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Estimation of Recharge Quantity of the Fractured Basement Aquifer in the Southern Portion of Eastern Desert, Egypt; Critical Importance of the Hydrological and Chemical Criteria

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Abstract: The Fractured basement aquifer constitutes a valuable groundwater source in the southern portion of the Eastern Desert especially in the Nile River side. It is distinguished into four water bearing formations (fractured metavolcanics, fractured metasediments, fractured Plutonic and fractured Hammamat aquifers). The main recharging source of this aquifer is the direct rainfall. Groundwater salinity ranges from 579 ppm to about 3513 ppm. The basement catchment area receives an average annual rainfall depth of about 12.3 mm while the maximum monthly rainfall was recorded as 68.8 mm in May 1972. The annual rainfall depth of 15.8 mm has a probability of exceedance of about 26 % while the maximum annual rainfall (68.2 mm) has a probability of about 2.9% every 34 years. Five hydrographic basins characterize the area; Wadi Midrik, Wadi Beizah, Wadi Shait, Wadi Natash and Wadi Kharit. The drainage characteristics of terrain surfaces of these basins were automatically computed applying WMS Software. Two methods were used to estimate the groundwater recharge of the fractured basement aquifer. One of these methods depends on chemical basis (chloride method), while the second method is depending on hydrologic criteria (the SCS Curve number method). According to the chloride method, the estimated recharge rate is about 0.89 % of the total annual recharge. On the other hand, the SCS Curve number method reflected that, the fractured basement aquifer receives about 1.5 million m^3 of water from Wadi Midrik, 0.8 million m^3 from Wadi Beizah, 1.6 million m^3 from Wadi Shait, 2.3 million m^3 from Wadi Natash and about 1.7 million m^3 from Wadi Kharit. The total amount of water recharging the fractured basement aquifer is estimated as 7.8 million m^3.The study area has promising water potentiality, so more studies are needed to assess it. It is highly recommended to drill groundwater wells at the basin's outlets and sheer zones of the basement rocks.

Key words: Groundwater · Recharge · Eastern Desert and Fractured basement aquifer

INTRODUCTION

The southern portion of the Eastern Desert especially the Nile River side forms one of the most promising areas in Egypt for future development especially land reclamation and tourist expansions. In addition, this area is rich in ore minerals, so, it attracts the attention of many investments but the limited water resources form a big challenge. In general, the Eastern Desert of Egypt has limited water resources. Such water resources are supplied either from rain water harvesting or groundwater wells. Groundwater is exploited from limited, low potential groundwater aquifers. In this respect, the Fractured basement aquifer constitutes a valuable groundwater aquifer where this aquifer is present in a wide area characterized by very limited water resources. Groundwater is present in the fractures of the basement complex especially the sheer and fractured zones. The aquifer is covered by thin weathered to highly weathered alluvial deposits increasing gradually in thickness from the upstream to the downstream. The main recharging source of this aquifer is the direct rainfall. So, the study of the aquifer recharge is of great importance.

Groundwater recharge is a critical component in estimating groundwater availability and sustainability. It is particularly important in regions of groundwater supplies, where such resources are the key to the economic development. Recharge has been defined as the

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process of addition of water to the saturated zone. The amount of moisture that eventually arrives to the water table is defined as the natural groundwater recharge (Kumar 1993) [1]. The amount of this recharge depends upon the rate and duration of rainfall, soil moisture conditions, the water table depth and the soil type. Quantification of groundwater recharge is a major problem in many water-resource investigations. It is a complex function of meteorological conditions, soil, vegetation and the characteristics of the geologic materials within the path flow.

Because recharge is almost difficult to be measured directly, it is usually estimated by indirect means. The accuracy of the indirect estimates is usually difficult to determine, so a common recommendation is that recharge should be estimated by the use of multiple methods and the results compared. Techniques for estimating recharge can be categorized as physical, chemical and modeling techniques according to the source of data, including surface water, unsaturated zone and groundwater (Scanlon *et al*., 2002) [2]. Many methods are used to determine the groundwater recharge; of those are the water budget method, groundwater modeling, water table fluctuation, watershed loss measurements, chloride and carbon 14. Precipitation, soil texture and vegetation constitute the primary controls of the groundwater recharge. Moisture movement in the unsaturated zone is controlled by the capillary pressure and the hydraulic conductivity.

Limited hydrogeological studies were carried out on the study area. Most of these studies were generally concentrated on the assessment of surface and groundwater resources including Abdel Kreem (2000) [3], Abdel Kader (2001) [4], Ahmed (2010) [5], Mohallel (2013) [6]. Also geologic studies, for example, were carried out to delineate the basement rock types and ore mineralogy e.g. Akaad and Noweir (1969) [7]. Other studies concentrated on the soil types of Wadi Shaiet and Wadi Khariet area e.g. Elwan (2008) [8]. This article aims to estimate the quantity of recharge of the fractured basement aquifer in the investigated area.

Site Description: The study area constitutes a portion of the Nile valley, located between Idfu and Aswan and extends eastward to the water divide line. It covers an area of about 22500 km^2 (Fig. 1). It is limited by Latitudes 24°00' & 25° 12' N and Longitudes 32°55' & 35° 48' E. The Egyptian Eastern Desert has a predominantly arid climatic condition for the whole year. The area is characterized by a long hot summer and short warm winter, low rainfall and high evaporation rates. The estimated maximum mean monthly temperature at Marsa Alam during the Period 1999 to 2006 was 32.7°C in August while the minimum monthly temperature value was 19°C in January while in Aswan governorate the maximum temperature is relatively higher; it reaches 41.8°C in June and 8°C in January as a minimum monthly degree. The average yearly precipitation in mountainous region is more than the precipitation in the Nile valley areas. In general the annual limited rainfalls rarely occur in some seasons. Sometimes heavy rainfalls take place once in a limited period. In Marsa Alam areas, the annual mean rainfall value is about 8 mm while; in Aswan governorate it is about 0.7 mm. The maximum monthly mean is 0.5 mm/month in April, while it is nil in summer months. Also, the maximum monthly mean is 0.6 mm/month in November at Marsa Alam.

Geomorphologically, the study area is discriminated into four geomorphic units; Nile Valley, Nile drainage basins, Nubian Sandstone Plateau (Ababda tableland) and the Watershed Basement Mountains (Fig. 2), (MPGAP, 1990 [9] and Abdel Kreem, 2000) [3]. These units reflect the effect of the tectonic, lithologic and climatic conditions of the study area. Digital Elevation Map (DEM) indicates that the area is slopping westward and ground elevation ranges from 55 m to about 650 m (a.m.s.l.). *Nile River Valley* is divided into two units: the young alluvial plain occupying the central strip of the Nile valley and the old alluvial plain which exists on both sides of the cultivated area. *The Nile drainage basins* include Wadi Midrik, Wadi Beizah, Wadi Shait, Wadi Natash and Wadi Kharit (Fig. 3). *The western sandstone tableland (Ababda tableland)* consists of almost flat bedded Nubian sandstone. Its elevation ranges between about 400 and 600 m above the mean sea level. *The watershed Basement Mountains* constitute the main watershed in the area under consideration. They consist of immense masses of igneous and metamorphic rocks and sometimes sedimentary rocks. The width of these masses in the investigated area varies between 60 and 160 km or more, increasing towards south.

Geologically, the study area is occupied by rocks ranging in age from Pre-Cambrian to Holocene. Generally, basement rocks occupy most of the area (Fig. 4) (Abdel Kader, 2001) [4]. *Holocene deposits* are represented by the top silty clay layer of the Nile in addition to the young out wash deposits of the desert wadis. *Late Pleistocene deposits (Prenile deposits)* are made of sand and gravel with clay interbreeds which has an exposed thickness of about 32 m (Qena Formation)

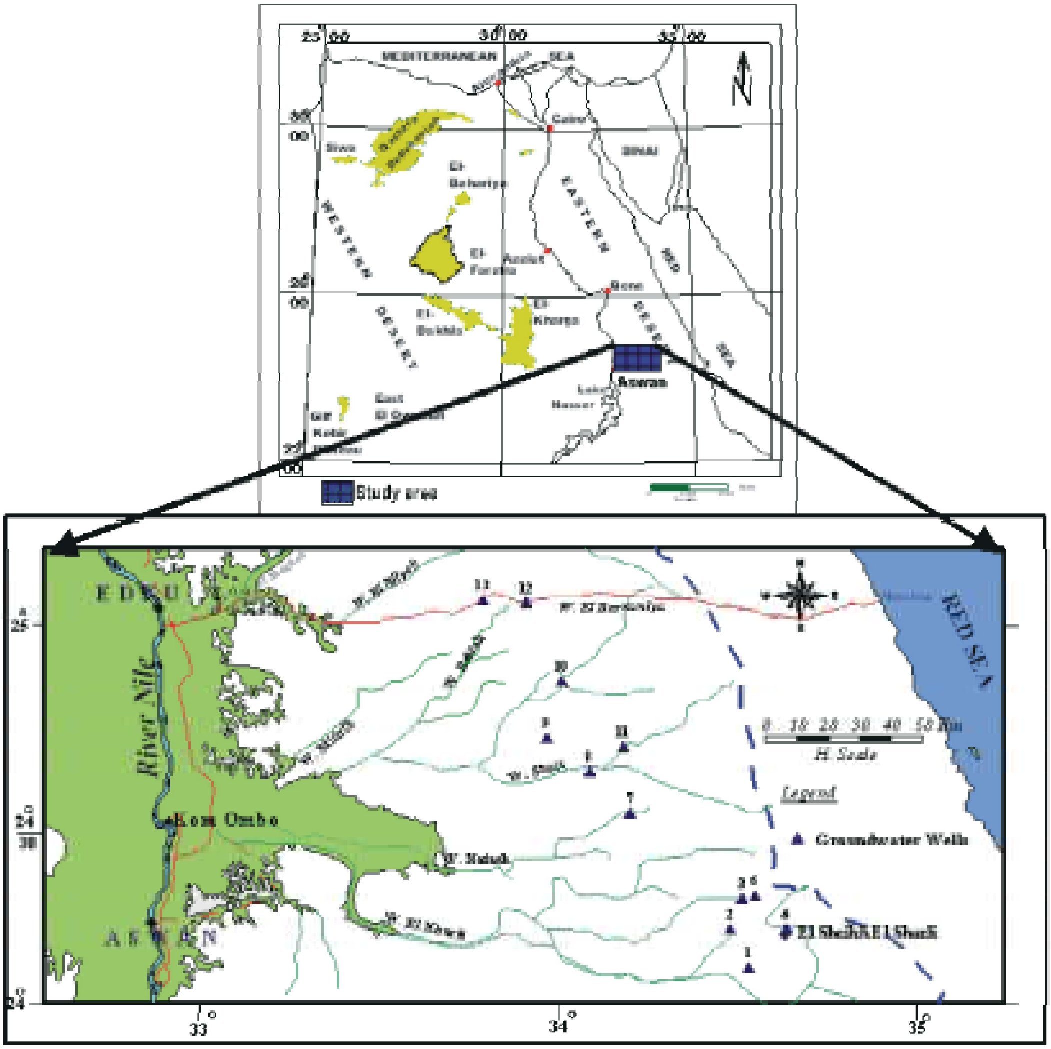

Fig. 1: Key map of the study area

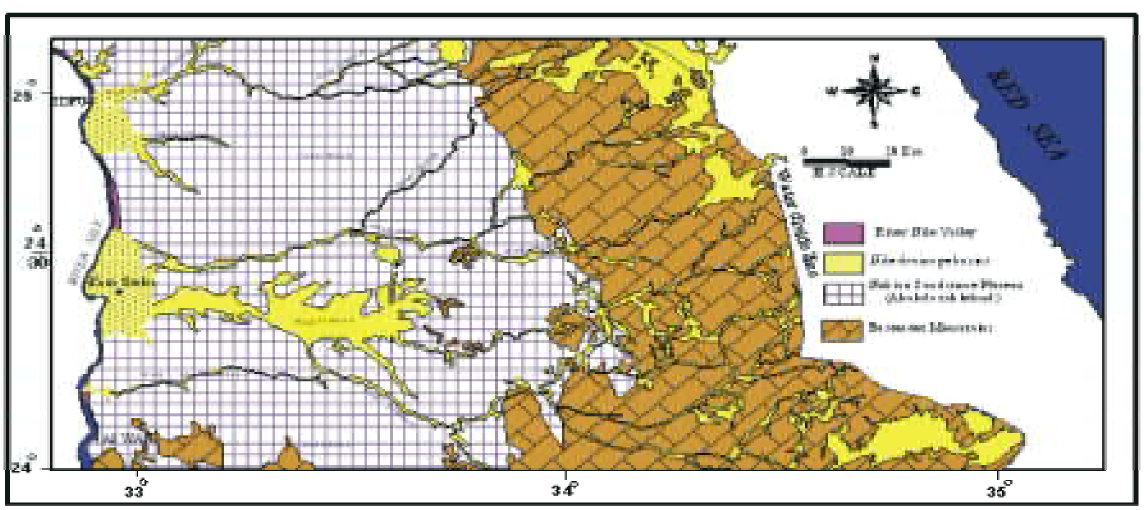

Fig. 2: The main geomorphic units of the study area (after MPGAP, 1990 and Abdel Kreem, 2000)

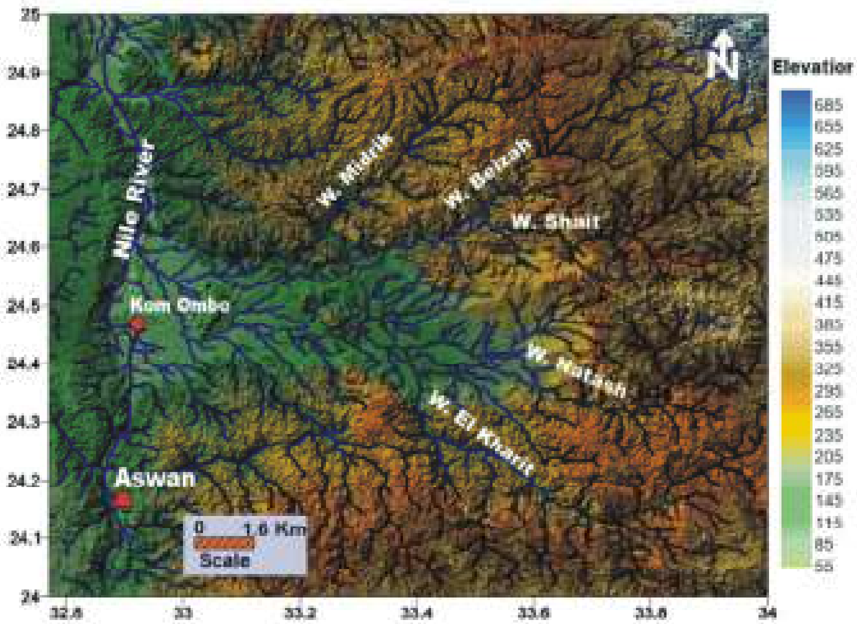

Fig. 3: The main hydromorphic basins in the study area

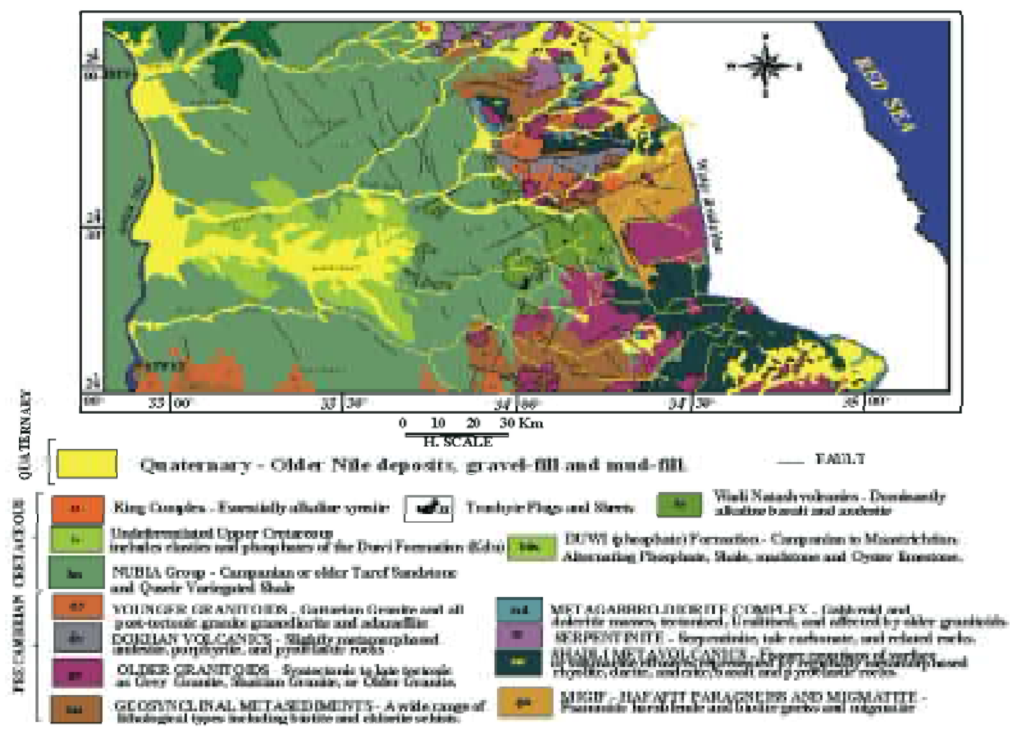

Fig. 4: Geologic map of the study area (After geologic map of Aswan quadrangle, Egypt 1978)

and extends also in the subsurface below the silty clay layer. *Pliocene rocks (Paleonile deposits)* are dominated by clay facies and are represented by clay with some interbreeds of sand (thickness of more than 50m). *Eocene Carbonate rocks* are made up of karstified chalky and dolomitic limestone and marl with flint bands and nodules. They are exposed westward direction with more than 500 m. *Nubian Sandstone rocks* cover the middle part of the study area which is predominantly non-marine terrain sequence overlying the Precambrian basement rocks. They are cross-bedded sandstone overlaid by variegated shale interbeded by sandstone with thickness of about 200 m. They are distinguished into two units: The lower unit is (200 m width) composed of non-fossiliferous sandstone beds intercalated by mudstone. The upper unit is made up of about 70 m thickness composed of variegated (Quseir) shale.

Pre-Cambrian rocks cover most of the study area. They are distinguished into three rock units:

- Metamorphic rocks, including metasediments and metavolcanics intruded by serpentinite and epidiorite masses.
- Post metamorphic intrusions of gabbro, granite and volcanic. This group is overlain by a less extensive metasedimentary group (Hamamat series) of post granite age followed by the intrusion of the younger or Gattarian granites (Abdel Kader 2001) [4].

Hydrogeologically, most of groundwater occurs in the fissured and weathered zones within the Pre-Cambrian complex. According to the rock type, the Pre-Cambrian aquifer can be distinguished into four water bearing formations including the fractured metavolcanics, fractured metasediments, fractured Plutonic rocks and fractured Hammamat aquifers. The Pre-Cambrian complex aquifer is covered by thin weathered to highly weathered alluvial deposits increasing gradually in thickness downstream ward. The main recharging source of this aquifer is the direct rainfall, (Abdel Kader, 2001) [4]. A little amount of this water is kept in catchment areas of the wadis and fractured or weathered basement rocks, while the rest is discharged through the fault planes or along the Wadis floor towards the Nubian plateau due west. The water is discharged by a means of productive wells, which are distributed in the main Wadi courses.

MATERIALS AND METHODS

The materials used in this paper were collected through the field trip carried out in study area during the year 2014. The basic hydrologic, hydrochemical data of the present drilled wells (30 productive well and spring) were collected during the field trip including collecting the water samples, groundwater depth measurements …etc..

Rainfall records were used in estimating the recurrence period and rainfall event distribution in the study area according to Weibull, (1932) [10] ranking method and Raghunath, (1990) [11]. The recurrence period T and the probability of exceedance P_r (Fig. 5) was estimated based on the following relations (Bennett & Doyle 1997) [12];

$$T = (N + 1) / M \qquad (1)$$

$$P_r \%= 100*M / (N + 1) \qquad (2)$$

M is the descending order rank (dimensionless) and N is the total number of records (dimensionless).

The first step is the inclusion of the Digital Elevation Model (DEM) and hydrologic data into the WMS system. DEM data was derived from the Shuttle Radar Topography Mission (SRTM) data. DEM data is used automatically to delineate basin boundaries and define stream networks. The United States Department of Agriculture (USDA) program TOPAZ (Garbrecht and Martz, 1993) is launched from WMS to define flow directions and flow accumulations for each DEM cell. This information is used to trace and convert the stream networks and basin boundaries to lines and polygons of the WMS drainage coverage (Nelson *et al.*, 2000) [13]. The polygon and stream network shown in Fig. 6 are delineated in WMS using this method. Moreover, drainage module generates the basin model which contains parameter and connectivity data for hydrologic elements. This information is processed by WMS drainage module and export into the basin file together with a series of parameters required by HEC-1 for the calculation of the runoff.

In addition, the runoff curve number method was used to estimate the run off resulted from a storm rainfall and then it is used to estimate the groundwater recharge. The method was developed in 1954 by the USDA Soil Conservation Service (SCS 1985) [14]. In developing the SCS rainfall run off relationship, the total rainfall was separated into three components; direct runoff (Q), actual retention (F) and initial abstraction (Ia). Consequently, the following relationship between P, Q, Ia and F was assumed:

The SCS-CN method is based on the principle of the water balance and two fundamental hypotheses. The first hypothesis states that the ratio of direct runoff to potential maximum runoff is equal to the ratio of infiltration to potential maximum retention. The second hypothesis states that the initial abstraction is proportional to the potential maximum retention. The water balance equation and the two hypotheses are expressed mathematically, respectively, as:

$$P = I_a + F + Q \qquad (3)$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad (4)$$

$I_a = \lambda S$ (5)

Here; P is the total precipitation (mm), Ia is the initial abstraction before runoff (mm), F is the cumulative infiltration after runoff begins (mm), Q is direct runoff (mm), S is the potential maximum retention (mm) and λ is the initial abstraction (ratio) coefficient. Small amount of rainfall events result in even smaller changes in runoff that can sometimes be difficult to discern in the discharge time series. To minimize uncertainty in the determination of the storm event discharge, storms events with $P \geq 5$ mm have been considered to determine CN values in calibration period (Manoj and Dholakia 2014) [15]. In validation period all events have been considered to measure performance of different procedures. $\lambda = 0.2$ was assumed in original SCS-CN model.

The general runoff equation combination of Equation (1) and Equation (2) is shown in Equation (4):

$$Q => \frac{(P - I_a)^2}{P - I_a + S} \, for P \quad I_a \qquad (6)$$
$$= 0 \, otherwise$$

The potential maximum retention S (mm) can vary in the range of $0 \leq S \leq \infty$ and it directly linked to CN. Parameter S is mapped to the CN using Equation (4) as:

$$S = \frac{25400}{CN} - 254 \qquad (7)$$

The CN depends on land use, hydrologic soil group, hydrologic condition, antecedent moisture condition (AMC) and it can vary from 0 to 100. Three AMCs were defined as dry (lower limit of moisture or upper limit of S), moderate (normal or average soil moisture condition) and wet (upper limit of moisture or lower limit of S) and denoted as AMC I, AMC II and AMC III, respectively. Higher amount of antecedent moisture and CN value would indicate the high runoff and vice versa, therefore, median CN was computed from array of CN values and was commonly adopted for the catchment (Mishra *et al.*, 2005) [16].

The weighted CN for the mixed land use can be determined through the following equation.

$$CN = \Sigma A_i \, CN_i \, / \, \Sigma A_i \qquad (8)$$

Here: CN_i is the CN for a part of the watershed of an area A_i.

On the other hand, chloride method is another method used to determine the recharge quantity of the fractured basement rock aquifer in the study area. Chloride is a significant chemical component due to its conservative character in the absence of evaporites. Eriksson (1975) [17] was the first who show mathematically that the frequency distribution of Cl- contents in regional groundwater basins could be quantitatively related to recharge rate and qualitatively related to the origin of Cl^- salinity. In the case of observing a normal distribution for Cl^- in a large set of the groundwater samples, dissolution of evaporites and mixing will be the most probable mechanisms of groundwater Cl^- build-up, whereas a log-normal distribution will be indicative of Cl^- acquisition through input from wet deposition and subsequent evaporation during and/or after recharge.

In conclusion, the log normal distribution of chloride reflects the recharge from meteoric water that is possibly infiltration of direct rainfall which is affected by terrestrial salts. According to Eriksson (1975) [17], the recharge rate of the groundwater has been calculated as follows:

$$\overline{R} = V_o x \, (C_o / C) \qquad (9)$$

Here;
$\overline{R}$ is the annual recharge (mm/y).
V_o is the annual mean precipitation (mm/y) in the hydrologic period from 1976 to 2006).
C_o is the initial mean concentration of chloride in rain water.
C is the harmonic mean of chloride concentrations.

Also, thirteen groundwater samples, representing the studied aquifer were collected in April 2011 and chemically analyzed. The analyses were performed in the Hydrogeochemistry Department, Desert Research Center (DRC), Egypt, according to the methods adopted by Rainwater and Thatcher (1960) [18], Fishman and Friedman, (1985) [19] and American Society for Testing and Materials (ASTM, 2002) [20]. The analyses include the determination of EC, pH, TDS and major ions Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^- SO_4^{2-}, Cl^- in addition to the inorganic substances. According to the obtained results the following could be deduced (Table 2).

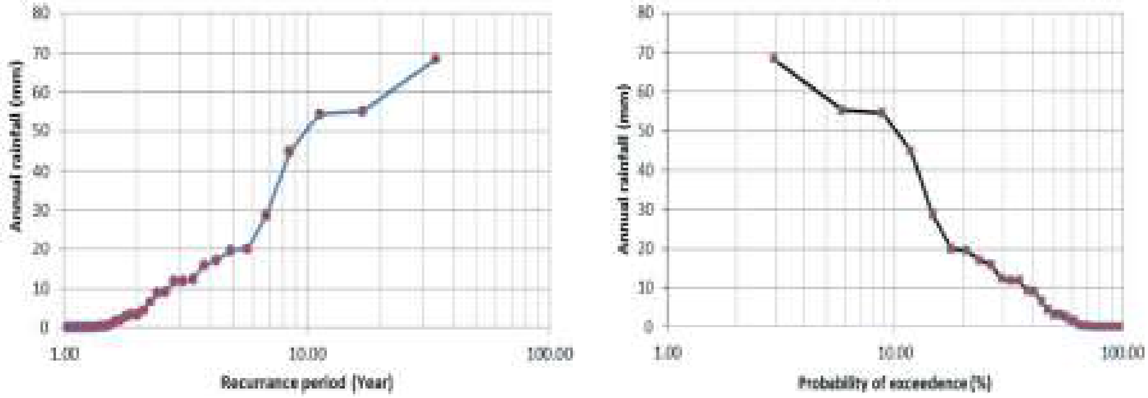

Fig. 5: Probability of recurrence and exceedance period of the annual rainfall data of the study area

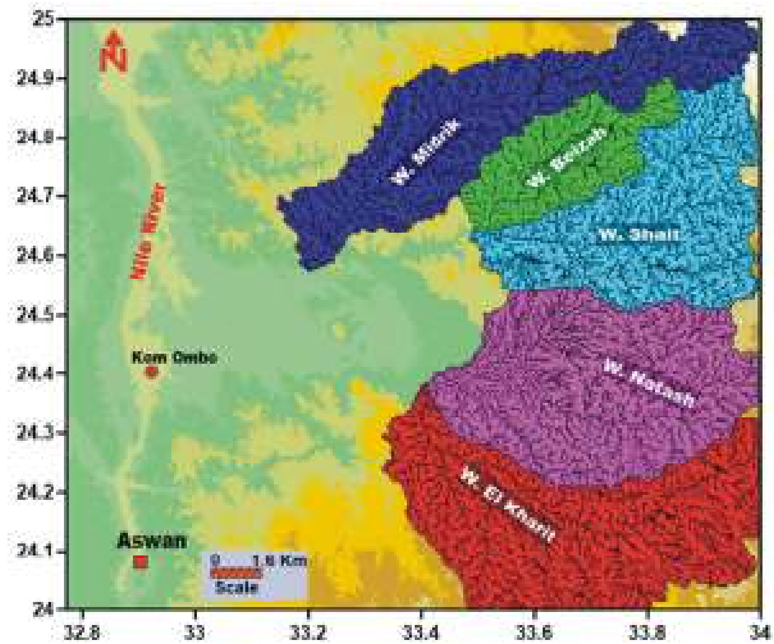

Fig. 6: The drainage network in the study area derived from DEM model (90 x 90 m) using WMS Software

RESULTS AND DISCUSSIONS

Rainfall: The study area belongs to the Red Sea mountainous area. So, the rainfall data used in this paper depended on the annual rainfall data recorded in Ras Binas meteorological station over a period of 33 year from the year 1968 to 2001 (Table 1). These data include the monthly rainfall data which were used to calculate the annual rainfall values. These values were used to estimate the recurrence period (T) and the probability of exceedence (Pr%) according to equations (1) and (2).

Accordingly, it is obvious that the basement catchment area receives an average annual rainfall depth of 12.3 mm while the maximum monthly rainfall was recorded as 68.8 mm in May 1972. In addition, the annual rainfall depth is directly proportion to the recurrence period (T) while it is inversely proportion to the probability of exceedance (Pr) (Fig. 5). The statistical analysis of these records shows that the annual rainfall of the value 15.8 mm has a probability level of exceedance of about 26 % (Table 1). In addition, maximum annual rainfall (68.2 mm) has a probability of about 2.9% and it may happen every 34 years. On the other hand, the minimum annual rainfall value (0.1 mm) has a probability of exceedance of about 79 % and it has a recurrence time of about 1.3 year. These results should be taken into consideration in surface runoff water management of the study area.

Table 1: The estimated recurrence periods and probability of exceedance of rainfall data of Ras Binas in the period 1968-2001

Year	JAN	FAB	MAR	APR	MAY	SEP	OCT	NOV	DEC	SUM	TAR	RANK	T	Pr%
1968	0	0	0	13.4	22	0	3.2	4.8	1.3	44.7	68.2	1	34.00	2.94
1969	0.1	0	0	0.1	0.1	0	0	0	0	0.3	55.3	2	17.00	5.88
1970	0	0	0.1	0	0	0	0	3	0	3.1	54.5	3	11.33	8.82
1971	0	0	0	0	0	0	0	0	0.1	0.1	44.7	4	8.50	11.76
1972	0	0	0	1.9	0	0	0	1.2	0	3.1	28.5	5	6.80	14.71
1973	0	0	0	0	0	0	0	0	0	0	20	6	5.67	17.65
1974	0	0	5.7	0	0	0	0	3.2	0	8.9	19.5	7	4.86	20.59
1975	0	0	0	0	0	0	0	0	0	0	17	8	4.25	23.53
1976	0	0	0	0	68.2	0	0	0	0	68.2	15.8	9	3.78	26.47
1977	0	0	0	0	0	0	0	0	0	0	12.3	10	3.40	29.41
1978	0	0	0	0	0	0	0	0	0	0	12	11	3.09	32.35
1979	5.5	0	0	0	0	0	49.8	0	0	55.3	11.8	12	2.83	35.29
1980	0	0	0	0	0	0	0	15.8	0	15.8	9.2	13	2.62	38.24
1981	0	0	0	0	0	0	1.5	0	0	1.5	8.9	14	2.43	41.18
1982	0	0	0	0	0	0	0	0	0	0	6.5	15	2.27	44.12
1983	0	0	0	0	0	0	0	20	0	20	4.3	16	2.13	47.06
1984	0	0	0	0	0	0	4.3	0	0	4.3	3.1	17	2.00	50.00
1985	0	0	0	1.8	0	0	0	7.4	0	9.2	3.1	18	1.89	52.94
1986	0	0	0	0	0	0.1	0	0	0	0.1	2.8	19	1.79	55.88
1987	0	0	0	0	0.1	0	0	0	0	0.1	1.8	20	1.70	58.82
1988	0	0	0	0	1.8	0	0	0	0	1.8	1.5	21	1.62	61.76
1989	0	0	0	0	0	0	0	0	0	0	0.5	22	1.55	64.71
1990	0	0	0	0	0	0	0	0	0	0	0.3	23	1.48	67.65
1991	0	0	0	0	0	0	0.2	0	0	0.2	0.2	24	1.42	70.59
1992	0	0	0	0	0	0	0	19.5	0	19.5	0.1	25	1.36	73.53
1993	0.3	0.2	0	0	0	0	28	0	0	28.5	0.1	26	1.31	76.47
1994	0	0	0	0.4	0.6	0	1.1	14.9	0	17	0.1	27	1.26	79.41
1995	0	0	0	0	6.5	0	0	0	0	6.5	0	28	1.21	82.35
1996	0	0	0.5	0	0	0	0	54	0	54.5	0	29	1.17	85.29
1997	0	0	1.1	0	0	0	7.5	3.2	0	11.8	0	30	1.13	88.24
1998	0	0	2.8	0	0	0	0	0	0	2.8	0	31	1.10	91.18
1999	0	0	0	0.5	0	0	0	0	0	0.5	0	32	1.06	94.12
2001	0	0	0	12	0	0	0	0	0	12	0	33	1.03	97.06
Avg	0.2	0	0.3	0.9	3.5	0	2.9	4.5	0	12.3				
Max	5.5	0.2	5.7	13.4	68.2	0.1	49.8	54	1.3					
StDev	1	0	1.1	3.1	12.6	0	9.8	10.6	0.2					

TAR= Total annual rainfall (mm), T= Recurrence period (year) and Pr%= Probability of exceedence

Basin Characteristics: The drainage characteristics of terrain surfaces of the study area were automatically computed applying the software WMS V 7.1 (2005) [21]. These characteristics reflect a great tendency of these catchments to receive flash floods. Five hydrographic basins characterize the area; Wadi Midrik, Wadi Beizah, Wadi Shait, Wadi Natash and Wadi Kharit.The estimated hydro-morphological parameters include basin area (A), basin slope (BS), average overland flow (AOFD), basin length (L), shape factor (Shape), sinuosity factor (Sin), mean basin elevation (AVEL), maximum stream length (MSL) and maximum stream slope (MSS) (Table 2 and Fig. 6).

The basic statistics of the selected hydro-morphological parameters show that the drainage area (A) of the studied basins ranges from 557 to 1584 km^2 (Wadi Beizah and Wadi Natash respectively) with a mean value of 1176.4 km^2 (Table 2). On the other hand, the basin slope (BS) ranges from 0.0343 (Wadi Natash) to 0.0532 (Wadi Shait) with mean value 0.0434. The basin length of overland flow (AOFD) describes the length of flow of water over the surface before it becomes concentrated in definite stream channels (Krishnamurthy *et al*., 1996) [22]. It ranges between 324.1 and 346.3 km with mean value 331.8 (Wadi Midrik and Wadi Natash respectively). The minimum value of basin length factor (L) reaches 45.2 Km (Wadi Beizah) and the maximum value reaches 92.2 Km (Wadi Midrik) with mean 62.2 Km. The perimeter of the studied wadis range from 180.1 Km (Wadi Beizah) to 364.3 Km (Wadi Midrik) with a mean value of about 269.5 Km.

Table 2: Drainage characteristics of terrain surfaces of the study area extracted from DEM applying WMS drainage module

Wadi name	A Km^2	BS m/m	AOFD m	L km	P Km	Sh	SIN	AVEL m	MFD km	MFS m/m	MSL Km	MSS m/m
Midrik	1265	0.0409	324.1	92.2	364.3	6.72	1.31	284.7	121.2	0.044	120.4	0.0035
Beizah	557	0.0354	324.9	45.2	180.1	3.67	1.31	296.2	59.8	0.004	591.7	0.0035
Shait	1238	0.0532	331.8	56.6	276.0	2.59	1.49	327.3	85.0	0.0041	84.1	0.0036
Natash	1584	0.0343	346.3	60.2	251.0	2.29	1.58	271.8	95.8	0.0026	95.2	0.0024
Kharit	1238	0.0532	331.8	56.6	276.0	2.59	1.49	327.3	85.0	0.0041	84.1	0.0036

A=basin area, BS = basin slope, AOFD =Average overland flow, L = Basin length, P = Perimeter, Sh= Shape index, Sin =Sinuosity factor, AVEL=Mean basin elevation, MFD=Mean flow distance, MFS=Maximum flow slope, MSL=Maximum stream length, MSS=Maximum stream slope.

Table 3: Depth to water (m) of the basement aquifer in the study area

Well No.	Name	Depth to water (m) April 2011	EC µmhos/cm	Depth to water (m) October 2010 (Mohallel, 2013)	EC µmhos/cm
1	Hileiya	7	3620	8.00	4400
2	Abu Hamamid	5.8	4340	5.40	4230
3	Meteiwit	8.4	7000	9.00	5430
4	Bir El Haja Zakiya	3	6370	3.80	7390
5	El Sheikh El Shazly	5	5390	5	3097
6	Al Mureara (n)	8.2	5130	-	-
7	Abu Masur	10.95	1051	10.70	834
8	Umm Qubur	7.8	2430	11.80	2500
9	Sibrit (n)	7.78	2080	-	-
10	Muweilha (Samut)	8.4	15540	8.4	19850
11	Al Murear	4	6000	4.00	5310
12	Beizah (Dungash)	11.2	10540	11.50	12100
13	El Kameen (El Barramya)	30.7	2660	31.50	2500

The basin shape factor (Shape) ranges between 2.29 and 6.72 (Wadi Natash and Wadi Midrik respectively) with a mean value of 3.57. The basin sinuosity factor (Sin) ranges from 1.31 (Wadi Beizah and Midrik) to 1.58 (Wadi Natash) with mean value 1.44 reflecting lithological and structural control. The mean basin elevation (AVEL) ranges from 271.8 m (Wadi Natash) to 327.3 m (Wadi Shait) with mean value 301.5. The basin mean flow distance (MFD) ranges from 59.8 Km to 121.2 Km (Wadi Beizah and Wadi Midrik respectively) with a mean value of 89.4 Km. On the other hand, the maximum flow slope (MFS) records 0.0026 as minimum value (Wadi Natash) and 0.044 in Wadi Midrik as a maximum value. The basin maximum stream length (MSL) ranges from 84.1 Km (Wadi Kharit) to 591.7 Km (Wadi Beizak) with mean value 195.1 Km. The basin maximum stream slope (MSS) ranges from 0.0024 (Wadi Natash) to 0.0036 (Wadi Shait) with mean value 0.0033.

Groundwater Conditions: The Fractured basement aquifer is recognized through thirteen water points. The depth to water ranges from 3.8 m (No. 4) to 30.7m (No. 13) (Table 3). Generally, the water thickness depends on the recharge rate, degree of weathering, intensity of fractures, faults and thickness of the water bearing formation. Four water bearing formations are recognized, according to the rock type (Fig. 7). *The fractured metavolcanics aquifer* is detected in Wadi Abu-Hammamid and El-Sheikh El-Shazly. The thickness of the aquifer is ranging from 5 to 35 m. The groundwater is detected at shallow depths (about 3.80 to 5 m at El-Sheikh El-Shazly) (Nos. 4 & 5) and 5.8 m in Wadi Abu-Hammamid (No. 2). The fractured metavolcanics aquifer is directly recharged from the local rainfall by infiltration through fractures. On the other hand, *The fractured metasediments aquifer* includes Migif-Hafafit para-gneiss and magmatite rocks in Wadi Hafafit. The thickness of this aquifer varies from 20 to 40 m increasing towards the south (Abdel Kader, 2001) [4]. The depth to water is about 19 m from the ground surface. Conversely, *the Fractured Plutonic aquifer* is recognized as a water-bearing formation in Wadi Natash. The thickness of this aquifer is so thin, especially in the upstream portion, where the massive Pre-Cambrian outcrops are on the surface. The depth to water is about 10.7 m (Bir Abu Masour, No. 7). *The Fractured Hammamat aquifer* is mainly composed of fine to coarse grained breccias and conglomerates derived from Dokhan Volcanic (Akaad and Noweir, 1969) [7]. The fractured Hammamat aquifer is tapped in Wadi Igli. The depth to water in Bir Igli is about 12m from the ground surface (Abdel Kader, 2001) [4]. The groundwater occurs under unconfined conditions, where the thickness of Wadi deposits is about 4 m. The recharge occurs through downward infiltration from direct rainfall through the wadi deposits.

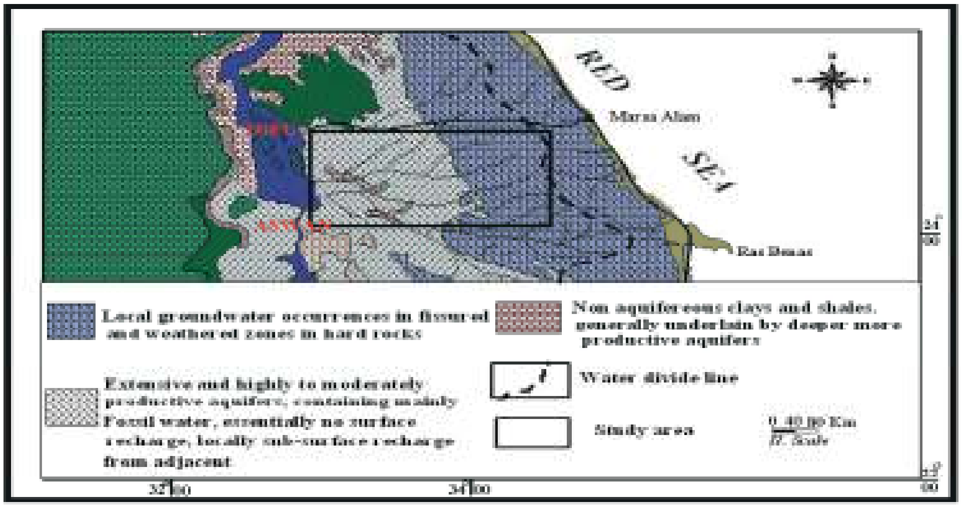

Fig. 7: Hydrogeologic map of the study area (After hydrogeologic map of Egypt, Second Edition 1999)

Table 4: Hydrochemical data of the investigated groundwater samples of the fractured pre-Cambrian aquifer, April (2011)

Sample No	pH	E.C µmhos/cm	TDS 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
1	8.4	3620	2618.41	354.57	146.63	312	25	16.8	596.064	1225	240.38
2	8.7	4340	2691.92	227.75	83.95	640	6	28.8	460.856	790	685.00
3	8.7	7000	4189.63	360.85	131.53	990	9	33.6	324.52	1000	1502.39
4	8.5	6370	5235.66	556.74	202.93	860	11	16.8	184.464	2270	1225.95
5	8.4	5390	3107.81	332.95	126.11	590	5	15.08	126.392	1050	925.47
6	8.7	5130	2969.74	329.92	120.26	540	7	26.88	228.872	1050	781.24
7	8.9	1051	578.62	98.72	39.10	49	9	23.52	198.296	176	84.13
8	7.9	2430	1335.41	185.58	67.64	224	18	0	751.52	200	264.42
9	8.3	2080	1131.22	189.06	87.71	70	17	13.44	307.44	420	180.29
10	8.3	15540	8421.93	329.92	120.26	2720	32	16.8	273.28	1100	3966.32
11	8.5	6000	4162.55	268.06	97.71	960	19	13.44	314.272	1890	757.21
12	8.6	10540	7682.39	670.15	244.27	1550	22	13.44	143.472	2760	2350.79
13	8.9	2660	1542.28	191.55	18.79	320	20	43.68	447.496	400	324.52

Table 5: The frequency distribution of groundwater salinity in the study area

	% Frequency distribution			Water salinity (mg/l)		
	Fresh water	Brackish water	Saline to highly saline water			
Total Samples	T.D.S<1500mg/l	T.D.S1500-5000mg/l	T.D.S>5000mg/l	Min.	Max.	Average
13	23%	54%	23%	578.62	8421.93	3512.89

According to Chebotarev classification (1955) [23], the salinity of the collected water samples representing the different aquifers shows wide variation as shown in Table (4). This is generally attributed to lithology variation, rate of evaporation degree of weathering, fractures intensity and amount of recharge. In the Fractured Pre-Cambrian aquifer, the groundwater salinity ranges from 578.62 mg/l at wadi Natash (No. 7) to 8421.93mg/l at wadi Beizah (No. 10), indicating that 54% of samples are brackish (Nos. 1, 2, 3, 5, 6, 11 & 12), while 23% are fresh (Nos. 7, 8 & 9) and also the rest of samples (23%) are saline water (Nos. 4, 10 & 12), (Table 5).

Recharge Estimation: Two methods are used to estimate the groundwater recharge of the Fractured basement aquifer. One of these methods depends on chemical basis (chloride method), while the other method is depending on hydrologic criteria (the SCS Curve number method).

Chloride Method: The trend of the distributions pattern for chloride ions of the investigated groundwater samples in the Fractured basement aquifer (13 total samples) shows that, the frequency distribution of Cl^- of the representative samples decreases as the categories (arithmetically progressing classes) increases, Fig. (8).

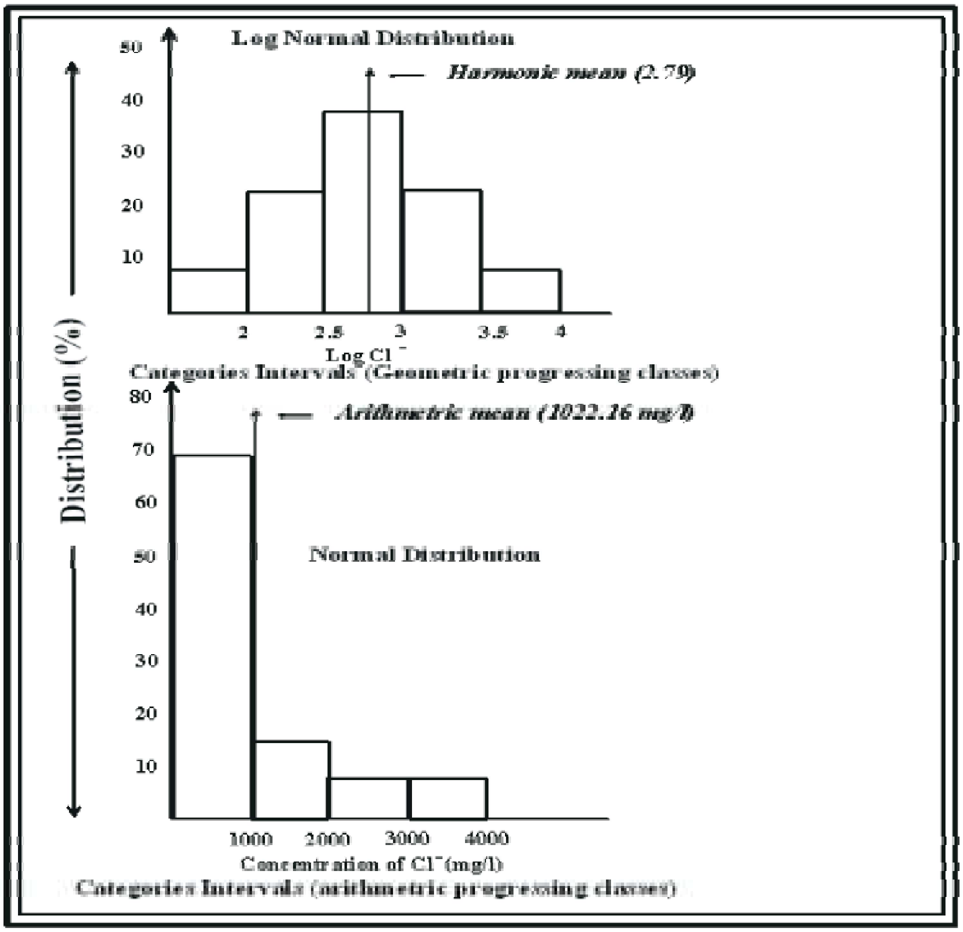

Fig. 8: Normal and log normal distributions of chloride ion concentrations in the Fractured basement aquifer

This figure of the distribution pattern of Cl^- in the groundwater samples shows that for unequal categories from 0 to 4000 mg/l, about 69% of the total samples have Cl^- concentration range from 0-1000 mg/l, while about 15% of the total samples have Cl^- concentration range from 1000- 2000 mg/l. Also, about 8% of the total samples have Cl^- concentration range from 2000 to 3000 mg/l and the rest of the total samples (8%) have Cl^- concentration range from 3000 to 4000mg/l. The mean value of Cl^- in the total samples is 1022.16 mg/l, thus this distribution pattern does not follow a normal distribution where the normal distribution shows that the frequency distribution of the Cl^- of the representative groundwater samples increases until reaching a maximum value then decreases as the categories (arithmetically progressing classes) increase.

The distribution pattern of log Cl^- in the groundwater samples of the investigated aquifer tends to be log normal distribution. Noteworthy to mention that the log-normal distribution shows that the frequency distribution of the representative samples increases until reaching a maximum then decreases as the categories (geometrically progressing classes) increase (Fig. 8). This log normal distribution has interval 0 - 4 as logarithmic. The log normal distribution represents five unequal categories.

The mean of normal log normal distribution in logarithmic units is 2.79, which gives 616.6 mg/l as arithmetic mean of all chloride ions concentration in the total groundwater samples. There is a negative skewness of logarithmic unit (-0.1335085), which gives 0.735 mg/l, but on the whole the distribution is not asymmetric tail extending toward more negative values. Negative kurtosis -0.4629711 of logarithmic units that corresponds to 0.344 mg/l indicates a relatively peaked distribution. The standard deviation of the distribution is 0.474 as logarithmic units which correspond to ±2.98 mg/l where the standard deviation is a measure of how widely values are dispersed from the average value (the mean). Thus about 77% of the data are found between the limits 2.32 (M-δ) and 3.27 (M+δ) as logarithmic values that correspond to 208.9 mg/l (M-δ) and 1862.087 mg/l (M+δ).

Table 6: Calculation of recharge rate of the Fractured basement aquifer in the study area according to Eriksson (1975)

Aquifer	Annual mean precipitation of in the investigated area (mm/y) V_o	Initial mean concentration of chloride in rainwater (mg/l) C_o	Harmonic mean of chloride concentrations in the groundwater (mg/l) C	Annual recharge (mm/y) R^-	Recharge Rate (%)
the Fractured basement aquifer	8	5.5	616.6	0.0714	0.89

Table 7: Runoff curve numbers for selected land uses with different hydrologic soil groups delineation defined from Landsat investigations (Ragan and Jackson, 1976 & SCS, 1972) and basin recharge calculations

Basin Name	Basin lithology	Land Use	Soil Category	CN	S (mm)	Ia (mm)	Area Km^2	Recharge Volume (x 10^6 m^3)	Total Basin Recharge Volume (x 10^6 m^3)
W. Midrik	Basement rocky area (watershed area)	LS4	D	98	5.18	1.04	1239.70	1.285	1.512
	Deep gravelly sand (streams reaches)	LS5	B	85	44.82	8.96	25.30	0.227	
W. Beizah	Basement rocky area (watershed area)	LS4	D	98	5.18	1.04	529.15	0.549	0.798
	Deep gravelly sand (streams reaches)	LS5	B	85	44.82	8.96	27.85	0.250	
W. Shait	Basement rocky area (watershed area)	LS4	D	98	5.18	1.04	1200.86	1.245	1.578
	Deep gravelly sand (streams reaches)	LS5	B	85	44.82	8.96	37.14	0.333	
W. Natash	Basement rocky area (watershed area)	LS4	D	98	5.18	1.04	1504.80	1.560	2.270
	Deep gravelly sand (streams reaches)	LS5	B	85	44.82	8.96	79.20	0.710	
W. Kharit	Basement rocky area (watershed area)	LS4	D	98	5.18	1.04	1188.48	1.232	1676
	Deep gravelly sand (streams reaches)	LS5	B	85	44.82	8.96	49.52	0.444	
Total									7.834

Then the average recharge of groundwater in the Fractured Pre-Cambrian aquifer in the Eastern desert of Egypt may be calculated based on the equation ($\bar{R} = V_o \times (C_o/C)$) in the order of 8 mm/y (annual mean precipitation) is about 0.89% of the annual precipitation for the Fractured basement aquifer, (Table 6). Consequently, the results indicate that, the main recharging source is the direct rainfall to the aquifer as mentioned by Abdel Kader (2001) [4].

CSC Curve Number Method: In the basin area, the Fractured basement aquifer is recharged through the initial losses (infiltration) and transmission losses when precipitation is fallen down over the soil or as it travels through the channel network. Initial losses are related to infiltration, soil type, evaporation, evapotranspiration, interception and surface depression storage. Initial losses occur in the sub-basins before runoff reaches the stream networks (Gheith and Sultan 2002) [24]. Its quantity depends on the rainfall intensity, basin morphology, soil type and land use. The study area is a perfect arid-desert condition where the initial losses are mainly due to infiltration and evaporation which can be ignored due to the very short rainfall period. On the other hand, another recharge quantity occurs along the valley courses which are generally composed of alluvial coarse sand and gravel deposits of high hydraulic conductivity values. Hydrographs of ephemeral streams in arid and semi-arid regions usually decrease significantly in magnitude downstream through transmission losses unless augmented by new tributary flows (Walters 1990) [25].

Transmission losses are controlled by the channel geometry, slope of the reaches, upstream flow volume, duration of flow and bed material size. Unfortunately, most of the transmissions losses occur in the down-stream area where the stream reaches are larger, gentility sloping with thick coarse grained soil bed. In contrary, small transmission losses occur in the upstream area (mountainous area) where the channel courses are narrow, steep sloping with thin soil bed. Accordingly, the study area, which belongs to the mountain area, has very small amount of transmission losses. So, it can be neglected but the valley courses will be considered as a different CN area in estimating the recharge occurred as initial losses.

The recharge of the Fractured basement aquifer is estimated by estimating the initial losses of the five hydrographic basins, covering the study area (Fig. 6). The initial losses were estimated to every basin by using the equation Ia = 0.2 S. The value of the potential maximum retention (S) depends on the value of the CN of every basin. Selection of this value depends on the land use and soil type of the studied watersheds. According to the geological assessment of the catchment rock exposures and field investigations (Fig. 3, geologic map), two soil categories can be clearly identified for every basin rocky soil (category D) and deep gravelly sand (Category B). A curve number (CN) is assigned to each category and the S value and Ia value can be calculated (Table 7).

Based on these calculations, the Fractured basement aquifer receives about 1.5 million m^3 of water from Wadi Midrik, 0.8 million m^3 from Wadi Beizah, 1.6 million m^3 from

Wadi Shait, 2.3 million m^3 from Wadi Natash and about 1.7 million m^3 from Wadi Kharit. The total amount of water recharging the FPCA is estimated as 7.8 million m^3.

CONCLUSION AND RECOMMENDATIONS

The Fractured basement aquifer constitutes a valuable groundwater source in the southern portion of the Eastern Desert especially in the Nile River side. It is distinguished into four water bearing formations (fractured metavolcanics, fractured metasediments, fractured Plutonic and fractured Hammamat aquifers). The main recharging source of this aquifer is the direct rainfall. Groundwater salinity ranges from 579 ppm to about 3513 ppm.

The basement catchment area receives an average annual rainfall depth of about 12.3 mm while the maximum monthly rainfall was recorded as 68.8 mm in May 1972. The annual rainfall depth of 15.8 mm has a probability of exceedance of about 26 % while the maximum annual rainfall (68.2 mm) has a probability of about 2.9% every 34 years. Five hydrographic basins characterize the area; Wadi Midrik, Wadi Beizah, Wadi Shait, Wadi Natash and Wadi Kharit. The drainage characteristics of terrain surfaces of these basins were automatically computed applying WMS Software.

Two methods were used to estimate the groundwater recharge of the fractured basement aquifer. One of these methods depends on chemical basis (chloride method), while the other method is depending on hydrologic criteria (the SCS Curve number method). According to the chloride method, the estimated recharge rate is about 0.89 % of the total annual recharge. On the other hand, the SCS Curve number method reflected that, the fractured basement aquifer receives about 1.5 million m^3 of water from Wadi Midrik, 0.8 million m^3 from Wadi Beizah, 1.6 million m^3 from Wadi Shait, 2.3 million m^3 from Wadi Natash and about 1.7 million m^3 from Wadi Kharit. The total amount of water recharging the fractured basement aquifer is estimated as 7.8 million m^3.

According to the results of the study the following points can be stated:

- The area has promising water potentialities
- More studies are needed to assess the groundwater potentialities of the study area
- Drilling of groundwater wells at the basin's outlets and sheer zones of the basement rocks are recommended
- Many Rain gauges are needed in the study area.

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