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GROUNDWATER QUALITY ASSESSMENT OF QUATERNARY AQUIFER, WADI QENA BASIN, EASTERN DESERT, EGYPT.

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ABSTRACT

The present study focused on assessing the quality of groundwater of the Quaternary aquifer in Wadi Qena Basin to deduce its suitability for different purposes according to the World Health Organization and Egyptian standards. Groundwater samples are collected from twenty three water points and analyzed to determine physicochemical parameters. Two effective techniques are used to develop the assessment of groundwater quality in the concerned aquifer; Groundwater Quality Information Mapping and Water Quality Index Estimation and mapping. Geographic Information System (GIS) was used to establish the integration of attribute data base and spatial data base for the studied aquifer. Therefore, by using GIS Tools; spatial interpolation Inverse Distance Weighted (IDW) as well as Reclassify and Weight Overlay methods are carried out to generate Water Quality Information map for the concerned aquifer. The Water Quality Index (WQI) estimation and mapping is used to generate WQI map by using GIS spatial IDW method. The obtained maps delineated the groundwater in studied aquifer into zones according to its suitability for human consumption. These maps revealed congruent results, where most of groundwater in this aquifer exists in the Not-suitable zone for drinking purposes however; it is suitable for irrigation purposes. The best sites for groundwater extractions from the Quaternary aquifer in Wadi Qena Basin are detected at the eastern side of the study area; where the groundwater exists in the Potable zone which suitable for drinking and human consumption. The spatial data base constructed in GIS technique is helpful for monitoring and managing groundwater quality of the Quaternary aquifer in the study area.

Keywords: Groundwater quality assessment, GIS, Water Quality Index (WQI), Wadi Qena Basi

INTRODUCTION

Groundwater in Wadi Qena Basin is available from different water bearing formations, occurring under different hydrogeologic conditions. These aquifers from the younger to the older are: Alluvium aquifer (Quaternary), Carbonate and sandstone aquifer (Eocene-Pliocene), Nubia sandstone aquifer (Turonian-Santonian) and Fractured basement complex aquifer (Precambrian) (Hussien, 2017). These hydrogeologic features control the groundwater occurrence, movement and quality. The Quaternary aquifer represents the most promising water bearing formation in the study area. Currently, it is the main source of water for the inhabitants at Wadi Qena Basin. The quality of groundwater in this aquifer is affected by variable sources of pollution. Mixing from waste water and agrochemicals, due to urbanization and agricultural activities, is the main pollution sources detected by Fathy et al., (2009). Ahmed et al., (2017) presented an integrated geoelectrical and hydrogeological study on Wadi Qena basin; and concluded that; the groundwater in the study area is unsuitable for drinking and other domestic uses and could be used for irrigation and some industrial activities under certain precautions. This study represents an assessment for groundwater quality of the Quaternary aquifer in Qena Basin to obtain optimal results help in groundwater management in this basin. Two effective techniques are used to develop the groundwater quality assessment in the concerned aquifer; Groundwater Quality Information Mapping and Water Quality Index Estimation and mapping.

The present study used GIS as a helpful tool that provides a good integration of various data bases (attribute data base and spatial data base) for the studied aquifer. Several studies have used GIS as a data base system in order to obtain maps of water quality according to concentration values of different chemical constituents such as Skubon, 2005; Yammani, 2007, Balakrishnan et al., 2011. WQI estimation and mapping technique is used to assess the suitability of groundwater for human consumption. It is initially proposed by Horton (1965) and Brown et al, (1970), then many different methods for the WQI's calculation have been developed by Debels et al., 2005; Saeedi et al., 2009; Tsegaye et al., 2006 and others. The main objectives of this study are: (1) to cast light on the hydrogeological sitting of the aquifer, (2) to assess the physicochemical characteristics of the groundwater and generate Water Quality Information map, (3) to obtain Water Quality Index (WQI) map, and (4) to discuss the effects of each water quality parameter on the WQI values.

STUDY AREA

The area of study occupies the southern part of Wadi Qena Basin (Fig. 1). Many previous studies have investigated the geomorphological, geological, and hydrologic features of the Wadi Qena. Aggour (1997) described the geomorphologic and geologic conditions of the wadi. Elewa et al. (2000) described the landforms of Wadi Qena basin. Based on the topographic, geologic maps, DEM and Landsat images besides field observations; Hussien, (2017) subdivided the area of study into two main landforms as shown in figure 2. Geology of the area has been studied by many authors among them are Said (1962, 1971, 1990), Ahmed (1983), El-,Shamy (1988), El-Hussaini et al. (1994), Abu El-Ella (2004), Galal (2005) Elewa et al. (2006), Elmalt (2008), , Abdel Gowad (2010), Seleem et al. (2013), Seleem (2014) and Abdel Moneim (2014). Based on the literatures; the lithostratigraphic succession of the study area ranges in age from Precambrian to Quaternary. Figure 3 shows the rock units and geologic formations along the area of Wadi Qena Basin. According to Aggour 1997 and RIGW 1998; the Quaternary alluvial deposits in the study area are formed of sand, gravel, and boulders filling the courses of the hydrographic drainage network. These sediments have great potentiality to store and transmit great amounts of groundwater. These deposits consist of the weathering products of the Cretaceous and Tertiary rocks. They have lateral and vertical variations in the lithological composition according to the dominated rock exposures through the hydrographic basins. The thickness of the Quaternary alluvial deposits varies laterally across Wadi Qena stream because of the undulation of subsurface strata and differential erosion of the surface layers. The thickness of these deposits generally decreases toward the Red Sea Mountains and increase toward the Nile Valley. Generally, the thickness is increasing downstream of the wadi, where it exceeds 100 m. The Quaternary aquifer in the study area is recharged directly through the infiltration of the local precipitation as well as the upward leakage of groundwater from the deep Nubia sandstone aquifer through the deep seated NW-SE faults which act as conduits for groundwater as shown in figure (4). Elewa et al., (2000) and Elewa and Abu El-Ella (2011) indicated the hydraulic connection between the Quaternary aquifer and the underlying Nubian aquifer system in Wadi Qena through the structural region.

Fig. 1: Location map of the study area showing the distribution of water samples from Quaternary aquifer in Wadi Qena basin.

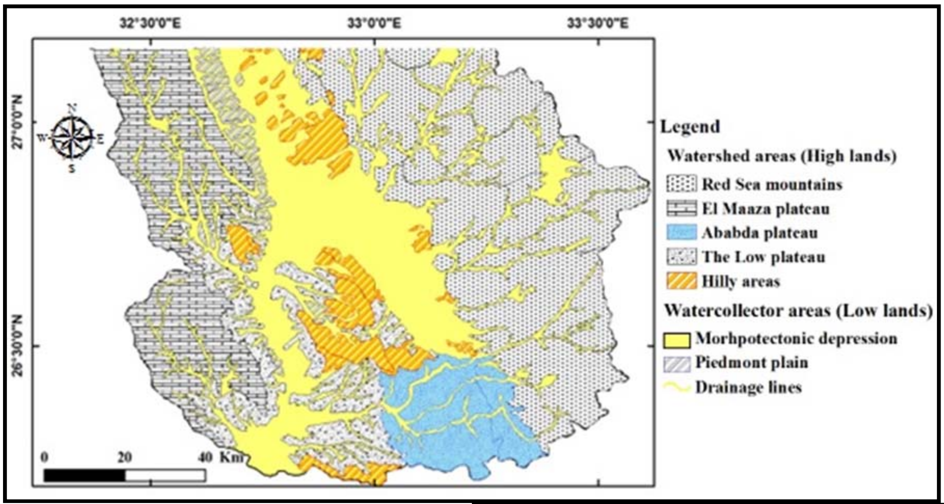

Fig. 2: Geomorphologic map of Wadi Qena Basin, Easter Desert, Egypt. (After Hussien, 2017).

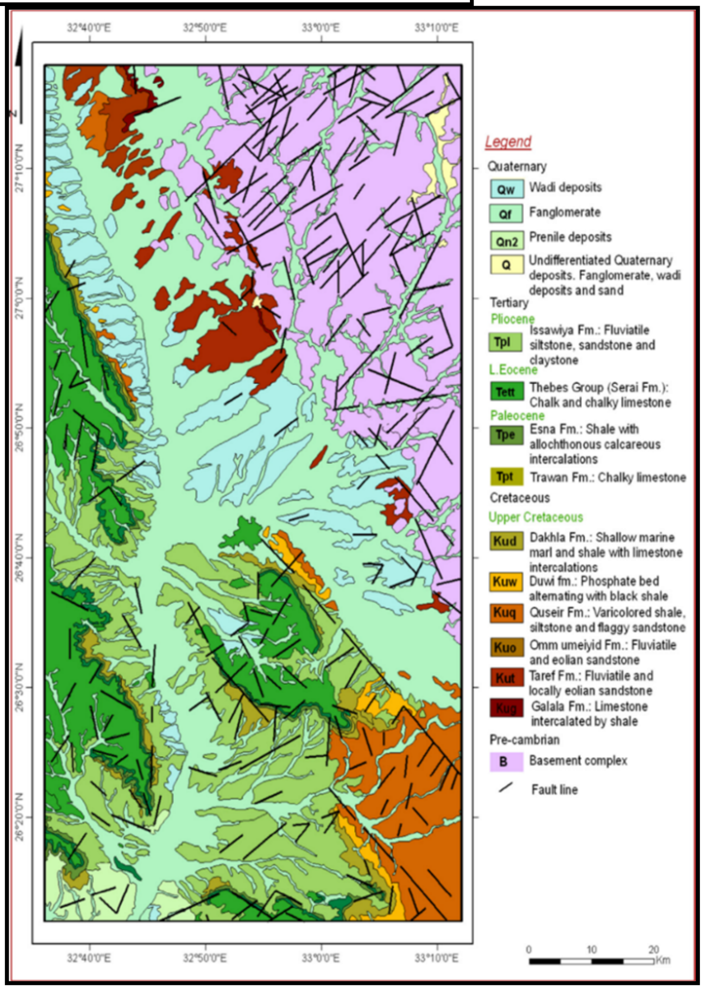

Fig. 3: Geologic map of the study area (After Conoco, 1987).

METHODOLOGY

Groundwater levels in twenty- three wells penetrating the Quaternary aquifer in the study area were measured using a suitable water level meter (See fig.1). Groundwater samples were collected from these wells and analyzed for physico-chemical parameters following US Environmental Protection Agency, 1997 (USEPA) method 300.1. The anions (SO_4^{2-}, Cl^-) and cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) concentrations were measured by Dionex Ion Chromatograph (Model: ICS 1100). While, carbonate and bicarbonate (HCO_3^-, CO_3^{2-}) were determined by titration using sulfuric acid according to the methods of Rainwater and Thatcher (1960) as well as Fishman and Friedman (1985). The measurements were conducted at the laboratories of Hydrogeochemistry Department, Desert Research Center, Cairo, Egypt.

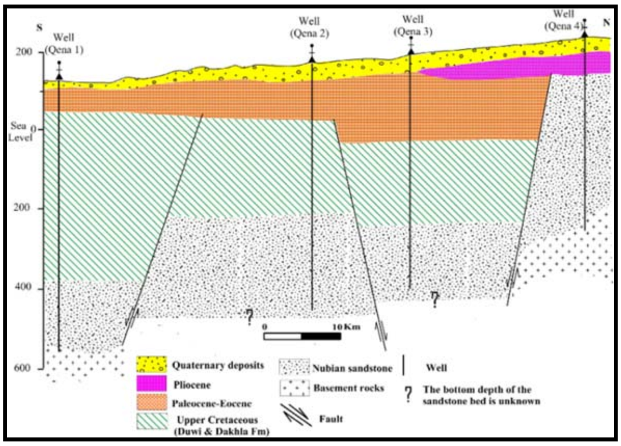

Fig. 4: N-S Geologic cross-section along traverse A-A′ in Fig. (1). (Modified after Garpad, 1985)

Methodology used in this study is summarized in the flow chart as shown in figure 5. Two techniques were used to assess the groundwater quality of the concerned aquifer for drinking and human consumptions; Groundwater Quality Information Mapping and Water Quality Index Estimation and mapping.

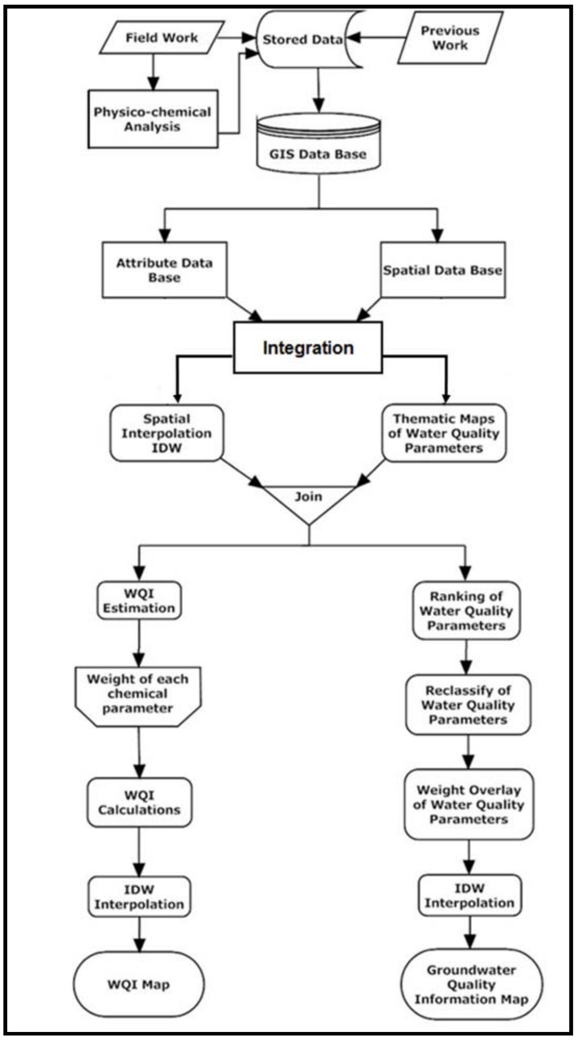

Fig. 5: Flowchart showing the main materials, techniques, tools and methods used in this study.

Groundwater Quality Information Mapping

This technique is used to delineate the spatial variations of groundwater quality in the study area for different purposes and classify the groundwater into three zones Potable, Permissible and Non-potable zone; as the following:

i. Spatial distribution thematic maps of water quality parameters TDS, TH and Cl^- (Skubon, 2005; Yammani, 2007, Balakrishnan et al., 2011) are obtained by integration of attribute data base (water quality data) and spatial data base in Arc GIS software.
i. Inverse Distance Weighted (IDW) method in GIS tools is used to delineate the spatial interpolation of groundwater pollutants.
ii. Based on WHO (1996 b, 2004 and 2011) standards for water quality, each water quality parameter is ranked according to its criteria for suitability and non-suitability (table 1).
iii. A reclassified thematic map is produced for each water quality parameter according to its ranking criteria.
iv. Arc GIS Spatial Analyst extension is used to weight overlay the reclassified thematic maps by weights; 40% TDS, 30% Cl^- and 30%TH and finally obtain spatial integration for groundwater quality zone (Potable, Permissible and Non- Potable) map for drinking purposes. Total hardness (*TH*) and sodium adsorption ratio (*SAR*) of groundwater samples were calculated according to Todd (1980).
v. GIS spatial interpolation technique with Inverse Distance Weighted (IDW) method is used to generate spatial distribution groundwater quality information map for drinking based on TDS classification after WHO (2011) and Davis and De Wiest (1966) (Table 2)
vi. The groundwater quality map for irrigation purposes is generated by equal (50%) weight overlay of the reclassified thematic maps of TDS and SAR.

Water Quality Index Estimation (WQI) and Mapping

This technique is used to assess the suitability of groundwater in the study area for human consumption. The WQI in this study is calculated following the method described; Sahu and Sikdar (2008), Raychaudhuri et al., (2014), Asadi et al., (2007) and Pradhan et al., (2001) as following:

Each of chemical parameters (pH, TDS, TH, CL^-, SO_4^{2-}, HCO_3^-, Na^+ , Ca^{+2}, Mg^{+2}, K^+) has been weighted (wi) from 1 to 5 according to its environmental and healthy effect (Table 3) (Dwivedi and Pathak, 2007, Srinivasamoorthy et al., 2008 and Mouna et al., 2011).

Table 1: Criteria for acceptability of water quality parameters based on WHO (2011)

Parameter	Rank	Criteria	Acceptability
TDS	1	<500	Desired
	2	500-1000	Acceptable
	3	>1000	Not Acceptable
TH	1	<500	Desired
	2	500-1000	Acceptable
	3	>1000	Not Acceptable
Cl^-	1	<250	Desired
	2	250-1000	Acceptable
	3	>1000	Not Acceptable

Table 2: Groundwater classification according to Davis and De Wiest, 1996.

Water Type	Concentration of dissolved constituent ppm)
Fresh Water	0-1,000
Brackish Water	1,000 -10,000
Saline Water	10,000 - 100,000
Brine Water	> 100,000

Table 3: Water quality parameters, WHO standards and assigned unit weights

Chemical parameter	WHO standard	Weight (w_i)	Relative weight (WI)
pH	8.5	3	0.107143
TDS (mg/l)	500	5	0.178571
Cl^-(mg/l)	250	3	0.107143
TH	300	4	0.142857
SO_4^{-2}(mg/l)	250	3	0.107143
HCO_3^- (mg/l)	120	2	0.071429
Na^+ (mg/l)	200	3	0.107143
Ca^{2+} (mg/l)	75	2	0.071429
Mg^{2+} (mg/l)	50	2	0.071429
K^+ (mg/l)	12	1	0.035714
		$\sum w_i=28$	$\sum WI=1$

i. WQI is calculated by applying equations [1- 4]:

The relative weight: $\mathbf{WI} = \frac{wi}{\sum_{i=1}^{n} wi}$ **(1)**

The quality rating: $qi = \frac{Ci}{Si} \times 100$ **(2)**

Ci is the concentration of each chemical parameter in each water sample in mg/l

Si is the WHO standard for each chemical parameter in mg/l.

$SIi = \mathbf{WI} \times qi$ **(3)**

WQI$=\sum SIi$ **(4)**

ii. WQI values are classified into five classes according to the type of water (Sahu and Sikdar, 2008) for human consumption (Table 4).

iii. GIS spatial interpolation technique with Inverse Distance Weighted (IDW) method is used to obtain WQI spatial distribution map.

Table 4: WQI values classification (Sahu and Sikdar, 2008)

WQI Value	Water Quality
< 50	Excellent
50 -100	Good
100 – 200	Poor
200 – 300	Very Poor
> 300	Unfit for human consumption

RESULTS AND DISCUSSIONS

The results of field measurements and phsico-chemical analysis for the collected groundwater samples are shown in table 5. The Quaternary aquifer in the study area is characterized by unconfined conditions and the depth to water from ground surface ranges from 2.7m (msl) (at well no.2&3) to 35.95m (msl) (at well no. 51). The water table map of the concerned aquifer (Fig. 6) shows recharge area at the northeastern part of study area; this is attributed to the presence of recharge sources from the upward flow from Nubia sandstone aquifer through NW-SE faults and fractured basement rocks as well as the surface recharge from the upstream courses of wadies of alluvium deposits. So the flow direction of groundwater in this aquifer is defined from the northeast to southwest. A second direction of flow is from north to south direction due to excessive pumping for irrigation activities at the south part of the studied area, where the estimated discharge from shallow dug wells and open pits reaches 107m^3/hour and the total drawdown after 4 hours pumping reaches 1.22m (EDP, 2006).

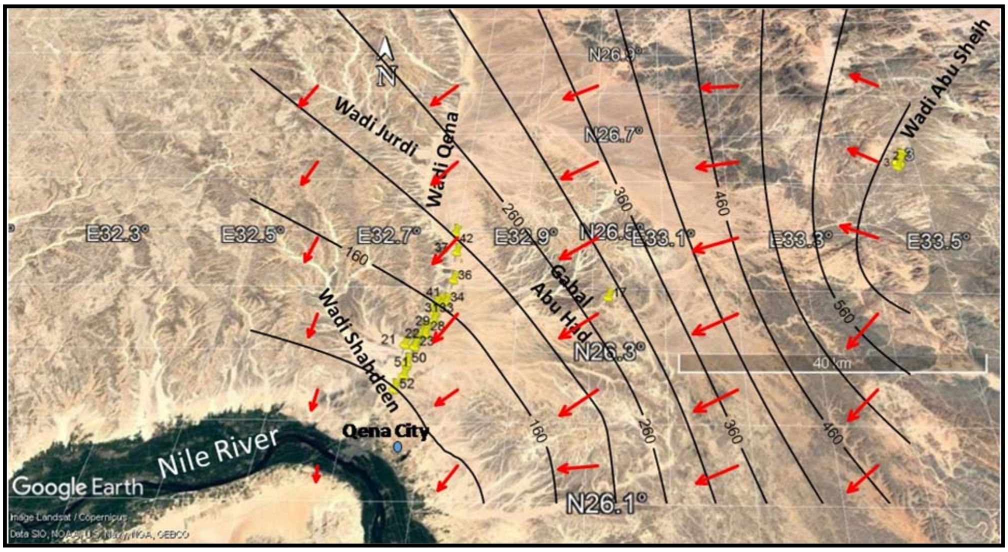

Fig.6: Water table map for the Quaternary alluvium aquifer at Wadi Qena basin, Eastern Desert Egypt.

Groundwater Quality Assessment

i. Evaluation of Groundwater for Drinking

The total dissolved solids (TDS) of groundwater in the concerned aquifer comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates). The concentrations of TDS in water vary considerably from locality to another locality owing to differences in the solubility of minerals forming the water- bearing formations. Where the TDS values vary greatly between 587 mg/l at well no. 2 to 36507 mg/l at well no. 34. The low salinity values are attributed to the replenishment from fresh groundwater recharge sources at the eastern part of the study area. The high salinity values are attributed to dissolving processes of natural salts present in the host sediments and soil in addition to recycling and leaching through irrigation. Based on Davis and Dewiest classification (1996), three main types of groundwater which are; fresh, brackish and saline waters are recorded in the studied water samples (Fig. 7).

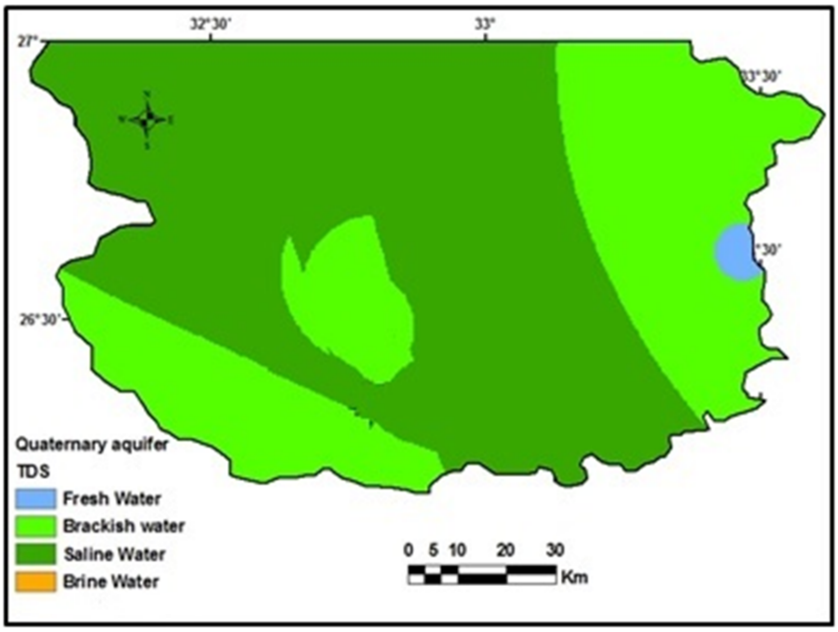

Fig.7: TDS Spatial distribution based on Davis and Dewiest classification (1996)

Table 5: Values of various physico-chemical parameters for groundwater samples, of the Quaternary aquifer, in Wadi Qena basin.

Well No.	Water Level (m amsL)	TDS mg/l	TH mg/l	Ca^{++} mg/l	Mg^{++} mg/l	Na^{+} mg/l	K^{+} mg/l	CO_3^{--} mg/l	HCO_3^{-} mg/l	SO_4^{--} mg/l	CL^{-} mg/l	pH	E.C μMhos/cm	SAR
34	112	36507	16520.28	3939.47	1627.22	7442.45	80.66	0	56	2851.08	20510.5	7.71	38400	25.18
35	116	4917	1836.138	501.28	142.18	950.48	21.3	0	79.33	1377.84	1844.12	8.11	6160	9.65
2	648.3	587	78.185	22.91	5.1	133.54	3.58	9.18	302.99	74.65	34.75	8.69	610	6.57
3	647.1	598	67.353	20.25	4.08	150.62	1.5	4.59	312.66	75.11	29.18	8.75	672	7.98
17	195.82	32432	2282.254	575.16	205.94	9322.53	131.13	0	177.33	20138.98	1881.11	8.39	27670	84.86
21	75	5765	2234.723	587.57	186.78	1122.04	27.19	0	112	1870.79	1858.9	8.3	7160	1032
22	71.86	5163	1781.805	490.83	135.3	1084.92	18.58	0	88.66	1656.18	1688.9	8.23	6610	11.18
23		6009	2229.149	595	180.89	1227.25	42.72	0	84	1976.38	1902.31	8.17	6780	11.3
24		7653	2819.917	781.32	211.37	1485.91	20.47	9.18	112	2365.67	2667.42	8.14	9440	12.17
25		9194	3517.95	971.35	265.75	1742.67	26.53	0	121.33	2659.38	3407.46	8.15	10950	12.78
26	74.07	7683	2915.341	806.96	219.01	1499.45	25.41	0	107.33	2371.02	2653.62	8.18	9610	12.08
28	106	17076	6655.5	1769.22	544.5	3400.32	54.86	0	121.33	2403.03	8783.15	7.94	21640	18.13
29	98.5	6619	2504.502	676.31	198.47	1333.64	31.63	0	74.66	1859.56	2444.77	8.1	8260	11.59
30	102	11515	5619.346	1680.2	346.06	1773.07	35.45	0	56	2269.51	5355.17	7.88	14420	10.29
31	11	10329	4089.717	1195.35	268.62	2007.98	29.97	0	74.66	1907.56	4845.13	7.97	13600	13.66
33	108	10072	3936.212	1106.15	285.57	1903.86	30.5	0	195.99	2454.85	4095.1	7.62	12640	13.2
36	124	4029	1712.31	474.84	128.1	677.58	16.34	0	93.33	1201.56	1437.15	7.74	5050	7.12
37	132	5948	2676.669	779.42	177.59	943.32	18.15	0	167.99	1687.65	2173.48	7.58	7270	7.93
41	115.8	7228	2707.473	774.21	188.28	1422.8	20.11	0	93.33	1597.34	3131.9	7.61	9190	11.89
42	133	6918	2843.4	795.83	208.25	1208.35	25.53	0	65.33	2172.54	2442.29	7.29	8350	9.86
50	72.44	6138	2463.283	595.19	237.88	1130.81	32.76	0	65.33	1966.72	2109.33	7.94	7690	9.91
51	69.85	10315	3162.529	787.46	291.19	2218.24	62.09	0	167.99	3307.58	3480.77	7.86	12170	17.15
52		8984	2383.634	588.16	222.74	2190.8	21.07	0	121.33	2032.47	3807.44	7.69	11440	19.51

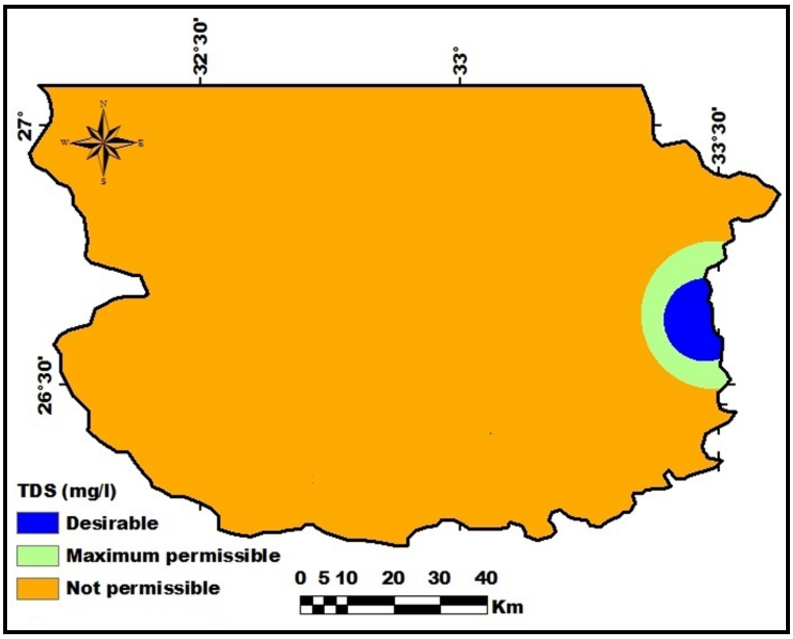

Fig. 8: TDS spatial distribution map for drinking in the study area according to WHO (2011).

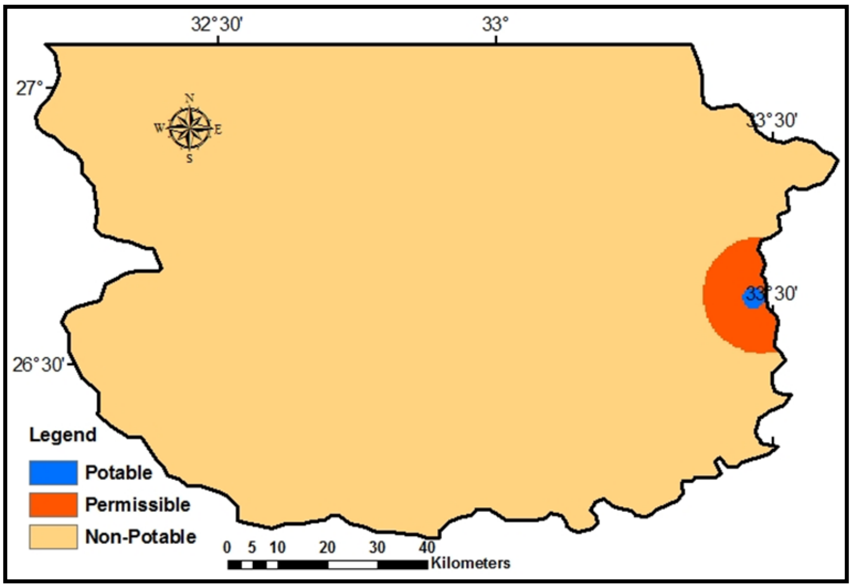

Fig. 9: Groundwater Quality Information Map for drinking in the study area.

ii. *Evaluation of groundwater for livestock and poultry*

The National Academy of Science NAS (1972) put the principle criteria for evaluation of the water for livestock depending on the concentration of total dissolved solids (Table 6). The concentrations should not exceed 5,000 ppm as far as possible. However, the animals can drink water with moderately high dissolved solids (about 10000 ppm) when Na Cl is the main constituent. Figure (10) shows the spatial distribution of TDS in the study area based on NAS, 1972 classification. It is obvious that the majority of groundwater in the studied aquifer belongs to class 6. Relatively lower salinity is found at the western part of the study area. Gradual decreasing in groundwater salinity occurs to the east direction of the study area results in different groundwater characters for different uses.

The TDS spatial distribution map for drinking purposes in the study area according to WHO (2011) (Fig. 8) shows that almost all the groundwater in the area exceed the permissible limit and unsuitable for drinking except at the eastern part of the study area.

As a result of the Water Quality Information mapping technique; the obtained Water Quality Information map (Fig. 9) detected that the groundwater in the study area is Non-potable except at the eastern part of the wadi where the groundwater ranges from permissible to potable.

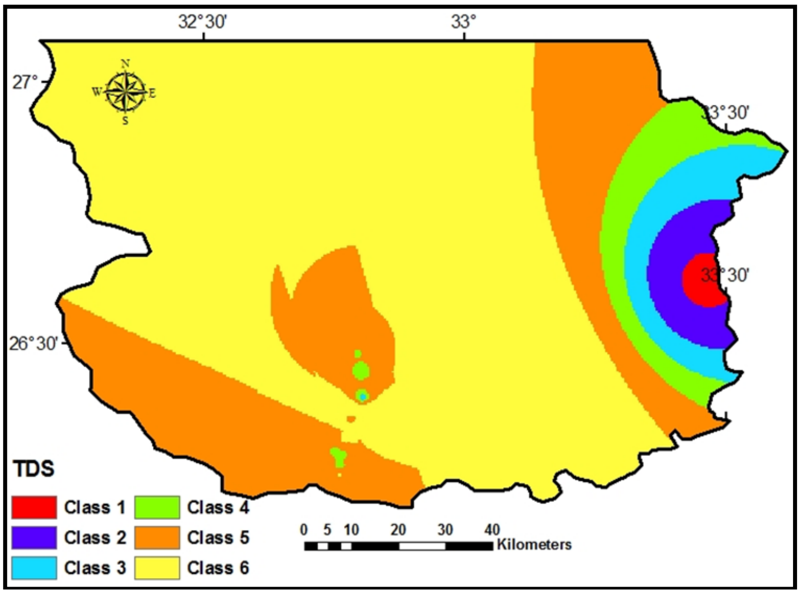

Fig.10: Groundwater quality map for livestock and poultry in the study area based on NAS, 1972 Classification.

iii. Evaluation of groundwater for irrigation

Based on the groundwater quality mapping technique; Groundwater Quality map for irrigation purposes by equal weighting of TDS and SAR is obtained (Fig. 11). It reflects that most of the groundwater in the study area has excessive salinity and undesirable ion exchange. Except some scattered small areas located at the eastern and western parts are of good groundwater characters.

Table 6: Classification of groundwater for livestock and poultry (National Academy of Science, NAS 1972).

Class	Concentration (TDS)	Characters
1	< 1,000	Excellent for all classes of livestock and poultry
2	1,000 - 2,999	Very satisfactory for all classes of livestock and poultry.
3	3,000 - 4,999	Satisfactory for livestock
4	5,000 - 6,999	Can be used with reasonable safety
5	7.000 - 10,000	Unfit for poultry and probably for swine
6	> 10,000	Not recommended for use under any conditions

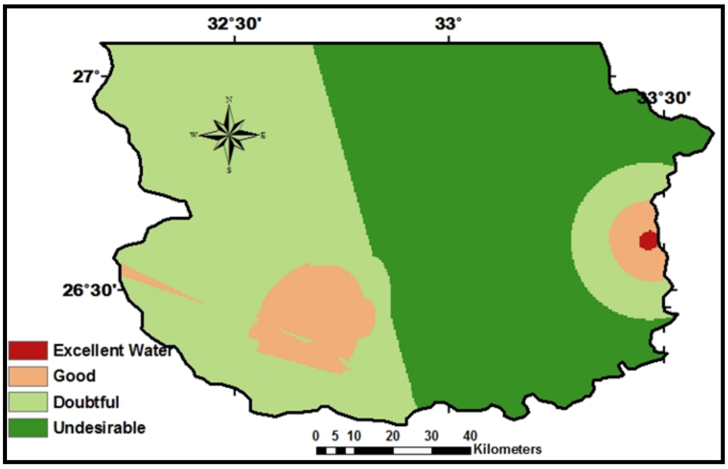

Fig.11: Groundwater Quality map for irrigation purposes by Equal Weighting of TDS and SAR.

CONCLOUSION

The present study introduces a new sight for the groundwater quality of the Quaternary aquifer in Wadi Qena Basin, Eastern Desert, Egypt. Two effective techniques are carried out to assess the groundwater quality in the concerned aquifer which are; Groundwater Quality Information Mapping technique and Water Quality Index Estimation and mapping technique.

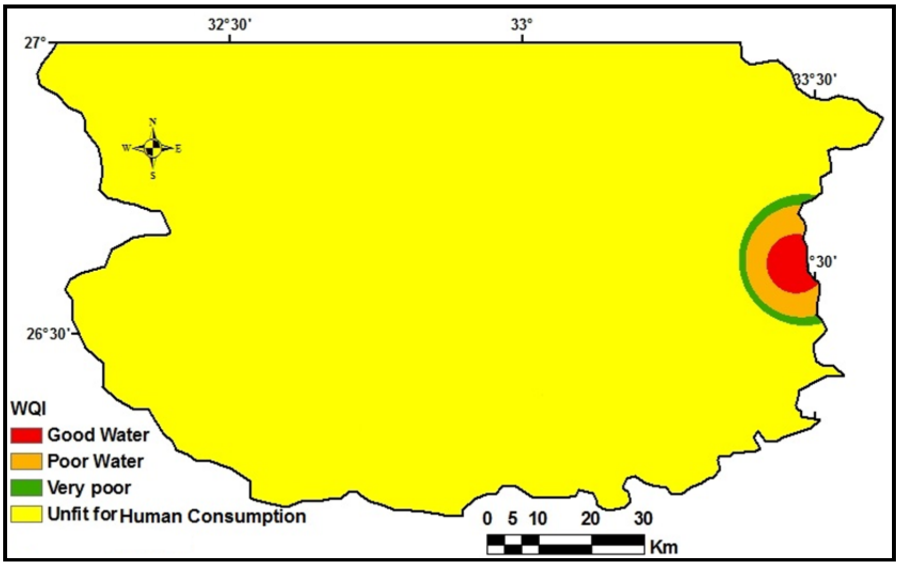

Fig.12: Water Quality Index map in the study area.

The GIS is used as a helpful tool to integrate, analyze and display of both attribute data base (non-spatial) and spatial data base of the study area. The resultant maps from the applied techniques revealed that, the groundwater in the eastern portion of the studied aquifer exists in the Potable zone and is suitable for human consumption. This is mainly attributed to the direct replenishment from the nearby watershed area and the lithologic composition of the parent rocks which are formed mainly of granite as well as its closeness to recharge sources from the fractured basement rocks and the Nubia sandstone water through NW-SE deep seated faults. The best sites for groundwater extractions from the Quaternary aquifer in Wadi Qena Basin are detected at the eastern side of the study area. At the western portion of the concerned aquifer; the groundwater exists in the Not-potable zone, and Un-fit for human consumption, while it is suitable for irrigation, livestock and poultry purposes under certain constraints. High evaporation intensity of shallow groundwater, continuous withdrawing of the water play an effective role in the groundwater degradation in the study area. At the downstream portion of Wadi Qena the total salinity is very high due to high leaching from the gypsferous and saliferous shales in addition to the excessive extraction from the aquifer for different human purposes. Continuous monitoring and earnest groundwater quality management are necessary for the present status of groundwater in the study area.

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تقييم جودة المياه الجوفيه في خزان العصر الجيولوجي الرباعى، حوض وادى قنا، الصحراء الشرقية، مصر.

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الخلاصة

تهدف الدراسة الحالية الى تقييم جودة المياه الجوفية في خزان العصر الجيولوجى الرباعي في حوض وادي قنا، الصحراء الشرقية، مصر وذلك لصلاحيتها للشرب والري ، وتربية الماشية والأغراض المنزلية طبقاً "منظمة الصحة العالمية" والمعايير المصرية .

تم جمع عدد ٢٣ عينة من المياه الجوفية وتم تحليلها كيميائيا . باستخدام نظم المعلومات الجغرافية، تم دمج البيانات المكانية وغير المكانية لمنطقة الدراسة. تقنية تقدير جودة االمياه(WQI) استخدمت لتقييم مدى ملاءمة المياه الجوفية في منطقة الدراسة للاستهلاك البشري. تقنية نظم المعلومات الجغرافية المكانية لإنتاج خريطة معلومات عن نوعية المياه الجوفية وتوزيعاتها فى منطقة الدراسة .

تم استنتاج خريطة (WQI) للمياه الجوفية و توزيعاتها في منطقة الدراسة . تشير النتائج التي تم الوصول اليها في هذه الدراسة إلى تدهور ملحوظ فى نوعية المياه الجوفية في منطقة الدراسة . كما ان معظم المياه الجوفية في منطقة الدراسة غير مناسبة لأغراض الشرب ولكنها مناسبة لأغراض الري . ما عدا في الجانب الشرقي من حوض وادي قنا حيث وجد ان المياه الجوفية صالحة للشرب وصالحة للاستهلاك البشري .