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Susceptibility of Shallow Groundwater Aquifers to Water Logging, Case Study Al Marashda Area, West Nile Valley, Qena, Egypt.

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Susceptibility of shallow groundwater aquifers to water logging, case study Al Marashda area, West Nile Valley, Qena, Egypt

قابلية خزانات المياه الجوفية الضحلة لغدق المياه ، دراسة حالة: منطقة المراشدة ، غرب وادى النيل ، مصر.

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الخلاصة

تهتم هذه الدراسة بدراسة الخصائص الطبيعية والهيدرولوجية لخزان المياه الجوفية وللنطاق الغير مشبع بمنطقة المراشدة محافظة قنا للوقوف على مدى حساسية الخزان الجوفى وقابلية مناطقه المختلفة لحدوث الغدق والتلوث نتيجة تسرب المياه السطحية والجوفية للخزان الجوفى. وقد تم تحديد الخصائص الطبيعية للتربة من خلال التجارب الحقلية والمعملية كتجارب الرشح ورطوبة التربة والتوصيل الهيدروليكى ، كذلك تحديد نوعية وامتداد الطبقات الأرضية أفقيا ورأسيا من خلال عدد 18 جسة جيوفيزيائية كما تم إجراء تجارب الضخ وتحديد سمك الخزان الجوفى وامتداداته الأفقية والرأسية وخصائصه الهيدروليكية. وقد تم إدخال كل تلك الصفات الى النموذج المعروف (DRASTIC) وعمل خريطة حساسية الخزان بناءا على ذلك. وقد تبين أن منطقة المراشدة تتميز بخمس مناطق ذات حساسية متفاوتة لحدوث غدق المياه والتلوث. المنطقة الأولى والثانية ذات حساسية منخفضة إلى منخفضة جدا وهى تميز المناطق الجنوبية ذات أعماق مياه كبيرة نسبيا (> 40m) والتغذية الضعيفة ، المنطقة الثالثة ذات الحساسية المتوسطة و تقع على جانبى المنطقة الأولى. أما المنطقة الرابعة والخامسة فهى مناطق ذات حساسية عالية إلى عالية جدا وتميز مناطق الإستصلاح القديمة وأطرافها والتى ظهرت بها هذه المشكلة فعلا ومتوقع أن تتفاقم وتتعاظم فى المستقبل القريب خاصة لو تم إطلاق المياه بترعة كوم أمبو بالمنطقة. وعليه يجب مراعاة ذلك فى تطبيق نظام صرف متكامل لتلافى الأثار السلبية لتلك المشكلة.

Abstract

Attempts were carried out to delineate the areas where the aquifer is vulnerable to water logging, head drop and pollution in the new and old reclamation areas as well. All of the hydrological, geophysical and soil factors were incorporated in the DRASTIC model. Parameters included are; depth to water, net recharge, aquifer media, water salinity, thicknesses and resistivity of successive geoelectrical layers soil media, topography and impact of the vadose zone. Saturated soil hydraulic conductivity varies from 4.43 $X10^{-4}$ to 243 $X10^{-4}$ m/sec. Groundwater is supplied from the gravel sand saturated sediments belonging to the Quaternary aquifer. The aquifer thickness rangs from 60 to 120 m. Groundwater depths are gradually increased from 2 m in north to about 72 m in the southern area. Groundwater levels are ranging from 58 m a.s.l. to 74 m a.s.l. Transmissivity is ranging from 155 m^2/day to 420 m^2/day. Applying the DRASTIC model reveals that there are five vulnerable classes characterizing the study area. Very low and Low vulnerable areas characterize the southern area located near the table land area. Medium vulnerable area present at the pediment area just above the old cultivated lands and extends through the old cultivated lands East of Al Marashda area where groundwater depths are ranging from 5 m - 40 m and recharge is essentially from excess irrigation water. A very high and high vulnerable area is located in the old cultivated lands where groundwater is very shallow (< 5 m) and recharge is very high from excess irrigation water and percolation from surface water systems.

Key words

Hydrology, hydrogeophysics, soil characteristics, saturated and vadose zone, vulnerability, DRASTIC Model, Al Marashda, Egypt.

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Introduction

In the last few decades water consumption exceeded the renewable freshwater resources in desert areas of Egypt. The freshwater resources in these desert fringes face the problem of head drop due to the intensive pumping and low recharge. This water shortage is covered by lifting of the Nile water to that desert fringes causing severe water logging problems in the old cultivated lands. Moreover, percolation of polluted water as a result of widely using fertilizers and pesticides form another problem. Kom Umbo canal is a new canal constructed to lift huge quantities of Nile water to this area. This canal is now under inspection but water is planned to be pumped as soon as possible. As a result, attentions should be paid to study the possible impacts of these activities on the groundwater regime in the old and new reclamation areas as well. Aquifer vulnerability assessment tool is a successful tool used to examine the susceptibility of different aquifer areas to water logging and pollution in Al Marashda area.

The vulnerability assessment studies became an important element for sensible resource management and land use planning. Vulnerability is considered as intrinsic property of the groundwater system that depends on its sensitivity to human and/or natural resources (Babiker (2005). Vowinkel et al., (1996) defined vulnerability as sensitivity and intensity, where intensity is a measure of the source of contamination. It was firstly used by Margat (1968). Many approaches have been developed to evaluate the aquifer vulnerability. They include the process based methods, statistical methods and overly/index methods (Tesoriero et al., (1998). The processes based methods use the simulation models to estimate contamination migration but they are constrained by data shortage and computational difficulties (Barbash and Resek 1996). Statistical methods use statistics to determine association between spatial variables and actual occurrence of pollutants in groundwater. Their limitation includes insufficient water quality observation, data accuracy, and careful selection of spatial variables (Babiker 2005). Overlay/index methods combine the ground surface into the saturated zone resulting in vulnerability indices at different locations. Their main advantage is that some of the factors such as rainfall and depth to water can be available over large areas which make this tool suitable for regional scale assessments (Thapinta and Hudak 2003).

The vulnerability of groundwater aquifers to water logging and pollution of an area can be assessed by the DRASTIC model, which incorporates the most important soil and Hydrogeologic factors that affect the aquifer potential to water logging and pollution. These factors including; depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity (Aller et al., 1987 and Kim and Hamm 1999) . Intrinsic vulnerability is controlled by geologic structures and hydrologic conditions while specific vulnerability includes besides the former parameters the type of the contaminant and the character of the contamination source (Vrba and Zaporozec 1994). The methodology was developed in the United States under a comparative agreement between the National Water Well Association (NWWA) and the US Environmental Protection Agency (EPA) for the detailed hydrogeological evaluation of pollution potential of countries and districts (Rundquist et al., 1991). The model is a relative evaluation tool at global scale (Goodchild 1991).

This paper attempts to delineate the areas where the aquifer is vulnerable to water logging, head drop and pollution in the new and old reclamation areas as well on the basis of the hydro-geophysical and soil characteristics of both unsaturated and saturated zones. All of the hydrological, geophysical and soil factors incorporated in the DRASTIC model are; depth to water, net recharge, aquifer media, water salinity, thicknesses and resistivity of successive geoelectrical layers soil media, topography and impact of the vadose zone. The hydraulic parameters of the aquifer (Transmissivity, Hydraulic conductivity) are also included.

Site description

The area of study is located south of the Nile Course in Qena Governorate between latitudes 25° 56\ and 26⁰ 08\ North and longitudes 32° 22\ and 32⁰ 34\ East (Fig. 1). It comprises an area of about 500 Km^2. The Nile River in the study area is unusually running from east to west. Kom Umbo canal is a new canal constructed to lift Nile water to the new reclamation area. It is firstly run north-south then turned to the west after station 2. The area is characterized by desert climate conditions. Temperature ranges between 27- 49 C° in summer season and 7-28 C° in winter season. Rainfall is rarely occur, the average annual rainfall is about 4 mm. The mean daily evaporation records 8.97 mm where the mean relative humidity is about 36.62%. The study area as a part of the Nile Valley and southern part of the Western Desert was subjected to many studies in the field of geomorphology, geology and hydrogeology. These studies include Faris (1947), Said (1962 & 1991), Salem (1986), El Husssaini et al.,(1992), Abu El Ella (1993), Omran et al., (2001), Mousa (2000), Aggour et al., (2005), Zaghloul (2006), El Sabri (2010), Masoud (2010) and Abdellatif et al., (2012).

Geomorphologically, the ground surface is gradually increases from + 60 m at the Nile Valley plain to about + 560 m at the southern escarpment (Fg. 2). The area is characterized by four geomorphic units, distributed from south to north as limestone plateau, drainage basins, Pediment plain and the River valley plain (El Hussaini et al., 1992) (Fig.3). The limestone plateau bounds the area from south as irregular mountainous surface of 560 m a.s.l. dissected by three main drainage basins; namely the wadi El Hol, wadi El Halab and wadi Abu Subaa. These basins are directed toward the Nile valley. The Pediment plain (70 – 210 m a.s.l.) is located between the cultivated lands and the calcareous plateau. It is covered by sand and gravelly surface where new reclamation projects are growing. The River plain comprises the old cultivated lands, old villages and irrigation canals. It is almost flat, sloping from east to west.

Geologically, the investigated area comprises surface stratigraphic rock units ranging in age from Lower Eocene to Recent (Fig.4). Thebes Formation represents the Lower Eocene rocks. It is consists of hard limestone with many flint bands and marl intercalations of about 300 m thickness. This formation overlies Esna shale Formation (45 m thickness) of the Upper Paleocene age. The Pliocene rocks consist of a long series of interbeded red brown clay. Alluvial sand and gravel deposits of Pleistocene and Recent ages are covering most of the Pediment and cultivated areas in the form of Neo-Nile deposits, alluvial deposits and recent Wadi deposits. ***Structurally,*** the area under investigation shows that faulting is the main structural features. They are mostly of high angle normal faults with various extensions and small throw values (Said 1962, Abd El-Razik and Razvalliaev 1972).

Materials and methods

The materials used in this paper were collected through carrying out two field trips in Al Marashda area, west Qena Governorate during 2014-2015. Five infiltration tests were performed beside each soil profile which determined under constant head using double ring infiltrometer, as described by Klute (1986) (Fig. 5). The cumulative depth of infiltrated water "D" in cm as a function of time was evaluated according to kostiakove (1932) and Philip (1957a, b) as follow:

$$D = S_p t^{0.5} + k\, t \qquad (1)$$

$$I = 0.5\, S_p\, t^{-0.5} + k \qquad (2)$$

Where: D is the cumulative infiltration (L), t is elapsed time (T), S_p is the sorpitivity, k is the soil parameter related to the hydraulic conductivity (LT^{-1}) and I is the soil infiltration rate (LT^{-1})

All soil samples were analyzed according to clay, silt and sand content (Gee and Bouder 1986), water content at 0.1 and 15 bars, according to Klute (1986). Undisturbed soil samples were taken to determine soil bulk density (Blak and Hartge 1986).

In order to recognize the groundwater condition and the subsurface geo-electric layers geophysical investigation were carried out in the study area especially in the areas free from groundwater wells. Geoelectrical field works involved the application of two geoelectrical methods of exploration to get an idea about circumstances governing water logging and the aquifer Vulnerability in the area of study. These field works involved twenty Vertical Electrical Sounding (VES) using Schlumberger array and one imaging profile of Electrical Tomography (ERT) using Wenner array (Fig. 5). The VES used to investigate the succession of the subsurface strata (saturated and unsaturated zones) of the study area. The process of Vertical Electrical Sounding (VES) takes sequential measurements of the resistance by increasing the virtual distance between the poles of the current deployment, while the center of array and the trend remains constant. The maximum current electrode separation (AB) ranges from 1000 m to 2000 m. and this is sufficient to reach the required depth that fulfill the aim of the study.

The apparent resistivity values of Schlumberger soundings for each of the soundings were plotted against half current electrode separation (AB/2) on transparent double log graph paper. The field curves were interpreted by computer program RESIX-PLUS, ver.2.39 (Interpex, 1996) and IP1 Win v.2.1 (Moscow, 2003). It is an interactive, graphically oriented, forward and inverse modeling program for interpreting the resistivity curves in terms of a layered earth model. The initial model has been constructed based on the geological data and the lithological succession of the existing wells in the area. In addition, Electrical Resistivity Tomography (ERT) is also used to determine variations with depth in soil resistivity. The resistivity changes along the vertical and horizontal directions are more accurate using the 2D model. The survey technique involves measuring a series of constant separation traverses (a) started with 10m and increased in the following traverses to 2a, 3a,…., i.e. 20, 30, 40,……and 80 m. The 2-D imaging section has been measured in NW-SE direction along distance of 240 m. The computer program RES2DINV, ver 3.4 written by Loke (1998) is used for interpretation imaging data. The device of direct current resistivity meter "Terrameter" model SAS 1000 C is used for measuring the resistance "R" with high accuracy. The land topographic survey was carried out to locate the sounding stations and determine their ground elevations.

To clarify the groundwater potentialities of the study area, data of seven pumping and recovery tests were analyzed applying Theis, (1935) and Jacob (1950) models using the following relationships:

For estimating Transmissivity:

$$T = 2.3\, Q / 4\, \pi\, \Delta s \qquad (3)$$

For estimating the Storativity:

$$S = 2.25\, T\, t_o / r^2 \qquad (4)$$

Where, $\boldsymbol{T}$ is the Transmissivity (L^2T^{-1}), **Q** is the pumping rate (L^3T^{-1}), $\boldsymbol{\Delta s}$ refers to the change in head over one log cycle (L), $\boldsymbol{t_o}$ refers to the time where the straight line intersects the zero drawdown line and $\boldsymbol{r}$ is the distance between observation well and production well (L).

Also, complete chemical analyses of 32 groundwater samples covering the present surface and groundwater systems were performed in the Central Laboratory of the Desert Research Center during the year 2015 according to the methods adopted by the U.S Geological Survey, Rainwater and Thatcher, (1960). After data normalizing, computer programs and statistical methods were applied to interpolate and visualize the data in maps and tables.

The overlay/index procedure utilized for generating vulnerability map represent the study area by DRASTIC method (Aller et al., (1987). The aquifer vulnerability overlay/index (Vbra and Zaporotec (1994), USEPA (1993) and Zhang et al., (1996) can be categorized into: (i) hydrologic setting classification and (ii) scoring method (Ckakraborty et al., (2007). In the DRASTIC model, specific criteria are assigned different degree of importance on a scale 1 to 5 (Table 1). These criteria include: depth to water, net recharge, aquifer media, soil type, topography, impact of vadose zone and hydraulic conductivity. The vulnerability DRASTIC index is the sum of the multiplication of variable rank and weight of individual criterions as follow:

$$DI = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w \quad (5)$$

Where:
DI is the DRASTIC index, D is the depth to water, R is the net recharge, A is the aquifer media, S is the soil media (texture), T is the topography (slope), I is the impact of the vadose zone, C is the hydraulic conductivity of the aquifer and the subscripts r and w denoting the rating and the weight respectively. Weights provide an indication on the relative impact of the parameter on the DRASTIC index. I is given a scale from 1 to 5, where 1 represent the least significant factor and 5 represent the most significant factor (Table 1). On the other hand, ratings reflect the relative significance of classes (1-10) within each of the seven parameters. All the variables are dimensionless. The calculated DRASTIC index indicates relative pollution and water logging potential. Higher the DRASTIC index greater the aquifer potential to water logging and pollution. The DI can also be categorized and mapped to low, moderate, high and very high vulnerable areas.

Results and discussions

A. Soil zone condition

1. Infiltration rate

Five infiltration tests were carried out representing the different soil types present in the study area. The data was analyzed according to kostiakove (1932) and Philip (1957a, b). The results and graphical representation of these data were shown in Table 2 and Fig 7 respectively. Accordingly, the basic infiltration rates ranged from 1 cm/h to 19.71 cm/h. According to Kohnke (1980) classification, the area displays three classes of soil. Moderately rate soil characterizes the site No.5 which has 1 Cm/h infiltration rate and 6.3 intake rate. Moderately rapid rate soil describes the sites No. 2, 3 and 4 where the infiltration rate is ranging from 1.45 to 5.15 cm/h and intake rate ranges from 8.02 to 23.2 cm/h. The third class is the rapid rate soil type. It is present in site No. 1 where the infiltration rate records 19.72 cm/h and intake rate records 73 cm/h. So, it is recommended to apply Drip or Sprinkler irrigation system because the values of basic infiltration rate reached 12 cm/h (Tallat et al., (2008). Irrigation intervals should be every day which it isn't suitable for furrow irrigation system. In all cases, irrigation consumptive rates should be less than values of basic infiltration.

2. Moisture content, total porosity and pore size

It was found that the texture of site No. 1 & 2 was loamy sand with high and rapid infiltration (Table 3). It influences the movement and availability of soil moisture, aeration, nutrient availability and the resistance to root penetration. It also influences physical properties related to the soil's susceptibility of soil degradation, such as aggregates stability. The data show that the clay percentage of site No. 3 is ranging from 26.43 to 26.50. A dry clod of clay soil is normally hard resistant to fracture. As water is added to the clod and it becomes moister, its resistance to breaking is reducing. The data revealed that moisture is held in the micro-pores (small pores) while water moves in the macro-pores (large pores). The corresponding increase in soil available water reached 4.97, 7.79, 8.89, 11.72 and 14.9 in sites No. 2, 1, 3, 5, and 4, respectively. These results rendered to different in soil texture or the percentages of sand, silt and clay in the soil. So, soil texture is the major inherent factor affecting infiltration. Water moves more quickly through the large pores in sandy soil than small pores in clayey soils, especially if the clay is compacted and has little or no structure or aggregation. Depending on the amount and type of the clay minerals, some clayey soil develops cracks from shrinkage as they become dry. The cracks are direct conduits from water to enter the soils. Pore size values show that the average large pores in sites No. 1, 2 and 3 are ranging from 15.68 to 20.32, whereas they record 12.37 to 13.05 in sites No. 4 and 5 respectively (Table 4). So, water moves more rapid in sites No. 1 and 3 than other sites. Also, water was held in small pores in sites No. 2 and 5 comparing with the other sites. Giusquiani et al., (1995) reported that, small pores (10-0.2 µm) are necessary for water storage and bacterial growing and activity. Medium pores (60-10 µm) are important for growing and activity of root hairs, where large pores (> 60 µm) are essential for drainage and soil aeration especially in fine texture soil.

3. Saturated hydraulic conductivity (Ks)

The estimated values of the saturated hydraulic conductivity show that the value of (K_s) varies from 4.4 $X10^{-4}$ to 243 $X10^{-4}$ m/sec (Table 5). As a result, the ability of soil to transmit water is ranging from slow to rapid according to the permeability classes of Marshall et al., (1996). These variations may attribute to the different type of the soil texture and pores, site No. 1 and No. 2 display loamy sand (light soil), whereas sites No. 4 and No. 5 have sandy loam (heavy soil) and site No. 3 holds sandy clay loam.

4. Soil texture

The data show that the percentage of clay content is very high in soil No 3 than other sites. It embraces about 26.43 % in Site No. 3 where it records 4 %, 14.79 %, 8.56 % and 14.53 % respectively (Table 3). Clay content is the major inherent factor affecting infiltration of water through the soil. Water moves more quickly through the large pores in sandy soil than it does through the small pores in clay soil, especially if the clay is compacted (site No. 3) and has little aggregation. Depending on the amount and type of clay minerals some clayey soils develop crusts from shrinkage as they become dry. The crakes are direct conduits for water to inter the soils. Thus clayey soils can have a high infiltration rate when dry and a slow rate when moist (cracks close). Management practices that improve soil organic matter content, soil aggregation and porosity can improve infiltration.

5. Penetration resistance

Table 6 reveals that the highest value of the Penetration resistance is present at site No.3 as 11.95 Kg/ cm^2 when the soil moisture percentage reached 10.08 % while the lowest value was 0.77 Kg/ cm^2 at site No. 5 when the soil moisture percentage reached 1.13 %.

B. Subsurface strata

1. Vertical Electrical Sounding (VES):

The interpretation of the geoelectrical resistivity data depends on determining and following up the geoelectrical parameters i.e. resistivity and thicknesses of a series of layers. The geoelectrical results are a geological model that can be reflected in terms of lithological variation and stratigraphy. The interpretation of Vertical Electrical Sounding (VES) data comprises qualitative and quantitative processes. The qualitative interpretation includes comparison of the relative changes in the apparent resistivity and thickness of the different layers. It gives information about the number of layers, their continuity throughout the area or in a certain direction and reflects the degree of homogeneity or heterogeneity of the individual layer. The quantitative interpretation, on the other hand, involves the determination of the number of the geoelectrical layers as well as the true depth, thickness and resistivity of each layer.

i. Qualitative interpretation:

The qualitative interpretation illustrates the lateral and vertical irregularities of electrical properties. They indicate and reflect heterogeneity characterizing the near surface variations. The area has field curves (Fig. 8) terminate with "AKQ", “HKH”, and "QHA" types which reflect a considerable heterogeneity of the succession and affect the structures.

ii. Quantitative interpretation:

The interpretation of the resistivity soundings led to the detection of three geoelectrical layers. Some of these layers have not been detected at some sounding stations. The initial model has been constructed in view of the lithological succession and well logging data of the existing wells (Fig. 9). The results of the resistivity and thickness of the geoelectrical layers are given in Table 7. In order to reach optimum correlation between the geoelectrical layers and the predominant geologic units, some successive thin geoelectrical layers (mostly the uppermost ones) have been grouped together in one layer. The resistivity of such a layer is expressed in terms of the average transverse resistivity (ρt). This parameter can be calculated from the resistivity and thickness of the group of thin layers as follows;

$$\rho t = \Sigma (\rho i . hi) / \Sigma hi \qquad (6)$$

$i = 1 \text{ to } n;$

where; ρi is the resistivity of the ith layer, hi is its thickness and n is the number of layers. The vertical and lateral extensions of the detected geoelectrical layers are illustrated through four geoelectrical profiles as shown on the location map (Fig. 5), the geoelectrical profiles “AA\" extends from west to east and “BB\”, “CC\”, “DD\” extend from south to north directions (Figs 10 and 11). The distribution of the resistivity and thickness of the three encountered layers, from the surface downwards, are given in Table 8. The following common features along the layers are given as following:

1. The first geoelectrical layer “A” is unsaturated zone and extends all over the study area. It consists of wadi deposits such as (gravel, sand, rock fragment which derived from the southern plateau) characterized with wide resistivity range from 3 to 11152 Ohm.m. The large difference in resistivity values of this geoelectrical layer is due to clay content and effect of water logging. The first geoelectrical layers decreases in their thicknesses towards southeast. The layer shows its maximum resistivity value at VES No. 8 whereas a minimum value of 3 Ohm.m is recorded at VES No. 1. The thickness of this layer increases toward the south at VES No. 8 (61 m) and decreases toward the north VES No.1 (15 m).
2. The second geoelectrical layer "B" is saturated with water and it can be classified into three zones according to resistivity values. The first one (B1) shows resistivity values range from 17 to 98 Ohm.m. The variation of the resistivity within this range indicates lateral lithological change from clayey sand to sand. The thickness of this zone varies from 11m at VES No. 19 to, 53m as recorded at VES No. 6. The second

zone "B2" consists of saturated sandy clay and it is not found in all over the study area. The resistivity and thickness of this zone are ranging from 0.5 to 9 Ohm.m and from 10 to 30m, respectively. Finally, the third zone (B3) consists of saturated clayey sand and also it is not found in the whole area. Resistivity ranges from 38 Ohm.m at VES No. 6 to 86 Ohm.m at VES No. 15. The thickness of this zone (B3) varies from 24m at VES No.19 to 30m at VES No.16.

3. The last detected geoelectrical layer is layer (C) which recorded at the western part of the study area. This layer can be divided to two zones. The first one (C1) attains resistivity values ranging from 120 Ohm.m to 271 Ohm.m and it is consists of fractured limestone. Most values fall within the range 20 -100 Ohm.m. According to the well's data, it is interpreted as sand sediments (water bearing formation). This layer extends at the western side of the study area with thickness ranging from 20 to 24m. The lower layer (C2) is consists of limestone. It represents the base of the rock succession. Its resistivity values reached more than 423 Ohm.m. The base of this layer has not been reached at several sounding stations. In order to spatially visualizing the structures affecting the study area, a structural contour map of the upper surface of the three geoelectrical layer were constructed (Fig. 12). As a result, inferred faults locations, extension and direction of displacement are outlined. The condensed contour lines indicate three main faults of NE-SW direction (F1,F2,F3). The correlation between the equivalent layers of the geoelectrical profiles indicates that the fault F1 has NE-SW strike, which throw down towards northwest while F2 and F3 has the same strike direction (NE-SW) but it is thrown down towards southwest.

2. Electrical Resistivity Tomography (ERT)

A two-dimensional (2-D) resistivity model of the subsurface succession was constructed using the imaging survey data. The imaging section was measured at VES No. 14 location to identify the possible recharge from surface water system. Vertical recharge forms one of the vital factors causing the water logging phenomenon. The results indicate generally decreasing of resistivity values along the profile. The values are not exceeding 6 Ohm.m. According to 2D imaging profile (Fig. 13) three resistivity zones were detected. The first one represents low resistivity values (3 Ohm.m) with 9m width. These low values may attribute to the high clay and water content of the area near surface. The second zone shows that the resistivity values are ranging from 3 to 4.5 Oh.m with 7m width. On the other hand, the third zone attains resistivity values of 6 Ohm.m. The relatively low resistivity values reflect the heterogeneity of the lithological composition near the surface layers and the influence of percolation of water from irrigation canals and excess irrigation water.

C.groundwater conditions

1. Aquifer type

Groundwater conditions are investigated through the hydrogeological cross sections, water depth measurements, pump test and chemical analysis of collected water samples (31 samples). According to the constructed hydrogeological cross sections (Fig. 14), groundwater is supplied from gravely sand saturated sediments intercalated with clay layers belonging to the Quaternary aquifer. This aquifer is detected in most of the groundwater wells and electric sounding stations. The aquifer thickness is not uniform due to the effect of the fault structure system of the Nile. The aquifer thickness is increasing to the north and northwest direction from 60 to

120 m. In some locations, clay lenses were detected in different depths so the aquifer is found under the unconfined to semi-confined conditions.

2. Groundwater level and flow directions

According to the depth to water measurements in 13 groundwater wells (Table 9) and the constructed depth to water contour map (Fig. 15), groundwater depths are gradually increased from 2 m in north to about 72 m in the southern area. The wide range of the groundwater depths reflect the effect of the steep gradient of ground surface which sharply increase to the south. Deep groundwater is present at the pediment plain where shallow groundwater aquifer is formed adjacent to the old cultivated land. Seepage from irrigation system and excess irrigation water lead to the continuous rising of the groundwater surface forming water logging areas. This phenomenon is detected in some areas in Al Waqf-Al Marashda district. On the other hand, groundwater levels are high in the southern part where they are ranging from 58 m a.s.l. to 74 m a.s.l. Groundwater general flows from north to south but the intensive pumping in the center reclamation area formed a big depression cone accompanied by many local groundwater flow directions (Fig.16).

3. Hydraulic parameters

Seven pumping testes were carried out in the study area to determine the hydraulic parameters of the aquifer, Theis solution (Theis 1935) was used to analyze the data. The results were listed in Table 10. Accordingly, the aquifer transmissivity is ranging from 155 to 420 m^2/day while the storativity is ranging from 0.00021 to 0.0064. On the other hand, the hydraulic conductivity of the aquifer attains values from 1.3 to 5.2 m/day. The areal distribution of these values (Fig. 17) shows general increase in the middle part (390 m^2/day) and decrease towards north and westward (155 m^2/day). Rapid changes of the transmissivity values characterize the middle part of the area which indicated by the concentric and crowded contour lines. These transmissivity variations may attribute to fracture, lateral facies and thickness changes of the aquifer caused by faulting of the aquifer layer.

4. Groundwater chemistry

Groundwater chemistry of Marashda area was investigated through the field measurements (pH, EC) and routine chemical analysis (Major and minor elements) of 31 groundwater samples (Table 11). The results specified the salinity variations of the area, the chemical water type, and the recharge sources. The total salinity distribution map (Fig.18) shows remarkable salinity variations from about 500 ppm to about 5500 ppm. The low salinity values characterise the north areas adjacent to the old cultivated lands and the southern parts close to the escarpment; salinity is lower than 1000 ppm. On the other hand, the Middle part that located betwwen the scarp and the old cultivated lands displays the highest values of groundwater salinity (5500 ppm). The Paleocene clay facies and the overpumping may be the reasons of this high salinity values of theis area. Furthermore, the distribution of the nitrate idicates that thers is notcable concentration of the nitrate in the middle parte of the area (Fig.19). The downward seepage of irrigation water rich in fertilizers may be resposible for the odd values of nitrate in this area.

D. vulnerability assessment/drasric model

The DRASTIC model is used to assess the vulnerability of the Quaternary aquifer of Al- Marashda area to water logging and pollution as well. As mentioned in the material and methods section, seven DRASTIC parameters (depth to water, net recharge, aquifer media, soil type, topography, impact of vadose zone and hydraulic conductivity) are used for this purpose. The rating of each parameter is calculated depending on the values of these parameters estimated in sections A, B & C as follow:

1. Drastic parameters

-Depth to water

Depth to water is a significant factor controlling the water logging and pollution of the aquifer. Shallow groundwater depths accelerate the appearance of the water logging and shorten the time needed for contaminants to arrive the aquifer and vies versa. So, shallow depths will lead to high vulnerability rating. Rating values of the groundwater depths were assigned according to the ranges of the field measurements and the assumption that the shallower the water tables the more vulnerable aquifer to logging and pollution (Table 12).

-Net recharge

Recharge describes the amount of water available at the surface that percolates through the vadose zone to recharge the groundwater aquifer. Recharge form the principal controlling factor for water logging and contaminant transport. So, the areas of higher recharge rates are more vulnerable to logging and pollution. Net recharge is computed applying the water budget equation of the area. Precipitation is very low in the study area (5mm/year), so the net recharge are restricted to the subsurface water flow through aquifers, excess irrigation water and percolation from irrigation canals. The net recharge values were calculated to the different areas of Al Marashda area (Table 13). Accordingly, the ranges and ratings were assigned.

-Aquifer media

The lithologic characteristics of the aquifer media have been identified from borehole data, Hydrogeologic cross sections and the geophysical electric investigation (section B & C). Accordingly, the aquifer is mainly consists of fine to medium sand with clay interbeds but the aquifer is more clayey to the north and more limy to the south. According to the USEPA criteria (Table 14), the aquifer has been assigned a value of 8 for the aquifer within the new reclamation area and 6 for the aquifer within the old cultivated lands.

-Soil media

The soil media is the upper most portion of the vadose zone which is characterized by biological and chemical activities. The soil media influence the recharge quantity and pollutants types reaching the groundwater aquifer. Soil was investigated through the grain size analysis of some soil samples, moisture content, total porosity and texture classes (section A). In addition the soil and geologic maps showing the different rock exposures present in the study area. Ratings were assigned to define soil classes based primarily on the texture of the soil which depend on the sand, silt and clay ratio (Ckakraborty et al., 2007). The finer the soil media the less is the vulnerability of the soil (Table 15).

-Topography

The striking factor of the topography related to vulnerability is the slope which is expressed by percent. Areas with gentile slope tend to retain water longer and then more recharge to groundwater and hence high potential to pollution and water logging. Inversely, areas of steep slope have low vulnerability potential. The Digital Elevation Model map (DEM) extracted from the Shuttle Radar Topography Mission (SRTM) was used to extract the topographic features of the study area (Fig. 2). This map is used to determine the slope percent of the study area and hence the rating of this parameter (Table 16).

-Impact of vadose zone

The vadose zone characteristics have been clarified from the lithofacies analysis (section B), infiltration rate, texture and hydraulic conductivity estimation (section A). Two main parameters play a vital role in the degree of vulnerability of the vadose zone; the thickness of the clay layers and the infiltration rate. The more clay content and low infiltration rate lead to low vulnerable aquifer and vies versa (Table 17).

-Hydraulic conductivity

Aquifer vulnerability is very close to the aquifer hydraulic conductivity which transports the pollutants away from point to another point through the aquifer formation. Hydraulic conductivity of the aquifer was determined by analyzing a number of pumping tests (section C, table 9). Accordingly, the ranges and rating table was obtained (Table 18).

2. Drastic index (di)

The DRASTIC index is the sum of the multiplication of variable rank of every well and the weight of individual parameters. The rating of every well of the different parameters is extracted from the rating distribution maps of the seven parameters (Fig. 20). This value is multiplied in the weight value of the different parameters (Table 1). Accordingly, the vulnerability values of the Quaternary aquifer in Marashda area are ranging from 116 to 172 (Table 19). These values were classified into five groups representing the vulnerability classes of the Quaternary aquifer of Marashda area (Table 20). They are including the very low variable class (<130), low vulnerable class (130-140), medium vulnerable class (140-150), high vulnerable class (150-160) and very high vulnerable class (>150).

3. Drastic vulnerabilty map

According to the estimated values of the DRASTIC Index of the productive wells (DI), the DRASTIC vulnerability distribution map was constructed (Fig.21). This map shows that five classes of the vulnerability groups are represented in the study area. This may be due to the wide range of the DRASTIC parameters and heterogeneity of the aquifer characters. The highest vulnerable class is present at the middle part of the study area where groundwater depths are relatively small (5m - 20m). In addition, the aquifer and soil media are sandy and hydraulic conductivity is higher than other parts of the area. These conditions facilitate the percolation of the polluted water downward. The aquifer is water logged and polluted by nitrate in some parts of this district. To the north, Al Waqf-Al Marashda area represents a high vulnerable class where groundwater depths are very small (< 2m), soil and aquifer media are sandy and silty clay and recharge from excess irrigation water is present. So, this area is now waterlogged and expected to enlarge with time. On the other hand, the lowest vulnerable class is present in the southern area where groundwater depths are very big (> 40 m) and recharge is very small. This area is relatively safe from pollution threat but it may be infected by heads drop problem due to the intensive pumping.

Conclusions and recommendations

In this paper, the vulnerability of the groundwater aquifer of Al Marashda area was investigated through the estimation of the characteristics of the vadose zone and saturated zone as well. Soil tests (infiltration, moisture content, and grain size analysis), Vertical Electric Sounding (VES), Electrical Resistivity Tomography (ERT) and hydrological measurements (Depth to water, water level, transmissivity, hydraulic conductivity and salinity analysis) were executed in the study area. Accordingly, the soil infiltration rate is ranging from 1 to 19.71 cm/h and area displays three classes of soil; moderately rate, moderately rapid rate and rapid rate soil. Saturated soil hydraulic conductivity varies from 4.43 $X10^{-4}$ to 243 $X10^{-4}$ m/sec. Groundwater is supplied from the gravely sand saturated sediments with clay interbeds belonging to the Quaternary aquifer. The aquifer thickness is increasing to the north and northwest direction i.e. from 60 to 120 m. Groundwater depths are gradually increased from 2 m in north to about 72 m in the south.

Small water logged areas are present in the low land southwest Al Marashda area. Groundwater levels are ranging from 58 to 74 m a.s.l where transmissivity values are ranging from 155 to 420 m^2/day. Applying the DRASTIC model reveals that there are five vulnerable classes characterizing the study area. Very low and Low vulnerable area characterizes the southern area located near the table land area where groundwater depths are very big (> 40 m) recharge is very low (4 mm/year). Medium vulnerable area present at the pediment area just above the old cultivated lands and extends through the old cultivated lands east Al Marashda area where groundwater depths are ranging from 5 to 40 m and recharge is essentially from excess irrigation water. A very high and high vulnerable area is located in the old cultivated lands where groundwater is very shallow (< 5 m) and recharge is very high from excess irrigation water and percolation from surface water systems.

Based on the above results, the following recommendation points can be stated:

1. Attentions should be paid to the old cultivated lands which may be more water logged and polluted as a result of intensive reclamation process carried out in the new desert area. Suitable drainage water system should be constructed to this area.
2. Using of fertilizers should be lowered to the international standards where nitrate concentrations recorded 155 ppm in some groundwater samples.
3. Drop irrigation method should be the only irrigation method used in the old and new reclamation lands as well.
4. Pumping rates and wells number should be lowered in the middle part where a big cone of head drop was formed.
5. Good drainage system should be applied to the new reclamation area if Kom Ombo canal works.
6. A cut off drain should be constructed parallel and immediately north Kom Ombo canal to collect the seepage water expected to percolate down slope.

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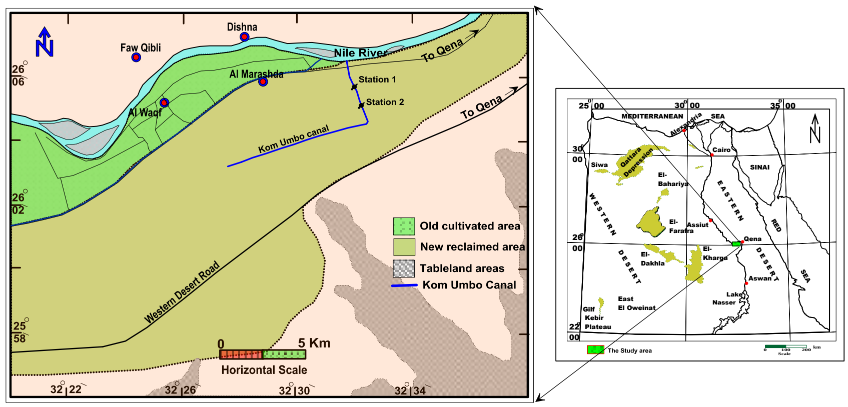

Fig. (1): Key map of the study area.

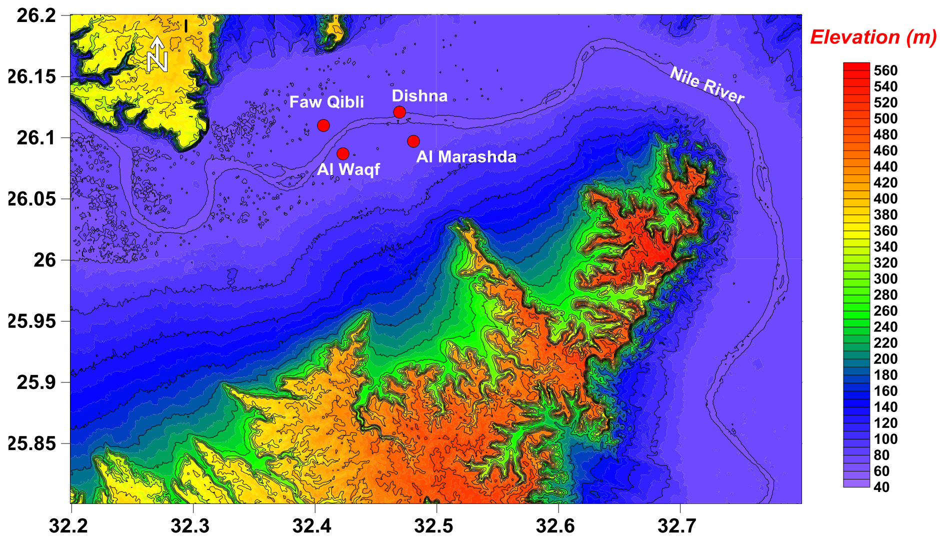

Fig. (2): Orthographic map of the study area and vicinities

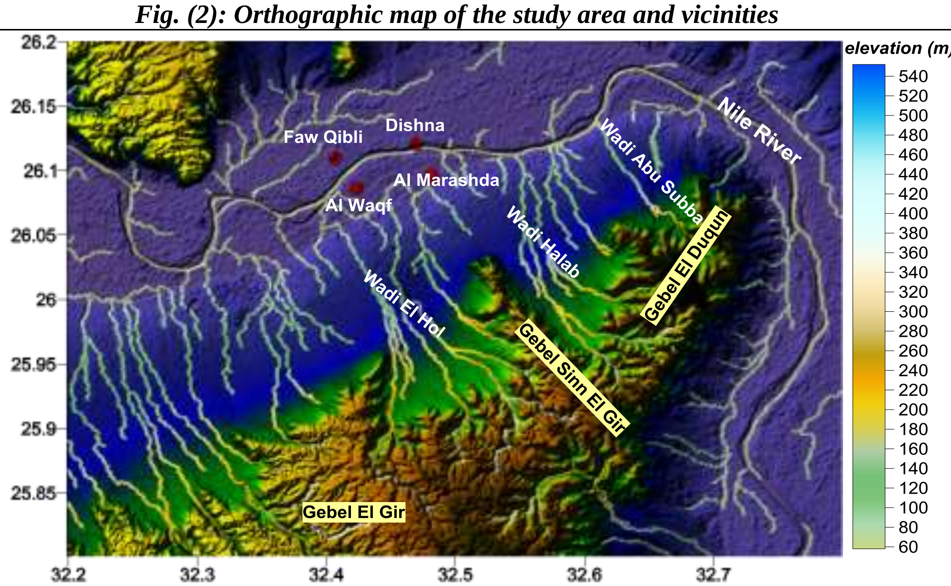

Fig. (3): Geomorphologic units of the study area

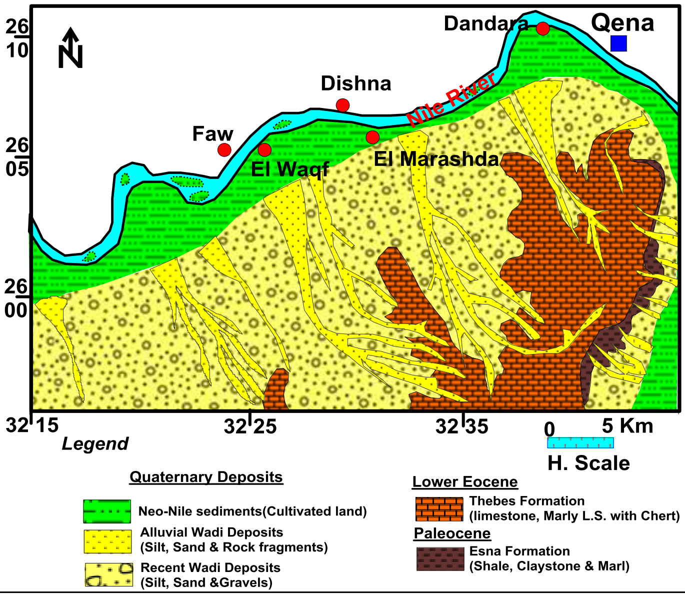

Fig. (4): Geologic map of the study area (after Said, 1991

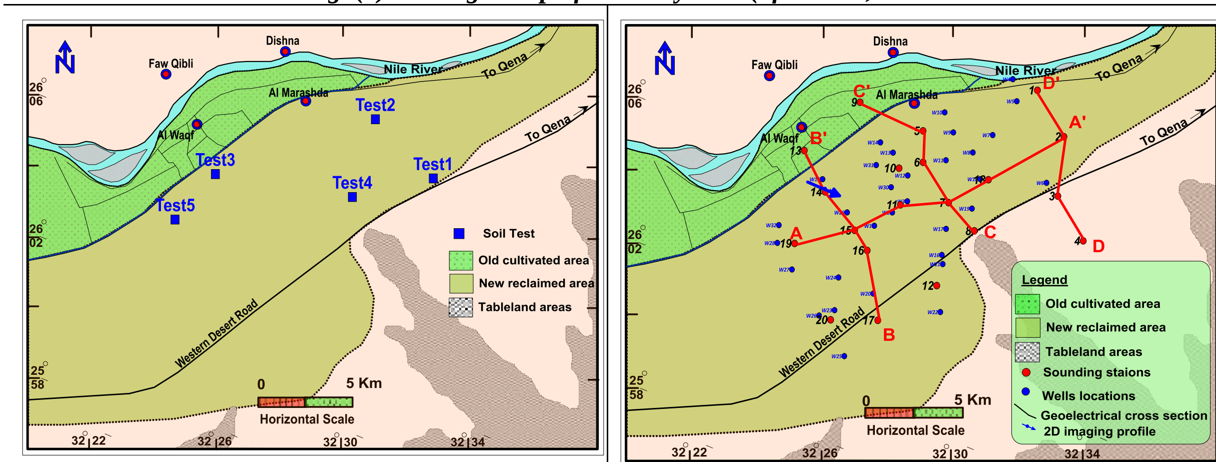

Fig. (5): Soil test (left) and Vertical Electrical Sounding (right) location maps of the study area

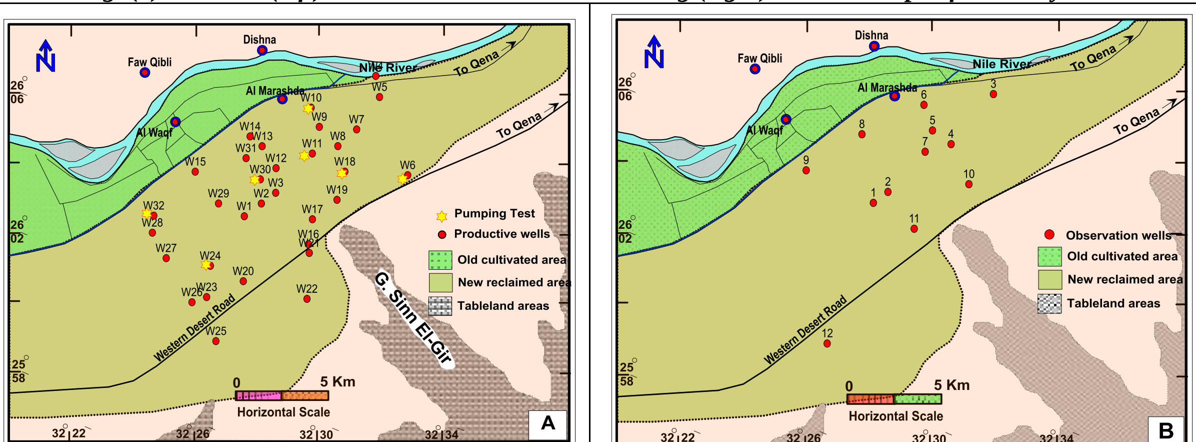

Fig. (6): Productive, Pump test wells location map (A) and Observation wells location map (B) of the study area.

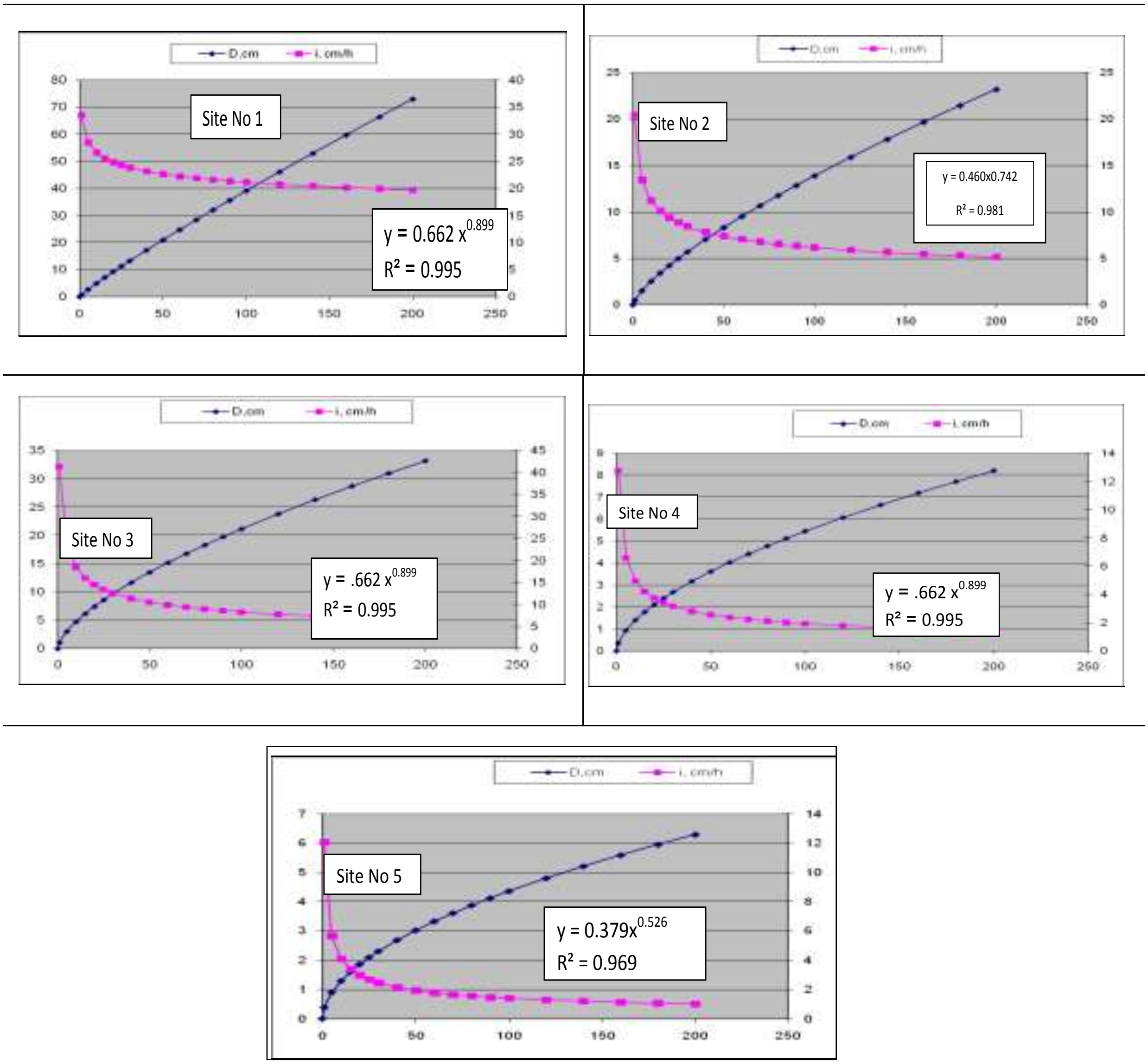

Fig. (7): Instantaneous and Cumulative Infiltration curves of the studied soil in Al Marashda area (Sites No. 1 to 5).

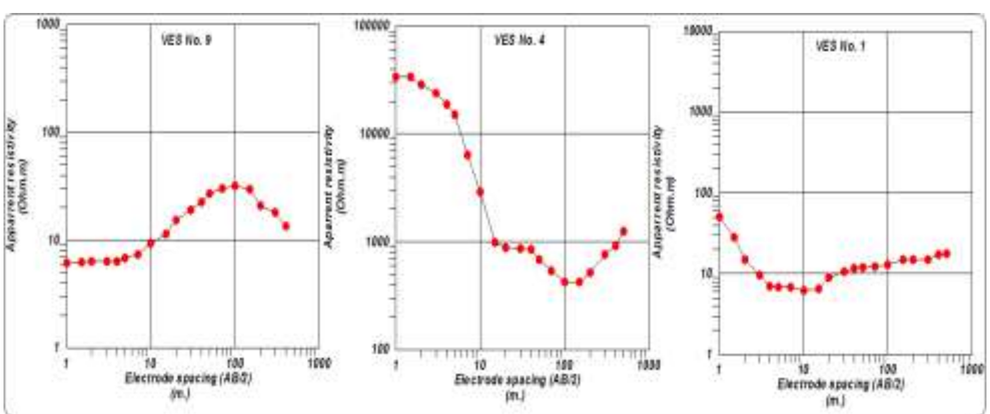

Fig. (8): Examples of the field curves of the Vertical Electrical Soundings (VES)

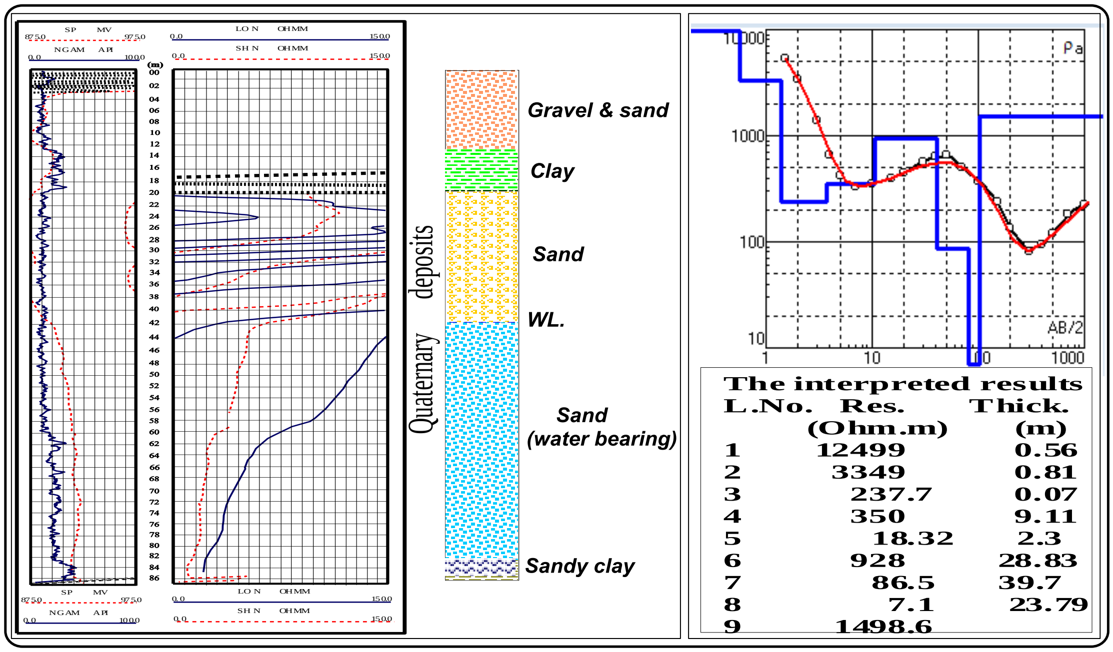

Fig. (9): The interpreted results of sounding station No.18 and lithological data of composite log at the nearest drilled well.

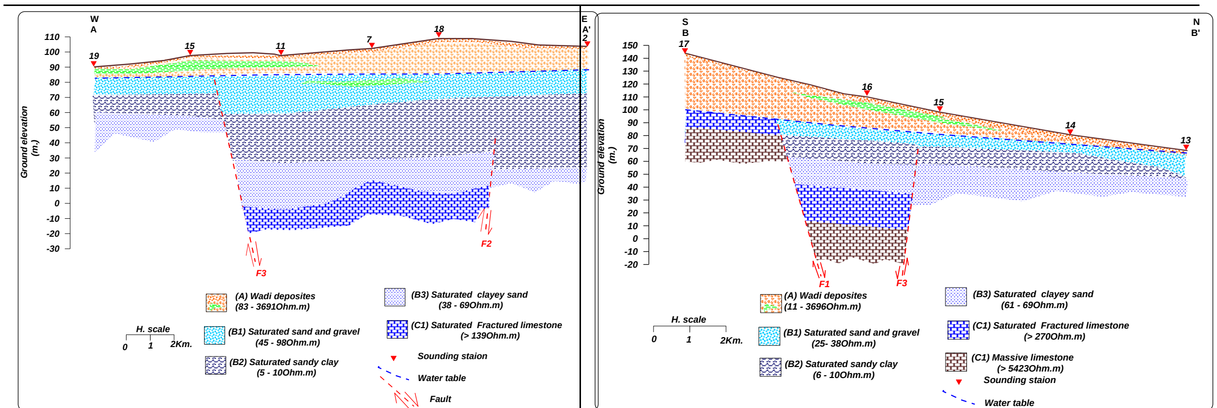

Fig. (10): Geoelectrical Profiles AA\ and BB

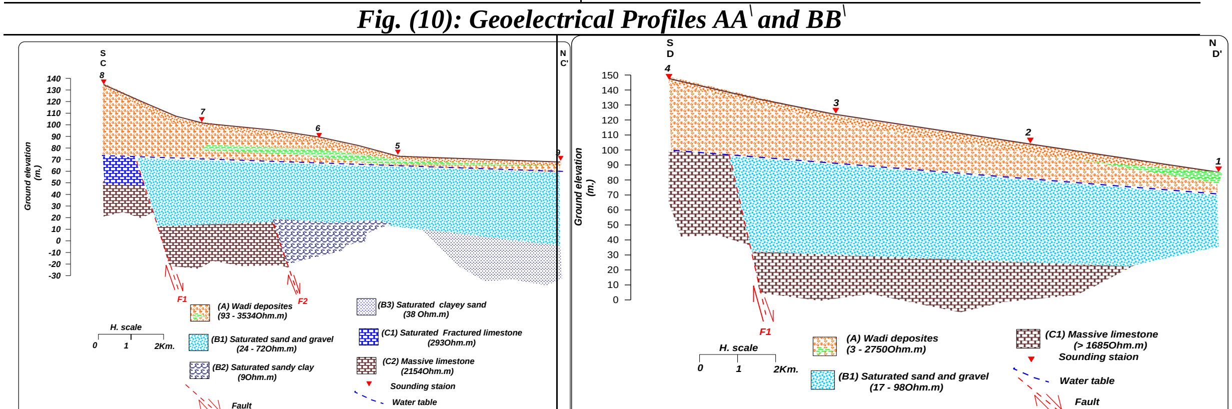

Fig. (11): Geoelectrical Profiles CC\ and DD

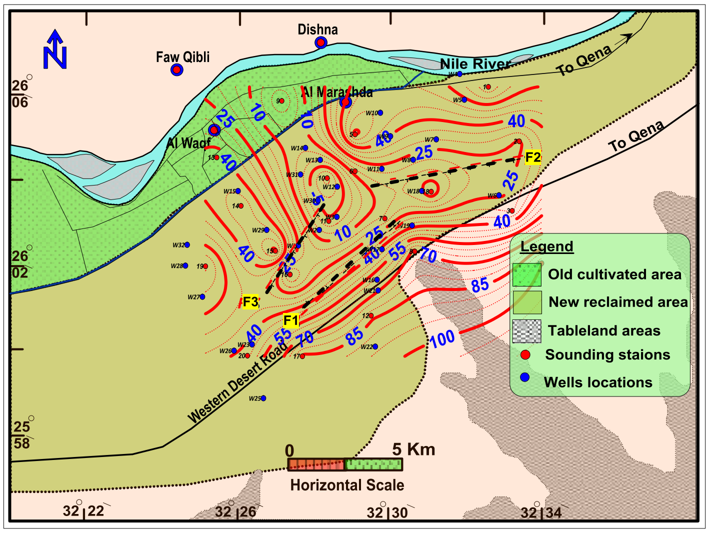

Fig. (12): Surface level contour map of the third layer "C"

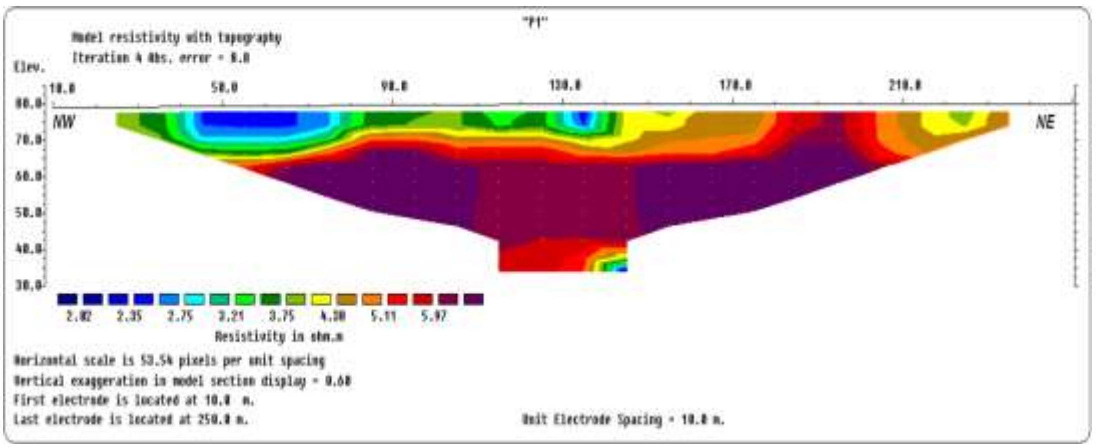

Fig. (13): The inversion results of the Wenner array 2-D imaging transect in the study area.

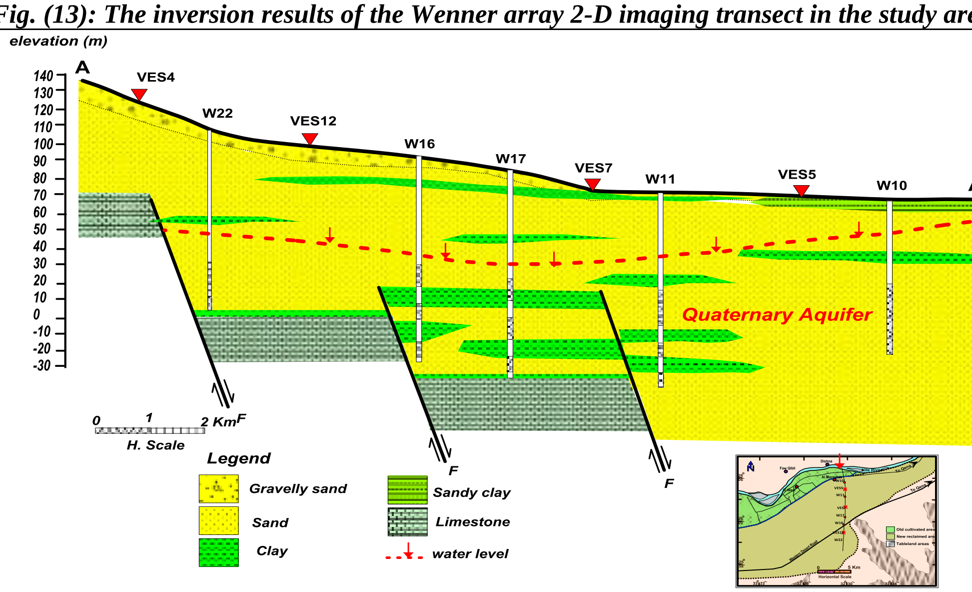

Fig. (14) Hydrogeological cross section A– A

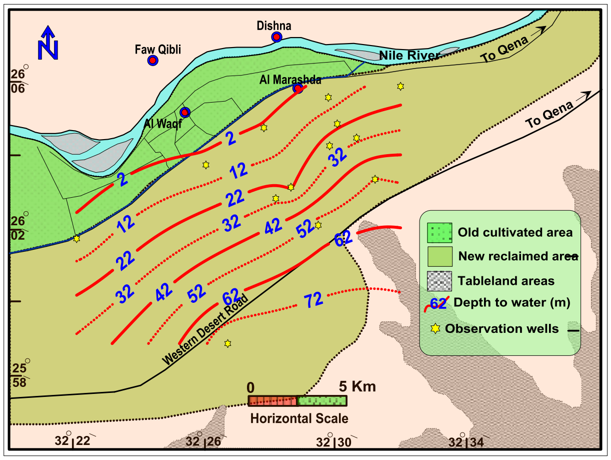

Fig. (15): Depth to water contour map

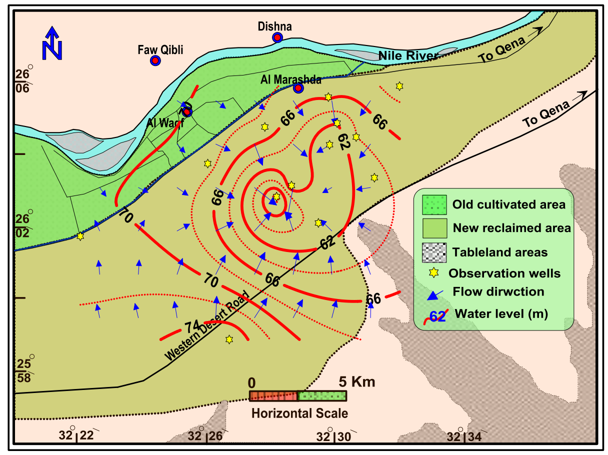

Fig. (16): Groundwater level and flow map

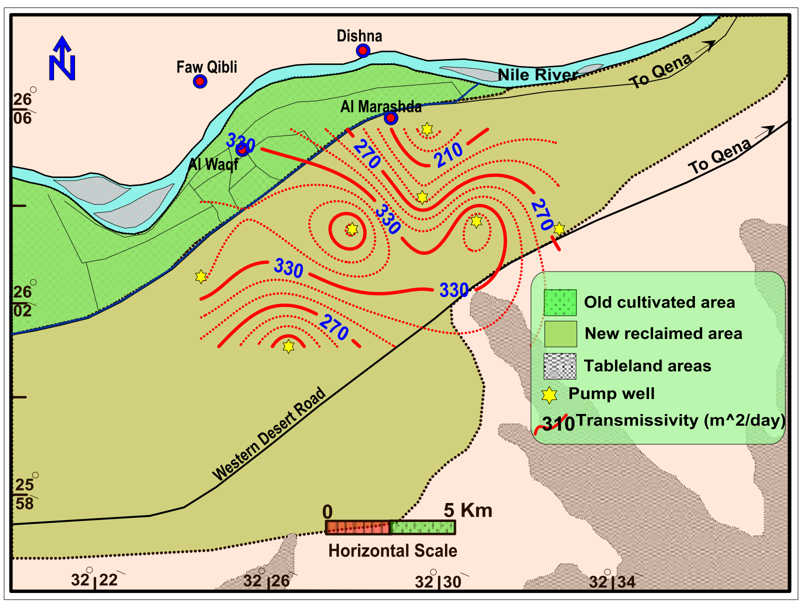

Fig.(17): Transmissivity distribution map of the study

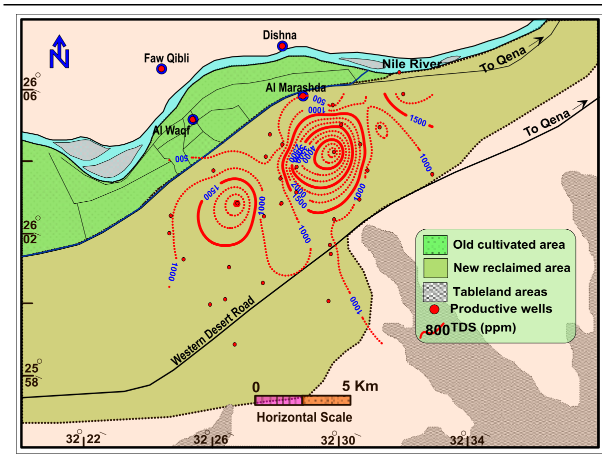

Fig.(18): Total salinity distribution map

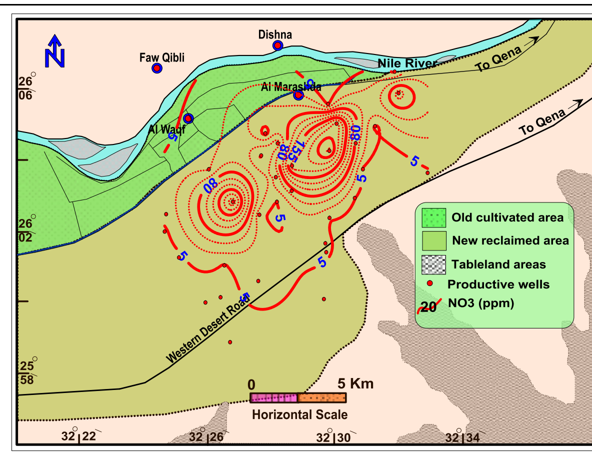

Fig. (19): Nitrate distribution map

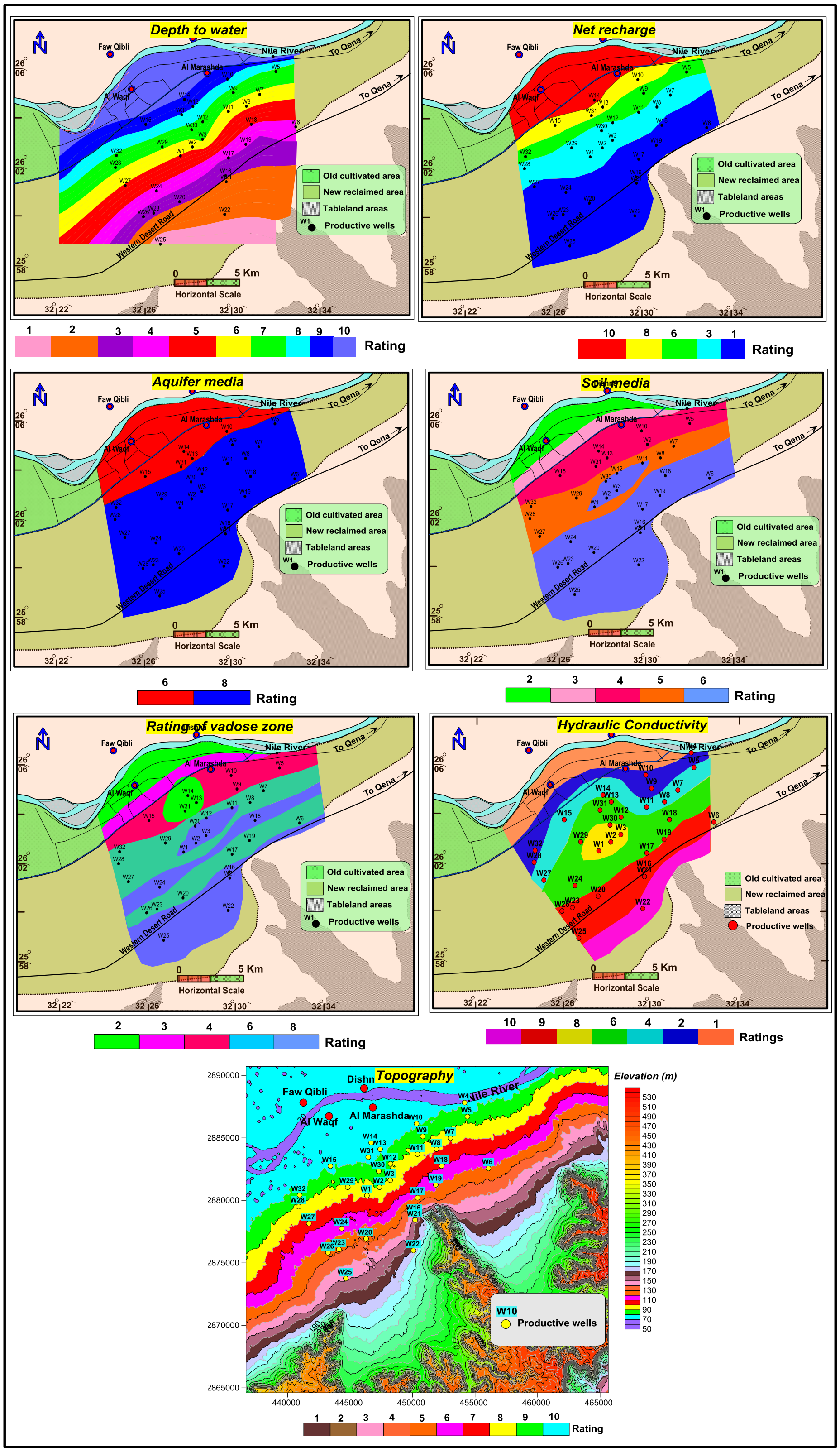

Fig.(20): Rating maps of the DRASTIC parameters of the study area

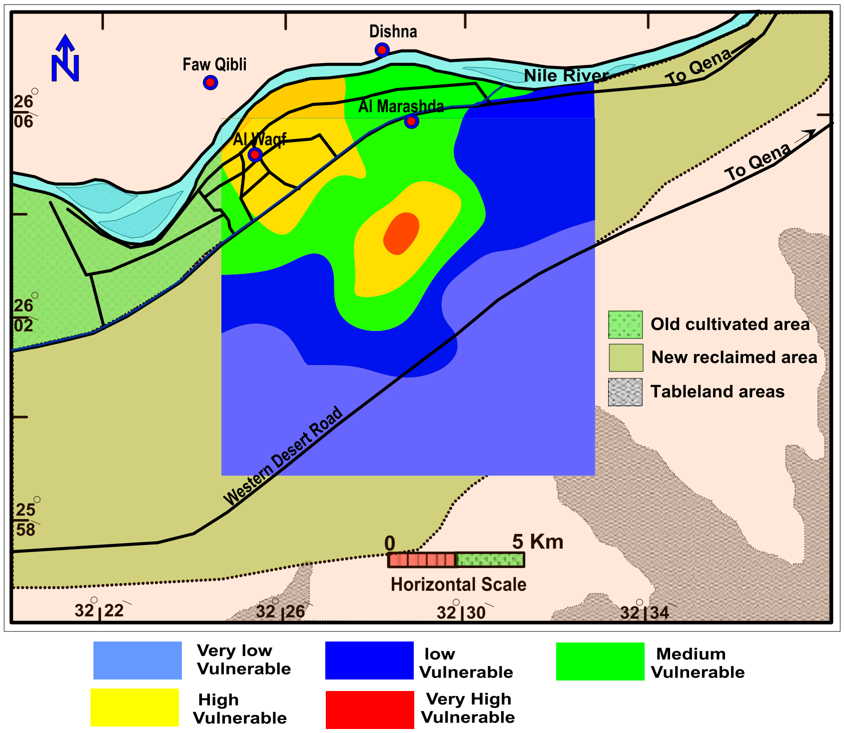

Fig.(21): DRASTIC vulnerability map of Al Marashda area

Table 1: Assigned weights for DRASTIC parameters

Parameters	Weight
Depth to water	5
Net Recharge	4
Aquifer Media	3
Topography	2
Soil Media	2
Impact of Vadose Zone	5
Hydraulic Conductivity	3

Table 2: Infiltration parameters of the studied areas

Site No.	Infiltration parameters		Initial intake Rate, cm/h	Basic infiltration rate (cm/h)	
	K	n		Value	Soil Class
1	0.62	0.90	73.00	19.71	Rapid rate
2	0.46	0.74	23.20	5.15	Moderately Rapid rate
3	1.06	0.65	33.19	6.47	Moderately Rapid rate
4	0.36	0.59	8.02	1.45	Moderately Rapid rate
5	0.38	0.53	6.30	1.00	Moderately rate

Table 3: Moisture %, total porosity, texture class of different locations of the study area

Location	Depths (cm)	Penetration Resistance, kg/cm^2	Moisture %	Particle size ratio (%)				Texture class	Bulk density gr/cm^3	Total porosity (%)
				Coarse sand	Fine sand	Silt	Clay			
1	0-20	1.63	3.14	69.20	3.58	23.22	4.0	**Loamy sand**	1.73	34.72
	20-40	2.45	1.9	69.33	3.60	23.20	3.87		1.80	32.41
	40-60	1.52	2.14	69.91	3.70	23.42	3.97		1.82	33.81
2	0-20	2.34	4.5	47.07	34.16	2.98	14.79	**Loamy sand**	1.30	47.79
	20-40	4.40	3.4	47.89	34.20	2.98	15.23		1.66	33.96
	40-60	2.45	3.5	47.04	34.72	2.99	15.25		1.83	32.52
3	0-20	9.75	4.4	42.23	3.77	27.57	26.43	**Sandy, clay loam**	1.51	48.99
	20-40	13	15.7	42.30	3.71	27.50	26.49		1.75	30.83
	40-60	13.1	10.2	42.32	3.71	27.47	26.50		1.82	37.24
4	0-20	5.3	11.6	59.02	4.47	28.15	8.56	**Sandy loam**	1.77	29.76
	20-40	7.1	11.5	58.02	5.47	28.20	8.31		1.79	31.15
	40-60	12.6	11.5	59.10	5.44	27.02	8.44		1.84	30.57
5	0-20	0.53	1.16	67.33	4.91	13.23	14.53	**Sandy loam**	1.55	41.51
	20-40	0.86	1.38	66.40	4.92	14.13	14.55		1.60	36.00
	40-60	0.92	0.84	67.18	4.95	13.30	14.57		1.70	27.97

Table 4: Pore size values of the studied soil samples.

Location	Depths (cm)	Moisture content at		Available Water	Moisture content at		Large pores	Medium pores	Small pores	Very Small pores
		0.1 Bar	15 bar		0.06 bar	Sat.				
1	0-20	3.38	1.09	2.29	2.85	12.21	16.22	1.55	3.96	12.99
	20-40	3.28	0.62	2.66	2.07	15.31	23.83	2.17	2.66	3.75
	40-60	3.48	0.64	2.84	7.89	19.38	20.91	8.03	2.84	2.03
2	0-20	11.17	2.82	8.35	6.90	14.10	9.36	5.55	8.35	24.53
	20-40	5.04	1.31	3.73	4.20	16.12	19.79	1.39	3.73	9.05
	40-60	4.03	1.0	3.03	4.04	20.38	17.90	3.03	2.44	9.15
3	0-20	14.67*	9.24	5.43	22.13	44.35	28.12	3.26	5.43	7.40
	20-40	15.59*	4.14	11.45	21.90	47.10	14.31	6.04	3.45	4.35
	40-60	17.14*	7.34	9.80	24.26	48.67	18.21	6.70	2.8	8.30
4	0-20	22.18	2.93	19.25	9.62	16.17	13.20	5.11	3.02	7.30
	20-40	12.28	3.27	9.01	8.64	18.92	15.24	4.12	4.69	6.11
	40-60	18.30	4.28	14.02	14.38	21.80	10.65	7.21	3.90	8.20
5	0-20	14.67	5.91	8.76	13.98	24.10	15.68	7.49	8.76	9.07
	20-40	15.59	2.95	12.64	9.37	26.17	14.10	8.10	4.02	9.30
	40-60	17.14	3.38	13.76	12.24	29.33	7.32	5.17	3.24	11.30

Site (3) Field capacity was determined at 0.33 bar

Table 5: Soil hydraulic conductivity K_s (m/Sec) in the studied area

Site No.	Hydraulic conductivity (m/Sec)	Class
1	243 X10^{-4}	Moderately Rapid
2	88.2 X10^{-4}	Moderate
3	79.9 X10^{-4}	Moderate
4	5.2 X10^{-4}	Slow
5	4.4 X10^{-4}	Slow

Table 6: Penetration resistance for different location of the study area

Sites	Depth	Penetration resistance Kg/ cm^2	Penetration resistance average Kg/ cm^2	Soil Moisture,%	Soil moisture Average %
Site 1	0-20	1.63	1.87	3.14	2.39
	20-40	2.45		1.90	
	40-60	1.52		2.14	
Site 2	0-20	2.34	3.06	4.52	3.80
	20-40	4.40		3.41	
	40-60	2.45		3.46	
Site 3	0-20	9.72	11.95	4.39	10.08
	20-40	13.0		15.69	
	40-60	13.1		10.16	
Site 4	0-20	5.30	8.33	11.63	11.54
	20-40	7.13		11.48	
	40-60	12.56		11.50	
Site 5	0-20	0.53	0.77	1.16	1.13
	20-40	0.86		1.38	
	40-60	0.92		0.84	

Table 7: Results of the interpreted VES curves.

VES No.	Elev. (m)	Geoelectrical layer (A)										Geoelectrical layer (B)						Geoelectrical layer (C)		
												B1		B2		B3		C_1		C_2
		ρ_1	h_1	ρ_2	h_2	ρ_3	h_3	ρ_4	h_4	ρ_5	h_5	ρ	h	ρ	h	ρ	h	ρ	h	ρ
1.00	85.00	91.30	0.55	6.49	14.90	—	—	—	—	—	—	17.00						—	—	—
2.00	104.00	565.00	1.66	409.00	4.31	8936.00	8.75	158.10	15.58	—	—	97.70	49.65					—	—	735.70
3.00	123.00	13720.00	0.85	3732.00	0.93	43606.00	3.38	1063.00	7.63	4952.00	33.60	59.30	47.60					—	—	631.00
4.00	148.00	32771.00	2.45	1131.00	21.90	97.00	23.70	—	—	—	—							—	—	1685.00
5.00	74.00	34.20	2.78	464.60	1.40	13.06	12.88	—	—	—	—	40.00						—	—	—
6.00	90.00	278.00	0.70	17.00	4.51	475.00	4.33	14.60	4.89	6.18	8.65	23.70	53.77			38.30		—	—	—
7.00	103.00	15849.00	1.03	541.00	20.00	484.00	0.48	1859.00	1.47	7374.00	13.30	45.22	50.50					—	—	423.00
8.00	135.00	410000.00	0.57	111318.00	1.79	11307.00	15.60	1856.00	44.00	—	—							293.00	20.90	2154.00
9.00	69.00	6.18	9.09	53.76	20.00	—	—	—	—	—	—	71.75	45.00	8.92				—	—	—
10.00	80.00	47.52	1.69	337.10	14.22	6.94	9.40	2.11	4.57	—	—	47.13	40.25	0.57	27.47			119.60		
11.00	98.00	2320.20	4.17	26780.40	2.17	961.00	6.62	2647.00	25.21	—	—	46.10	33.80	8.17	30.13			139.00		
12.00	140.00	70572.00	0.56	3465.20	3.62	28.68	0.28	429.40	24.92	14.17	27.44							242.40	24.30	546.00
13.00	69.00	3.54	0.56	2.19	1.93	11.90	21.56		—	—	—	25.67						—	—	—
14.00	80.00	120.10	2.57	9.35	0.80	807.30	2.72	59.85	5.68	4.13	19.51	38.50						—	—	—
15.00	98.00	1392.60	3.63	2990.70	1.76	30.95	4.22	421.10	7.33	28.72	9.16			10.10	14.56	68.80		—	—	—
16.00	110.00	13882.00	3.31	1192.80	7.97	189.90	14.14	1316.00	6.76	—	—	25.32	20.28	6.14	19.45	61.37	29.72	270.60	—	—
17.00	144.00	108324.00	0.39	23440.00	1.10	7022.80	13.20	1204.00	42.72	—	—							271.10	20.20	5423.00
18.00	110.00	12498.00	0.56	3349.00	0.82	237.70	0.07	349.90	9.11	928.00	30.00	86.49	39.70	7.04	23.79			—	—	1498.60
19.00	91.00	1407.50	0.66	282.90	1.63	37.20	5.86	3.43	11.77	—	—	48.19	11.48	3.40	22.05	52.16	23.73	—	—	71685.00
20.00	130.00	84637.00	1.46	2172.00	0.71	39874.00	0.60	6197.00	55.60	—	—	66.89	18.20	4.58	10.00			—	—	28187.00

Table 8: Resistivity, thickness ranges and the corresponding lithological composition of the detected geoelectrical layers:

Layer No.		Resistivity (Ohm.m)	Thickness (m.)	Lithological description
A		3 - 11152	15 - 61	Wadi deposits (Dry)
B	B1	17 - 98	11 - 53	Sand with clay intercalation (water bearing)
	B2	0.5 - 9	10 - 30	Sandy clay (waterbearing)
	B3	38 -86	24 - 30	Saturated clayey sand
C	C1	120 - 271	20 - 24	Fractured limestone (water bearing)
	C2	423 - 71685	------	Limestone

Table 9: Groundwater depth and level measurements of the studied wells

Observation well	Y	X		*DTW (m) Dec. 2014	*GE (m)	*WL(m) Dec. 2014
1	32.46885	26.04752	Quaternary aquifer	30	85	55
2	32.47653	26.05263		21	84.5	63.5
3	32.53222	26.09842		15	84	69
4	32.50987	26.07498		30	94	64
5	32.50005	26.0814		20	82	62
6	32.49553	26.09337		7	73.3	66.3
7	32.49617	26.07143		27	87	60
8	32.46282	26.07962		3	70.5	67.5
9	32.43338	26.06275		5	74	69
10	32.51927	26.05625		52.35	115.5	63.15
11	32.4904	26.0354		56	116.5	60.5
12	32.44447	25.9817		80	156	76
13	32.36772	26.02929		5	75	70

DTW Depth To Water *GE Ground elevation *WL Water Level

Table 10: Results of the pumping test analysis of the studied wells

Well	Transmissivity (m^2/day)	Storativity	Hydraulic Conductivity (m/day)
W6	258	0.00021	4.3
W10	155	0.0065	1.3
W11	236	0.00005	2.6
W18	370	0.0006	3.9
W24	187	0.0001	2.2
W30	420	0.0034	5.2
W32	356	0.00065	3.7

Table 11: Results of the chemical analysis of studied samples

well No	Ec	pH	TDS (ppm)	Major elements (ppm)							Minor elements (ppm)				
				Ca	Mg	Na	K	CO3	SO4	Cl	F	Br	NO3	PO4	Li
1	1908	7.1	743.85	37.33	26.33	194.50	3.55	0	164.5	291.5	1.1	0.2	12.5	0	0.0160
2	1124	6.9	485.99	16.16	12.55	145.50	2.68	6.06	96.7	194.5	1.1	0.05	4.2	0.2	0.1364
3	3670	6.9	1830.74	93.51	74.98	410.80	5.18	0	763.5	400.6	0.8	0.2	67.8	1	0.0500
*4 (Nile)	375	6.6	176.56	23.00	9.46	22.88	4.33	0	70.96	10.81	0.3	0.04	0	0	0.5333
5	4460	6.9	2393.86	190.73	68.03	487.07	6.39	0	1060	420.4	0.2	0.6	120.8	0.2	0.2000
6	2170	6.9	1014.08	60.72	26.84	266.85	3.85	6.06	298.7	330.8	1.1	0.3	2.5	0	0.2000
7	725	7.1	266.24	29.24	13.54	43.66	2.70	6.06	86.14	80.12	0.34	0.04	0.3	0.04	0.9706
8	3640	7	1855.18	119.85	48.11	425.97	5.45	0	795.4	375	1.8	0.2	70.6	0.4	0.0778
9	5700	7.1	2790.79	270.23	119.59	471.18	6.80	0	798	892.4	0.6	0.2	219	0.4	0.0833
10	720	6.9	275.55	31.31	17.67	39.11	3.11	6.06	86.92	80.72	0.26	0.04	0.04	0.04	1.0385
11	10670	6.9	6045.63	453.89	295.13	1077.86	9.68	0	1769	2160.7	0.3	1.25	262.1	0	0.7667
12	6700	7.1	3929.75	228.58	118.57	897.31	9.52	6.06	1598.2	854.4	1.8	0.2	196.2	0.8	10.4000
13	833	6.9	304.36	35.54	19.94	40.67	3.39	11.06	78.7	59.35	0.45	0.05	12.8	0.05	0.0444
14	1206	6.9	401.12	32.10	15.98	55.26	4.50	0	92	60.8	0.5	0.05	91	0.1	0.3400
15	1314	6.9	697.77	78.74	30.34	97.90	7.17	0	342	72.9	0.2	0.05	26.8	0.2	0.2000
16	2418	6.7	1052.49	41.81	30.45	301.56	4.48	0	190.5	434.9	2.3	0.4	10.1	0.2	9.6261
17	2326	6.9	1021.06	43.01	28.36	290.87	3.82	0	225.4	394.7	2.5	0.2	6.7	0.2	0.0480
18	1840	6.9	797.31	38.95	19.06	227.20	3.79	0	189.8	298.9	0.9	0.5	0.5	0	0.4000
19	1970	6.9	836.77	34.64	22.45	238.14	3.27	0	208.2	298	1.7	0.2	5.8	0	0.1353
20	2354	6.9	1051.28	55.32	19.63	298.75	3.16	0	257	389.8	1.4	0.2	13.8	0.8	0.2571
21	2517	6.9	1057.70	40.14	29.14	308.78	4.03	0	203.5	455.1	2.3	0.6	7.7	0	0.0652
22	2470	6.9	1107.51	55.72	32.96	299.27	4.84	0	302.9	398.8	2.7	0	0.1	0.3	0.1667
23	2690	7.1	1210.21	81.61	33.01	314.30	3.68	0	286.1	478.7	1.9	0.5	0.5	0.3	0.3684
24	2384	7	1049.08	52.72	18.27	312.34	2.71	0	212.8	436.7	1.2	0.4	2.4	0	0.3000
25	2627	6.9	1168.00	78.34	43.84	288.01	3.82	0	257.5	478.3	1.9	0	0.4	0.2	0.2947
26	2822	6.9	1231.88	93.28	42.45	297.11	3.45	0	286.8	496.5	1.4	0.1	0.7	0.3	0.5500
27	2800	6.9	1040.09	60.01	21.15	300.23	3.06	0	174.2	470.6	0.7	0.5	0	0.1	0.3000
28	2472	6.9	941.30	59.98	29.66	246.70	4.07	0	170	420.3	0.3	0	0.5	0.4	0.1667
29	5830	6.9	3188.46	201.18	127.55	674.75	6.37	0	956.4	985.4	1.2	1	227.4	0.6	0.4500
30	1537	6.8	765.34	23.25	16.91	212.54	2.90	0	268.35	194.25	0.9	0	33.45	0.15	0.3222
31	750	6.8	327.65	35.10	20.12	51.06	2.99	0	98.26	95.12	0.24	0.02	0.74	0.02	0.5000

***Nile water**

Table 12: Ranges and ratings of depth to water

Ranges (m)	Rating
< 2	10
2-5	9
5-10	8
10-20	7
20-30	6
30-40	5
40-50	4
50-60	3
60-70	2
>70	1

Table 13: Ranges and ratings of net recharge

Ranges (mm/year)	Rating
0-20	1
20-40	3
40-60	6
60-90	8
>90	10

Table 14: Ranges and ratings of aquifer media

Ranges	Rating
Massive shale	2
Glacial till	5
Bedded sandstone and shale sequence	6
Massive sandstone	6
Sand and gravel	8

Table 15: Ranges and ratings of soil media (Ckakraborty et al., 2007)

Ranges	Rating
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Clay	2

Table 16: Rating calculations of topography

Ranges of Elevation (m)	Area (m^2)	Average distance (m)	slope	Slope (%)	Rating
70 - 80	62838383	3091	0.003	18.8	10
80 - 90	37790297	1224	0.008	11.3	9
90 - 100	41786814	1150	0.009	12.5	8
100 - 110	36576434	980	0.010	10.9	7
110 – 120	35419065	840	0.012	10.6	6
120 – 130	28380447	650	0.015	8.5	5
130 – 140	26817218	580	0.017	8.0	4
140 – 150	24349353	610	0.016	7.3	3
150 – 160	21801951	465	0.022	6.5	2
160 - 170	19082686	380	0.026	5.7	1
Total	334842648			100	

Table 17: Ranges and ratings of vadose zone

Ranges	Rating
Clay	2
Clay and silt	3
Sandy clay	4
Clayey sand	6
Sand and gravels	8

Table 18: Ranges and ratings of hydraulic conductivity

Ranges (m/day)	Rating
1.3	1
2.2	2
2.6	4
3.7	6
3.9	8
4.3	9
5.2	10

Table 19: the estimated DRASTIC Index (DI) of the study area

Well NO.	D	R	A	S	T	I	C	DI	Well NO.	D	R	A	S	T	I	C	DI
1	25	12	24	12	16	40	24	153	17	20	4	24	12	10	30	18	118
2	30	12	24	12	16	40	24	158	18	25	4	24	12	14	40	18	137
3	35	12	24	12	16	40	24	163	19	20	4	24	12	12	30	18	120
5	35	24	24	8	20	20	6	137	20	15	4	24	12	10	30	27	122
6	20	4	24	12	10	30	27	127	21	15	4	24	12	8	40	27	130
7	30	12	24	10	16	30	12	134	22	10	4	24	12	2	40	30	122
8	30	12	24	10	16	30	12	134	23	15	4	24	12	10	30	27	122
9	35	24	24	8	18	20	6	135	24	20	4	24	10	12	40	18	128
10	45	32	18	8	12	20	6	141	25	5	4	24	12	8	40	27	120
11	30	24	24	10	16	40	12	156	26	15	4	24	12	10	30	27	122
12	35	24	24	12	18	40	18	171	27	25	4	24	10	14	30	12	119
13	40	32	18	8	20	10	12	140	28	35	12	24	10	16	30	6	133
14	45	40	18	8	20	10	12	153	29	20	12	24	10	16	30	18	130
15	45	32	18	8	20	20	12	155	30	35	12	24	10	18	40	24	163
16	15	4	24	12	8	40	27	130	31	40	32	18	8	20	10	18	146

D is the depth to water, R is the net recharge, A is the aquifer media, S is the soil media (texture), T is the topography (slope), I is the impact of the vadose zone, C is the hydraulic conductivity and DI is the DRASTIC index.

Table 20: Aquifer vulnerability classes of Al Marashda area according to the DRASTIC Index values

Vulnerability degree	DI value
Very Low Vulnerable	<130
Low Vulnerable	130-140
Medium Vulnerability	140-150
High Vulnerability	150-160
Very high Vulnerability	>160