in comparing to Pleistocene and Eocene aquifers. Also, the evaluation of the groundwater quality of the irrigation suitability was studied using the five parameters; EC, Na%, MR, TH, RSC, SAR, Table 9.

Table 9. Classification of groundwater quality based on suitability for irrigation.

Parameter	Range	Classes	Pleistocene		Plio-Pleistocene		Eocene		Area	
			No.	(%)	No.	(%)	No.	(%)	No.	(%)
EC	<250	Excellent	0	0	0	0	0	0	0	0
	250-750	Good	34	53.12	11	25.58	9	40.90	54	41.86
	750-2000	Permissible	24	37.5	18	41.86	13	59.09	55	42.63
	2000-3000	Doubtful	2	3.12	3	6.97	0	0	5	3.87
	>3000	Unsuitable	4	6.25	11	25.58	0	0	15	11.62
Na% (Wilcox, 1955)	<20	Excellent	0	0	1	2.32	0	0	1	0.77
	20-40	Good	23	35.93	7	16.27	3	13.63	33	25.58
	40-60	Permissible	35	54.68	26	60.46	7	31.81	68	52.71
	60-80	Doubtful	6	9.37	8	18.60	12	54.54	26	20.15
	>80	Unsuitable	0	0	1	2.32	0	0	1	0.77
MR (Paliwal, 1972)	<50	Suitable	17	26.56	10	23.25	5	22.72	32	24.80
	>50	Unsuitable	47	73.43	33	76.74	17	77.27	97	75.19
TH (Todd, 1980)	<75	Soft	0	0	1	2.32	1	4.54	2	1.55
	75-150	Moderately	13	20.31	9	20.93	9	40.90	31	24.03
	150-300	Hard	41	64.06	10	23.25	12	54.54	63	48.83
	>300	Very Hard	10	15.62	23	53.48	0	0	33	25.58
RSC (Ragunath, 1987)	<1.25	Safe	42	65.62	34	79.06	13	59.09	89	68.99
	1.25-2.5	Marginally suitable	21	32.81	8	18.60	9	40.90	38	29.45
	>2.5	Not suitable	1	1.56	1	2.32	0	0	2	1.55
SAR (Hem, 1991)	<20	Excellent	64	100	42	97.67	22	100	128	99.22
	20-40	Good	0	0	1	2.32	0	0	1	0.77
	40-60	Permissible	0	0	0	0	0	0	0	0
	60-80	Doubtful	0	0	0	0	0	0	0	0
	>80	Unsuitable	0	0	0	0	0	0	0	0
KI (Kelly, 1940)	<1	Suitable	46	71.87	24	55.81	5	22.72	75	58.13
	>1	Unsuitable	18	28.12	19	44.18	17	77.27	54	41.86

EC; Electrical conductivity, Na%; Sodium percentage, MR; Magnesium ratio, TH; Total hardness RSC; Residual sodium carbonate, SAR; Sodium adsorption ratio, KI; Kelly's index.

For irrigation purposes about 75% of water samples are unsuitable for MR (Magnesium Ratio) indicating unfavorable effects on crop yield and an increase in soil alkalinity. Calculating Kelly's Index (KI) indicating 42% of water samples have (KI >1) shows an excess of sodium.

4.2 The DRASTIC Parameters:

4.2.1 Depth to water table (D)

Depth to the water table is a significant factor controlling the ability of pollutants to reach the aquifer. It affects the time available for contamination to undergo chemical and biological reactions such as dispersion, oxidation, natural attenuation, sorption etc. The depth to the water is defined as the distance (in meter) from the ground surface to the water table. The depth to the water table in study area was shown in Fig. 5.

The identification of all seven input parameters used in DRASTIC system, require a good knowledge of geology, Hydrogeology, soil media, topography and meteorology in the study area. The data used in this study are taken from the previous works of geological studies, hydrogeological studies, a geophysical study, climatology studies, soil study and topographic studies as well as published researches and maps. Each parameter of the DRASTIC method is explained in the following.

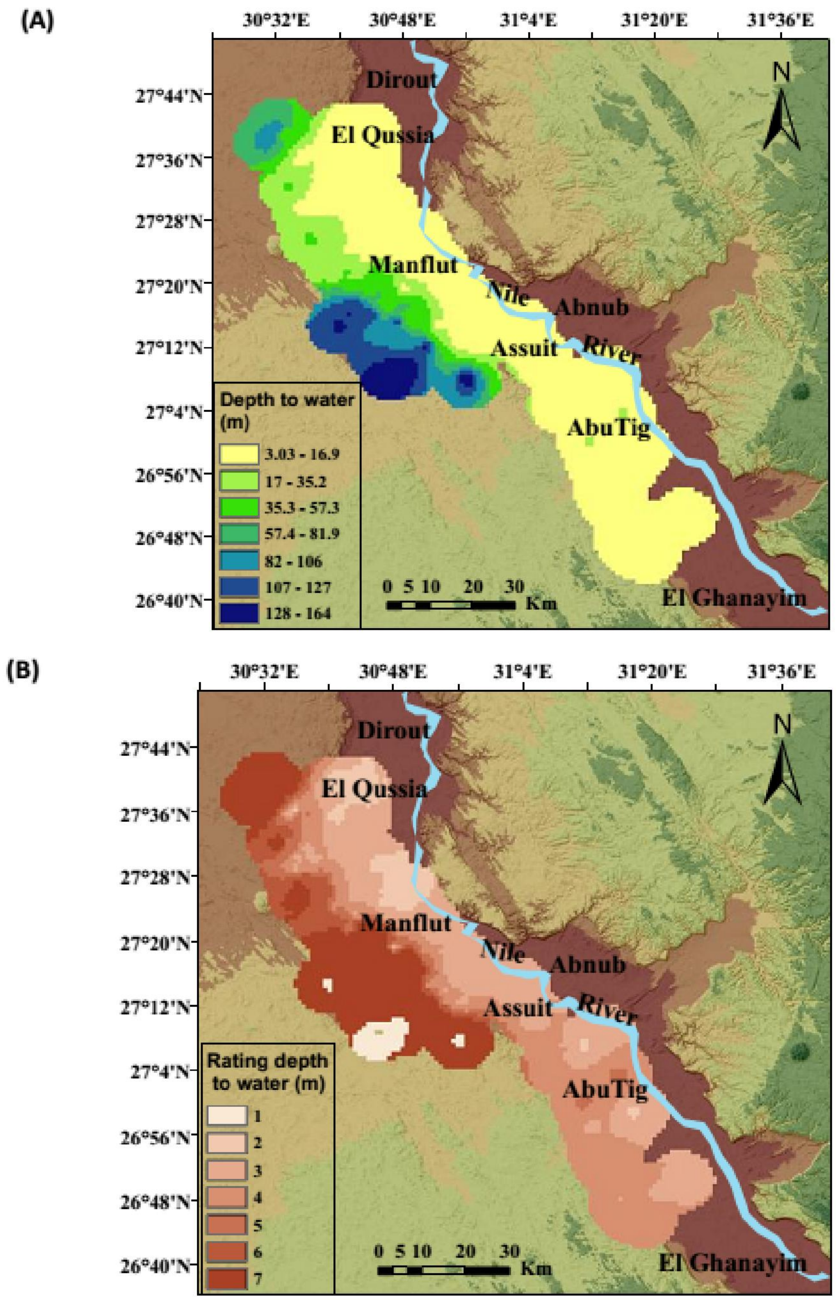


Fig 5. (A): Spatial distribution of depth to water (m) in Assuit governorate.
(B): Spatial distribution of depth to water generated by reclassification tool.

dispersion of the contaminants in the vadose and saturated zones. In general, the greater the recharge, the greater is the chance for pollutants to reach the water table.

The recharge of the aquifers can be classified according to each aquifer Fig 6. which exits in the Assuit governorate as follows.

The Quaternary aquifer is principally recharged from different sources and through different processes such as the seepage from surface water, i.e., Nile River and irrigation canals as well as the infiltration of return flow after irrigation. The Plio- Pleistocene and Eocene limestone aquifers recharges from the seepage from the Quaternary aquifer and the vertical upward leakage from the deep Nubia sandstone aquifer system through the deep seated faults and fractures. Other sources of recharge to this aquifer are available by the occasional rainfall and the possible upward leakage from the older aquifers especially the deeper Nubian sandstone aquifer where groundwater is subjected to artesian conditions and hence flow upwards through the deep-seated faults.

4.2.3 Aquifer media (A)

Aquifer media describe consolidated and unconsolidated rock where water is contained. This will include the pore spaces and fractures of the media where water is held. Aquifer medium governs the route and groundwater flow within the aquifer, Fig 7.

The depth to the water of the Quaternary aquifer varies from 3 to 20 m in the flood plain area of the Nile Valley. It generally increases from areas adjacent to the old cultivated lands in the Nile Valley to those adjacent to the Eocene tablelands.

The depth to the water of the Plio-Pleistocene aquifer ranges from 13 to 65 m. It increases from wells close to the Nile Valley towards the Eocene plateau scarp due to the high topography of the ground surface in this direction.

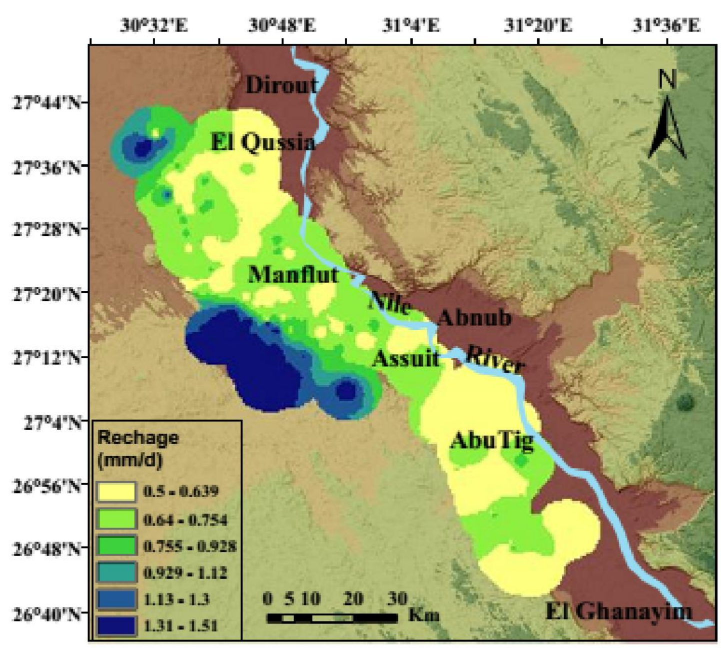
The depth to the water of the Eocene Limestone aquifer ranges from 92 to 150 m below the land surface. It increases from the east to the west following the same trends in the previous two aquifers.

The risk of contamination increases with a shallower depth, while groundwater with deeper water tables has a lesser chance of contamination because deeper water levels imply longer travel times.

4.2.2 Net Recharge (R)

Net recharge is a very important factor for assessment of aquifer vulnerability since pollutants can move further in groundwater with the increasing mobility of the water. Net recharge represents the amount of water that penetrates the ground surface and reaches the water table, on an annual basis, through different flow paths. This recharge water is available to transport a contaminant vertically to the water table and horizontally within the aquifer. In addition, it controls the volume of water available for dilution and

(A)



(B)

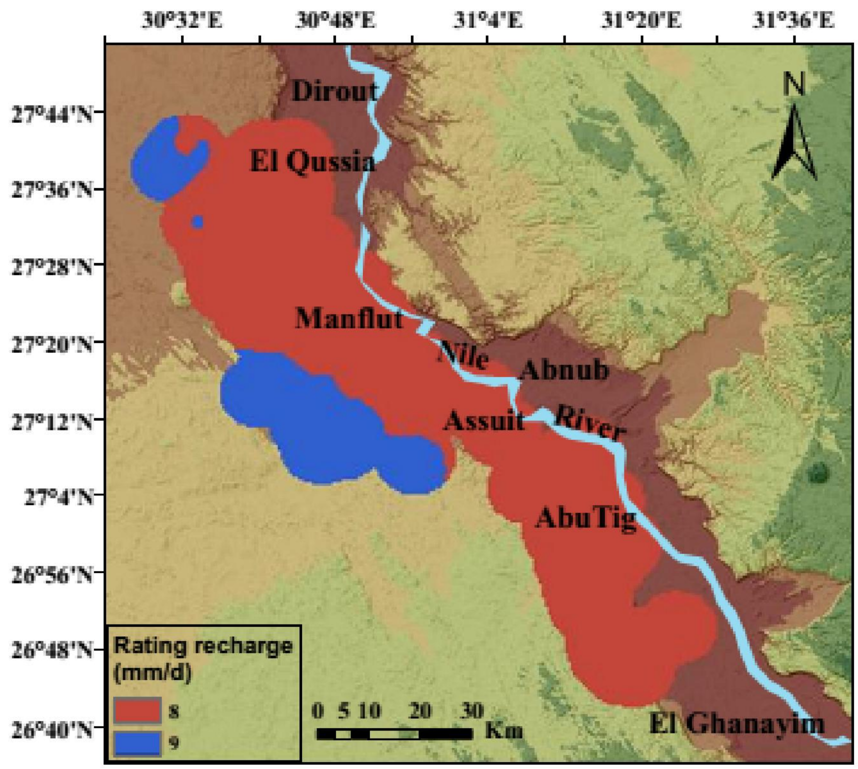


Fig 6. (A): Spatial distribution of recharge (mm/day) in Assuit governorate.
(B): Spatial distribution of recharge by reclassification tool.

decrease relative to soil permeability and restrict contaminant migration. The thickness of soils determines the length of time contaminants reside within the media; as the soil zone is thick, the attenuation processes of filtration, biodegradation, sorption, and volatilization may be significant. In general, the soil of the study area is formed from the Holocene deposits that are made up of Nile silt and clay and form the top layer of the floodplain old cultivated land. They vary in thickness from one place to another and become thinner towards the Nile Valley edges where these deposits lie unconformable over the eroded surface of Pleistocene sediments. The Holocene sediments are characterized by a high infiltration capacity, and reflect a great return flow of water downward after irrigation to replenish the underlying Pleistocene aquifer. Fig 8. shows that soil media can be reclassified into six classes. The desert land has been assigned with 4 rating because annually rate of rain is very low that it doesn't affect the groundwater in these regions.

The aquifer media were identified by the available geological map and lithological units of the basin, benefiting from previous investigations, The main water bearing formation of Quaternary aquifer is composed of fluvial graded sand and gravel intercalated with clay lenses. While the Plio-Pleistocene aquifer is dominated by fine-grained sand, silt and sandstone with thick marine dark clays occupying the bottom of the valley (El-Sayed, 1993). On the other hand, the Eocene aquifer is composed of fractured limestone. Following the US EPA recommendation, (see Table 3), In GIS the three aquifers (Quaternary, Plio-Pleistocene, Eocene) have been assigned a value of 8, 6-8, 6, respectively.

4.2.4 Soil media (S)

Soil media are the portion of the unsaturated zone characterized by significant biological activity. The characteristics of the soil have a significant impact on the amount of recharge which can infiltrate to the water table, the amount of pollutant transfer and the purifying process of contaminants. The presence of fine-textured materials, such as silts and clays, can

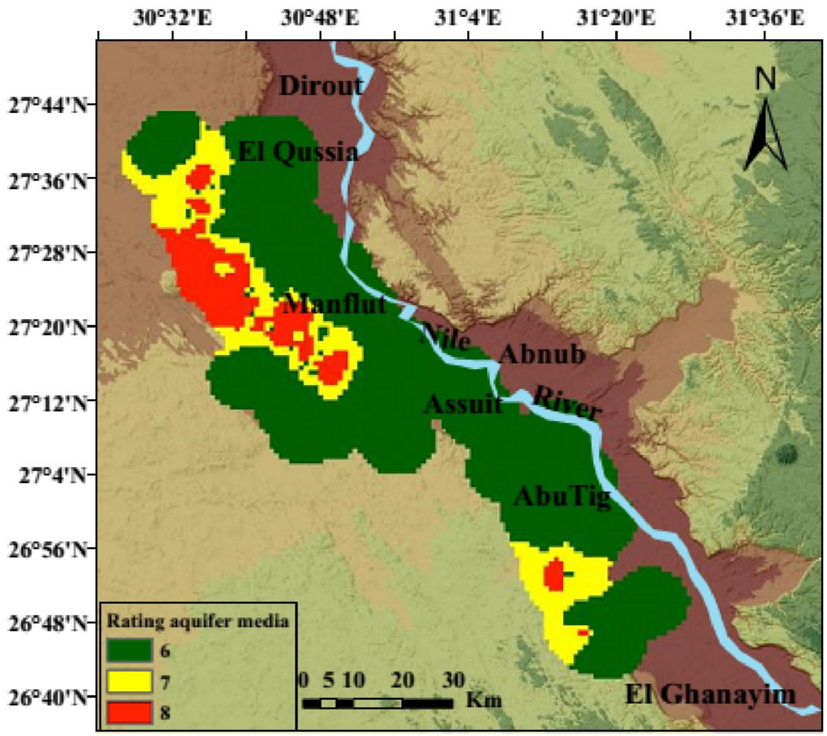
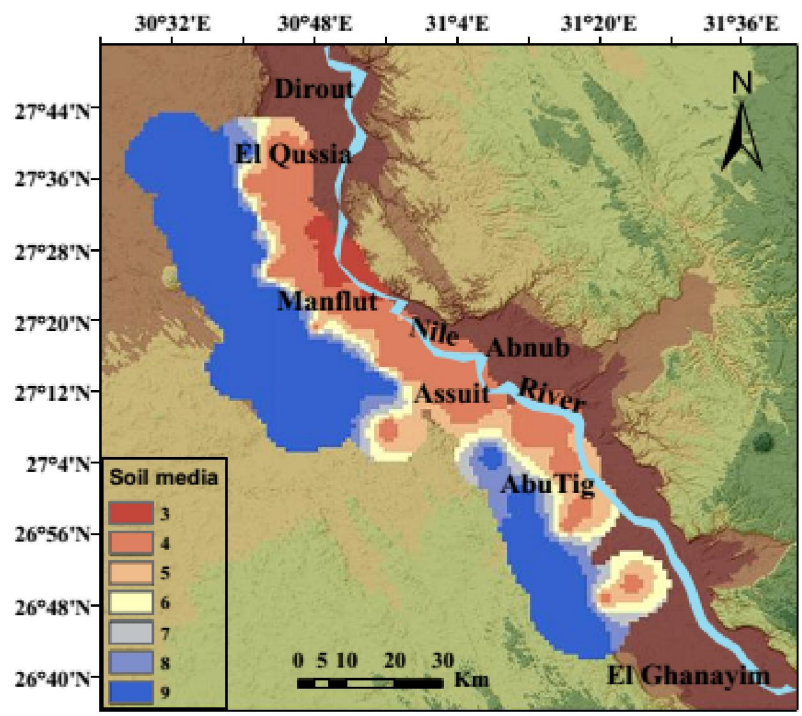


Fig7. Spatial distribution of aquifer media map of Assuit Governorate

(A)



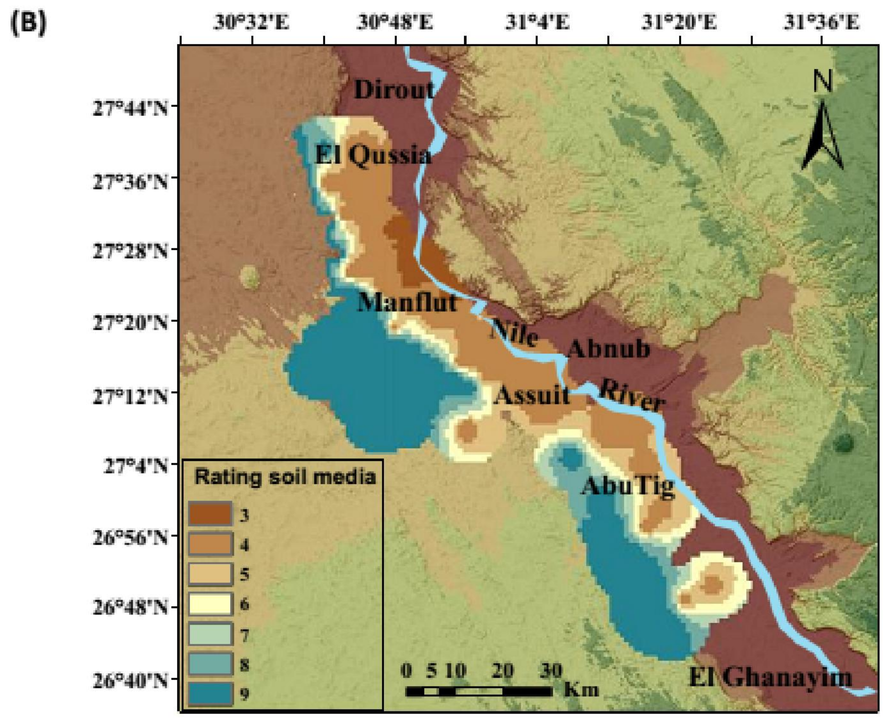
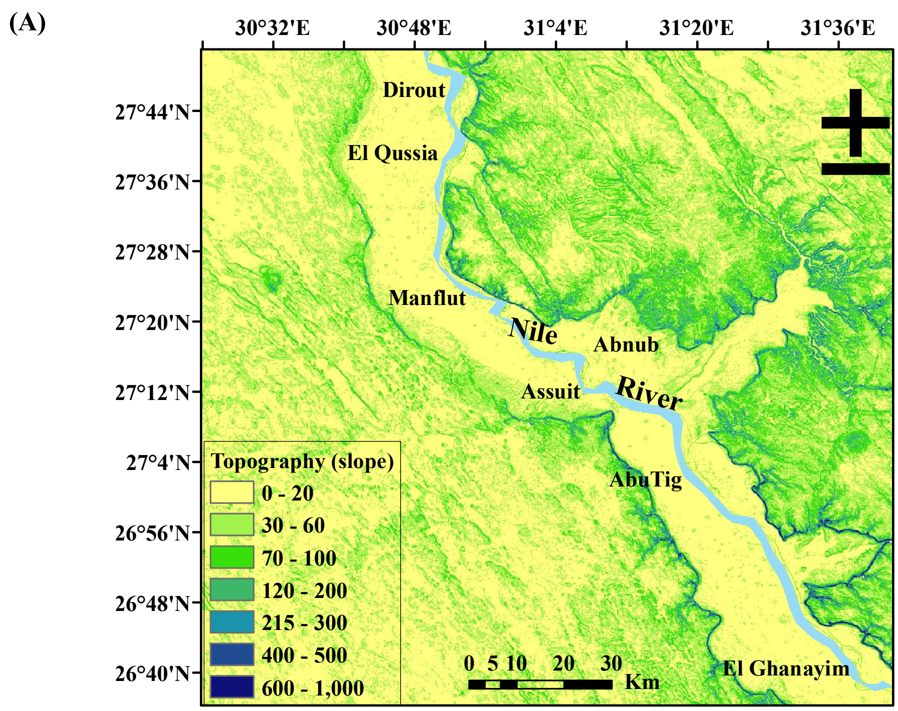


Fig. (8) (A): Spatial distribution of Soil media in Assuit Governorate B): Spatial distribution of soil media generated by reclassification tool.



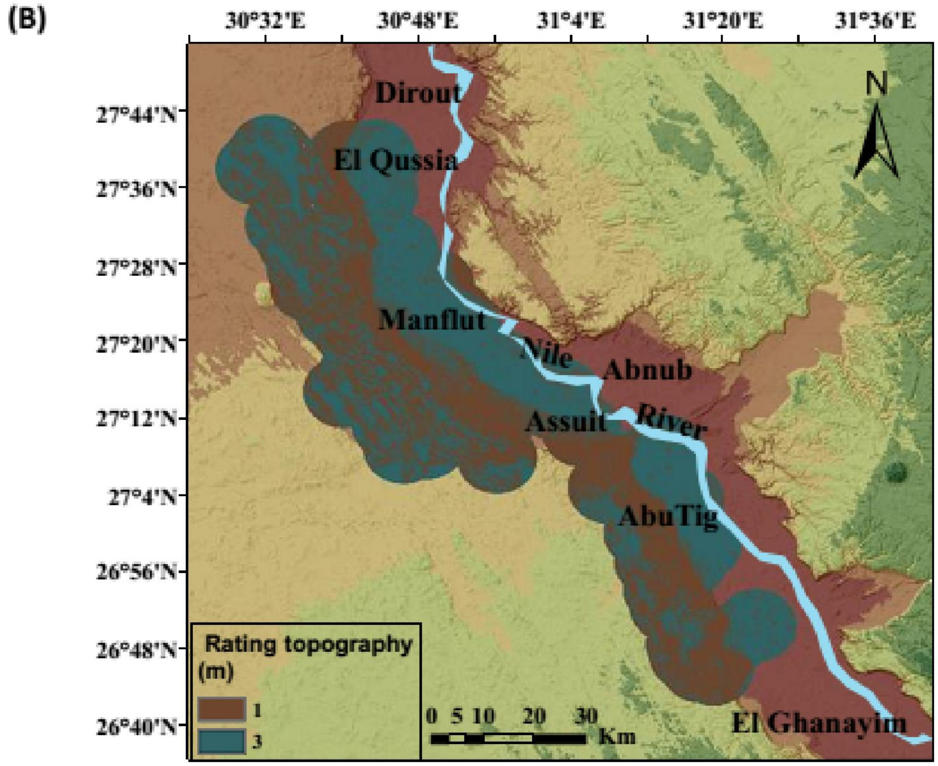


Fig 9. (A): Spatial distribution of Topography (slope) in Assuit Governorate (B): Spatial distribution of Topography (slope) generated by reclassification tool.

rating accordingly, the cell which is a very flat slope was assigned 10 rating, whereas, the cell has very steep slope was assigned rating 1.

4.2.6 Impact of Vadose Zone (I)

The vadose zone refers to the unsaturated or discontinuously saturated zone above the water table, which controls the passage and attenuation of the contaminated material to the aquifer. Many processes that influence the pollution potential of the aquifer system take place in the vadose zone.

The character of this zone determines attenuation characteristics of the media above the water table. Moreover, this zone controls the path of contaminant particles in the aquifer system. The clay-rich textures are impermeable and allow fewer contaminants to infiltrate, and thus receive a lower rating, while sands and gravels are very permeable and allow more contaminants to enter the groundwater system. Sand and gravel with significant silt and clay are the main components of Vadose zone in the area of study, Fig. 10. According to vulnerability properties, the impact of the vadose zone is ranked at 1–10 standard scale and has been assigned a value of 6 Table 3.

4.2.5 Topography (T)

In DRASTIC system, topography is expressed in the form of slope variability of the land surface and is expressed as percent slope. This factor affects the flow rate at the surface, and consequently affects biodegradation and attenuation. The degree of slope will determine the extent of runoff of the pollutant and settling long enough to infiltrate. Slopes that provide a greater opportunity for contaminants to infiltrate will be associated with higher groundwater pollution potential. Runoff from agricultural crops will be channeled from a higher elevation to a lower elevation, making lower slopes more vulnerable to contamination. The digital elevation model (DEM) was used to extract the slope of the study area from the topographic map. In general, the ground elevation in Assuit Governorate ranges from 29 to 615 m above mean sea level (amsl) from south to north, respectively. It varies from 56 m at the southern part (the edge with Sohag Governorate) to 44 m in the north (the edge with El- Minia Governorate). The reclassification of slope as a percent of the land surface was illustrated in Fig 9. The higher the slope the lower

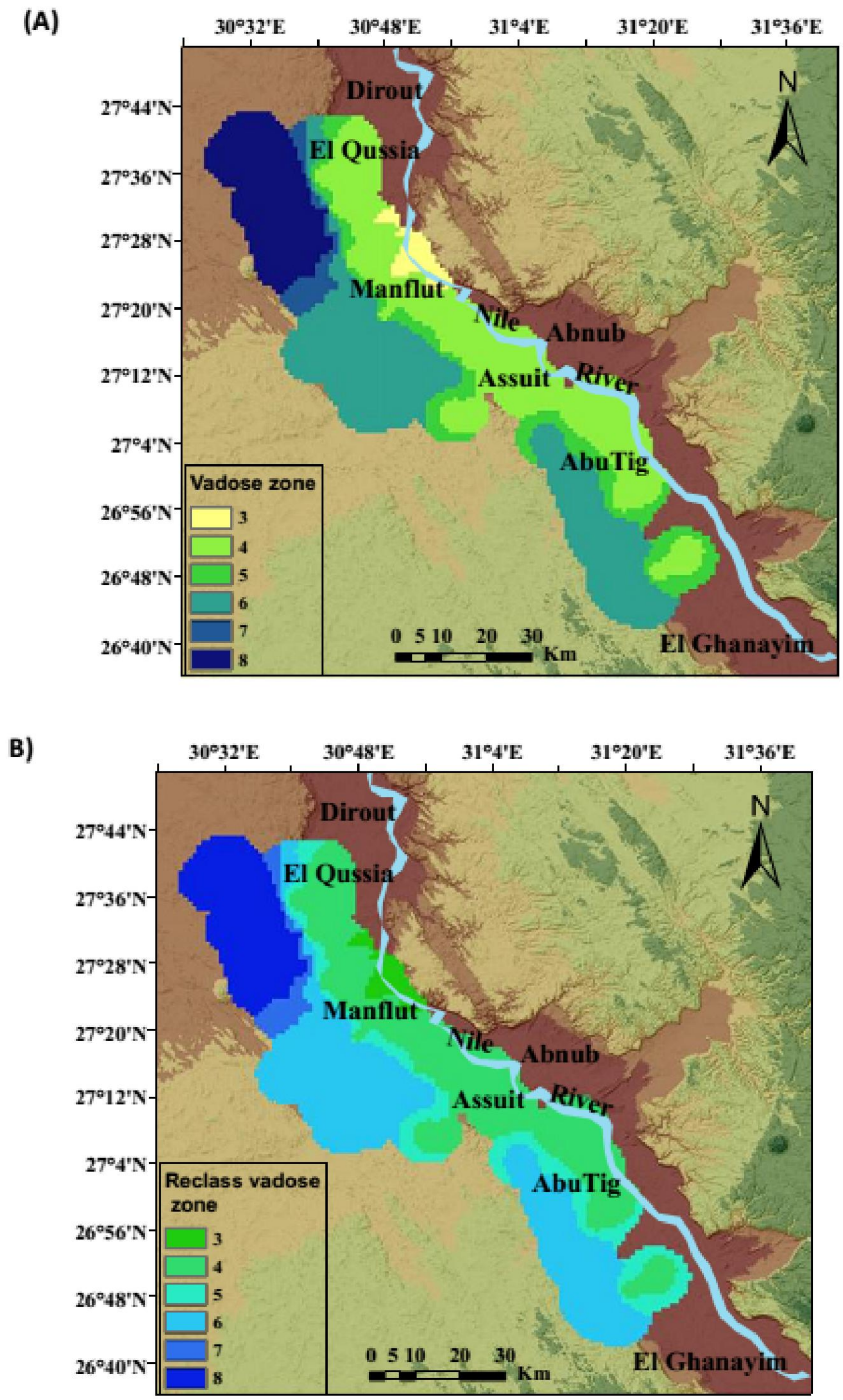


Fig 10. (A): Spatial distribution of Vadose zone in Assuit Governorate
(B): Spatial distribution of Vadose zone generated by reclassification tool.

hydraulic conductivity the further contaminants will travel and potentially contaminate greater volume of groundwater.

The hydraulic conductivity of the Quaternary aquifer varies from 20 to 70 m/day in the lower sandy gravel part, whereas it ranges from 0.04 to 1 m/day in

4.2.7 Hydraulic Conductivity (C)

Hydraulic conductivity is defined as the ability of aquifer materials to transmit water, which in turn, controls the degree and fate of the contaminants. It depends on the intrinsic permeability of the material and on the degree of saturation. The greater the

20 m/day. This high variation is due to the fracture density. The hydraulic conductivity rating value was assigned according to DRASTIC method, Fig 11.

the upper silty layer. While, the hydraulic conductivity of the Plio-Pleistocene aquifer ranges from 5 m/day to 20 m/day. On the other hand, the hydraulic conductivity of the Eocene aquifer ranges from 0.77 to

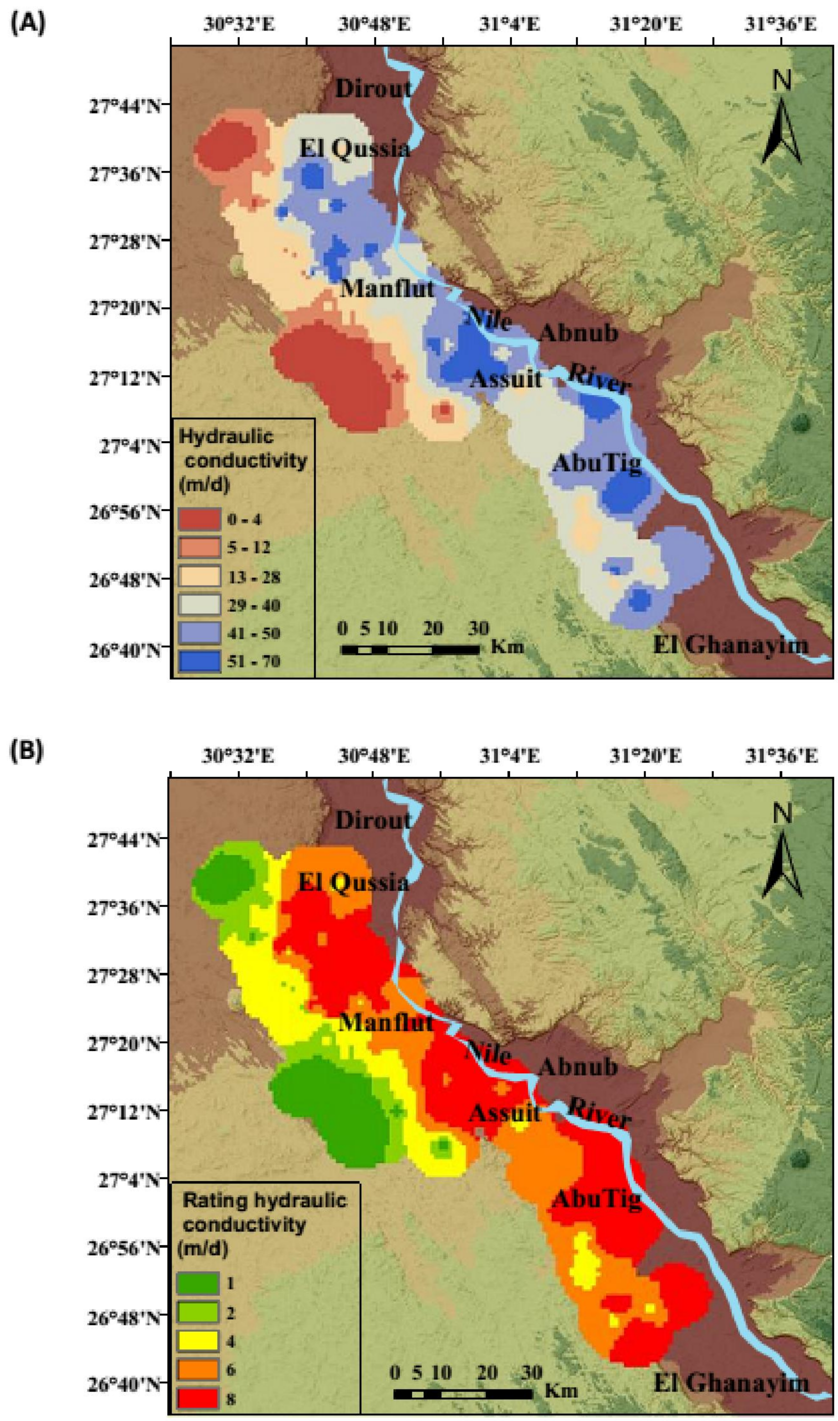


Fig 11. (A): Spatial distribution of hydraulic conductivity in Assuit Governorate
(B): Spatial distribution of hydraulic conductivity generated by reclassification tool.

130) vulnerability. Fig 12. shows that, the generic DRASTIC index varies from 91 to 160 that can be categorized into three classes according to Piscopo, 2001. It is seen that high vulnerability levels are concentrated on the south of the study area, including Abo-Tig, and the western side of Assuit city. As well as there are small areas in the eastern side on both east Abnoub city and Beni Muammadyat city have high vulnerability level. Also, the high vulnerable area can be seen in the northern area beginning from Dirout ending with Sanabuo village.

On the other hand, the agricultural vulnerability map of the study area, Fig 13, the agricultural DRASTIC index varies from 100 to 180 that can be categorized into four classes; low, low-moderate, moderate and high groundwater vulnerability to contamination according to (Piscopo, 2001).

4.3 The DRASTIC Aquifer Vulnerability Maps

The hydrogeological parameter units were rated according to DRASTIC specified ranges (Tables 2 and 3). The DRASTIC rating from each input parameter was multiplied by the Generic DRASTIC and Agricultural DRASTIC weight Table 10. for that parameter and summed to determine the DRASTIC index according to Eq. (1). The output of these calculations was utilized to generate Generic and Agricultural DRASTIC vulnerability maps (Figs 12, 13).

Both generic and agricultural maps incorporated the use of all important geological as well as hydrogeological parameters which govern the occurrence and movement of groundwater into the system. These maps were used to estimate the areas represented by each intrinsic vulnerability qualitative categorie typically ranging from low (< 120) to high (>

Table 10. Generic and Agricultural Vulnerability classes

Vulnerability classes			
Class	Generic DRASTIC	Class	Agricultural DRASTIC
Low	< 120	Low	<140
Moderate	120-130	Low-Moderate	140-150
High	>130	Moderate	151-160
		High	>160

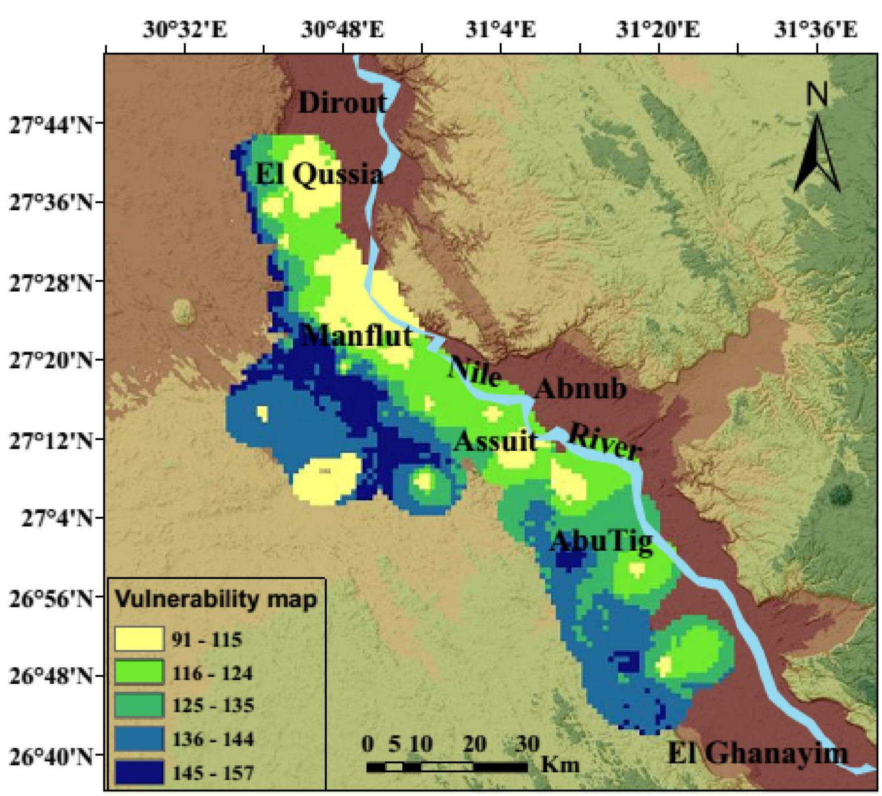


Fig12. Generic vulnerability map of the three aquifers in Assuit governorate

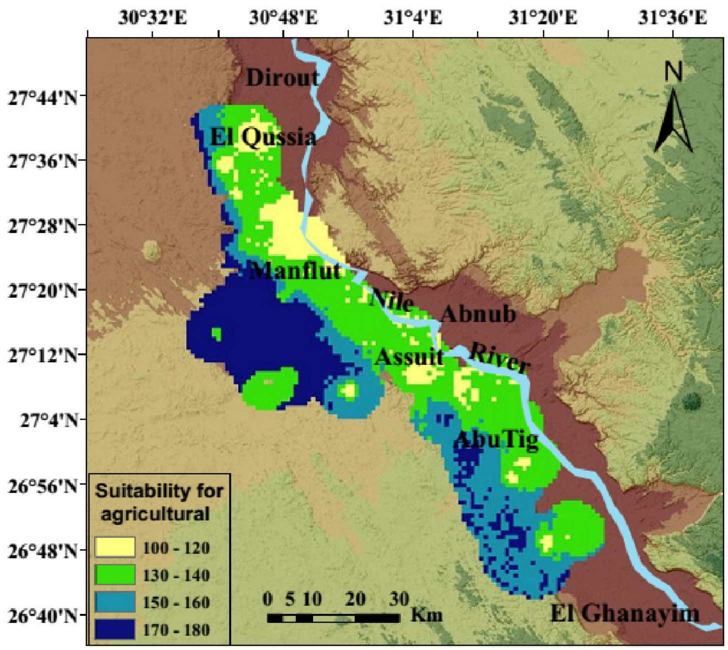


Fig13. Agricultural vulnerability map of the three aquifers in Assuit Governorate

versa of iron Fig 16. Since the old cultivated lands around the Nile are intensively irrigated, highest concentration of nitrate in groundwater reaches 83.9 ppm in Pleistocene aquifer compared with Plio-Pleistocene aquifer 79.9 ppm and Eocene aquifer 66.3 ppm can be resulted from the agricultural activities and fertilizer applications. So, it is very important to study the water quality and evaluate the groundwater for drinking and irrigation purposes.

4.4 Groundwater vulnerability implemented by Nitrate, Iron, Manganese

It is obvious that, there are some groundwater samples were polluted with nitrate, iron and manganese. Also, there is a trend of decreasing in both nitrate Fig.14 and manganese concentrations Fig.15 from East to West, i.e., the degree of pollution, decrease as we get far from the old cultivated lands (from Pleistocene aquifer to Eocene aquifer) and vice

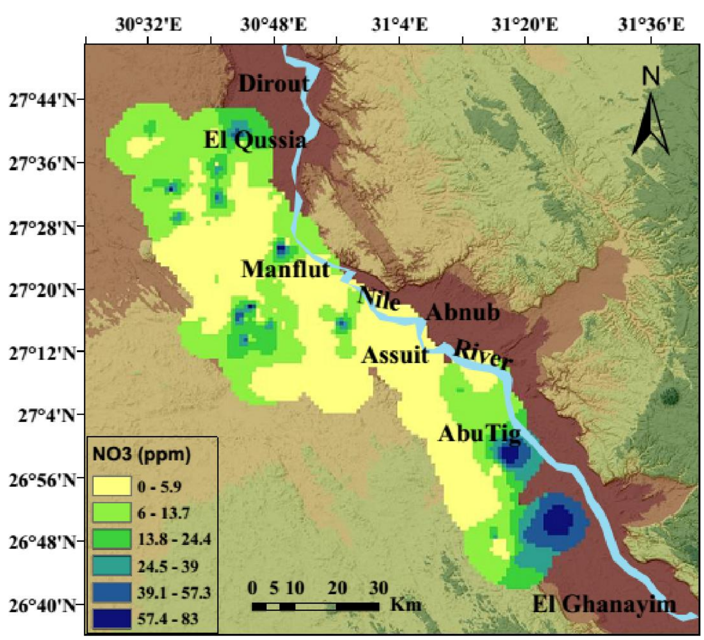


Fig14. Nitrate concentration (ppm) in the study area.

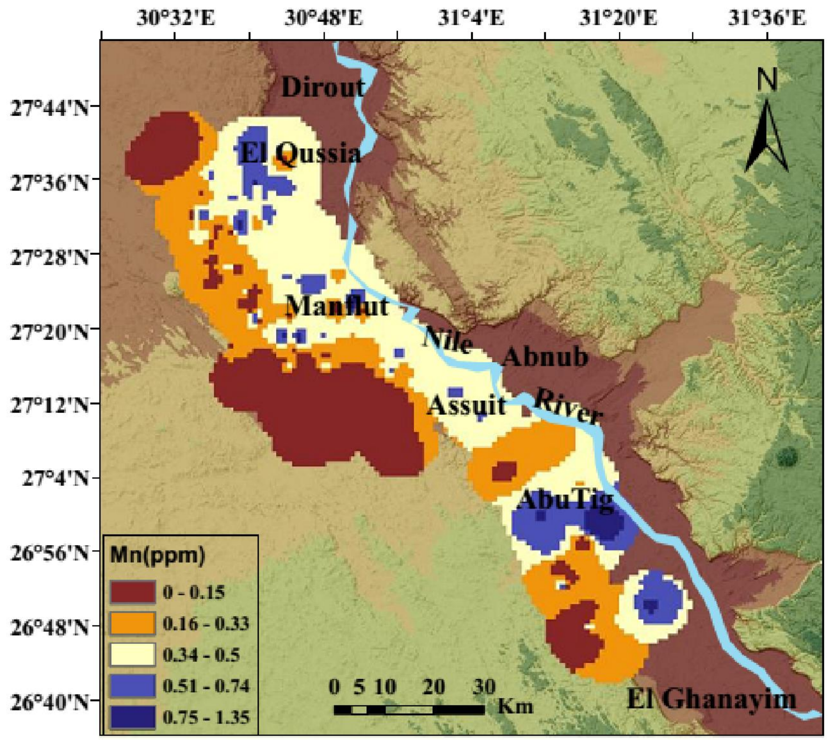


Fig15. Manganese concentration (ppm) in the study area

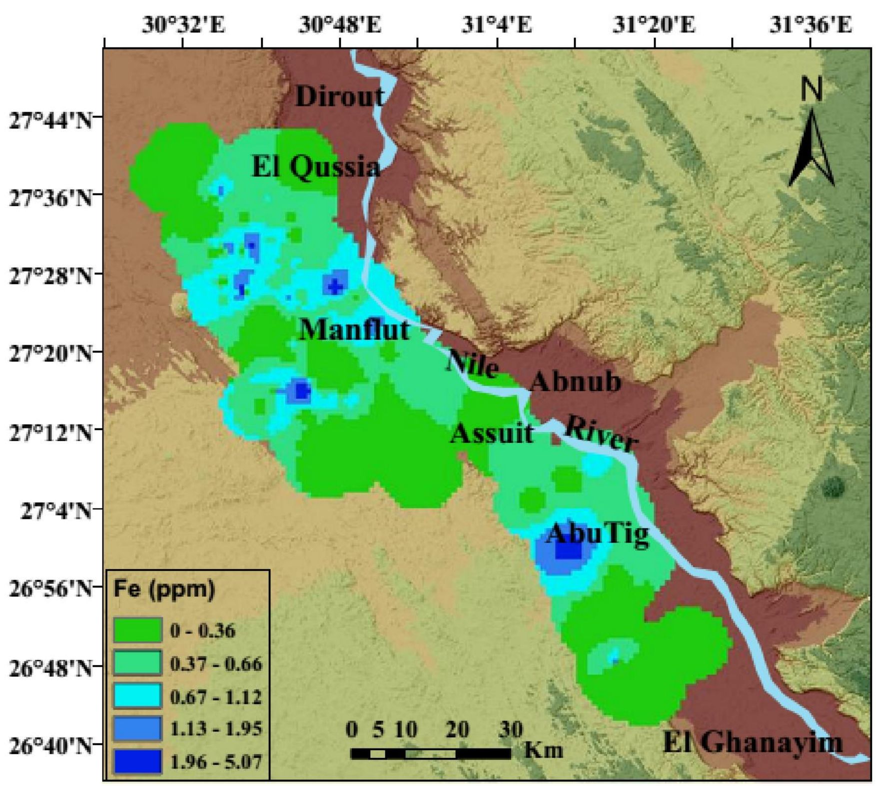


Fig16. Iron concentration (ppm) in the study area

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Conclusion

DRASTIC index model of the U.S. Environmental Protection Agency (EPA) has been used to address vulnerability of shallow groundwater to contamination potential. This model focuses on vulnerability and thus bases their prediction on solely hydrogeologic parameters. DRASTIC has the capability to highlight zones that are vulnerable to surface contamination. The vulnerability index can assist in the implementation of groundwater management strategies to prevent degradation of groundwater quality. On the other hand, the vulnerability mapping approach can provide decision makers with regional groundwater vulnerability and risk maps, due to the accessibility of most of the input data at regional scales, which cannot be achieved using real groundwater flow models. Seven environmental parameters were used to represent the natural hydrogeological setting of Assuit governorate; Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity.

The Generic DRASTIC aquifer vulnerability map indicated that Assuit governorate is under low, low-moderate and moderate vulnerable aquifer areas. While the vulnerability maps of Generic and Agricultural DRASTIC have some common zones of vulnerability, Agricultural DRASTIC is prone to overestimating vulnerability, as evidenced by designating most of the study area as moderate to moderately high vulnerable. For some polltants measurements Nitrate, Iron and Manganese show high levels of contamination especially in areas of old cultivated lands due to agricultural activities. From this study, it would appear that DRASTIC index model provides a reliable tool for environmental managers to delineate zones of protection for the aquifer. Areas denoted as high vulnerability could be given top priority for restricting certain land use types while future development may be directed to those areas of low vulnerability. Operational policies for groundwater assessment activities should be developed for the different aquifer classes; including types of investigations, monitoring programs and other initiatives that support management. Finally, DRASTIC is demonstrated to be a good approach for groundwater vulnerability assessment. Despite the fact that DRASTIC analysis requires a large amount of data, the results obtained are realistic and representative to the actual situation in the area of study.

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10/23/2016