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Integrated study of groundwater aquifers and productive wells for sustainable development in El-Kharrouba area North East Sinai Peninsula, Egypt

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ABSTRACT

During this work, an approach was made to determine and evaluate the hydraulic parameters of the water bearing formations in El-Kharrouba area, so eight pumping tests and six recovery tests were carried out on selected wells. Field data were analyzed by two different ways and the results pointed to that Marine Kurkar aquifer reflects wide range of Transmissivity ranged from 612.7 to 7789.73m^2/day, this aquifer has high potentiality. Moreover, the hydraulic conductivity ranges from 3.287 m/day to 121.617m/day, which pointed to a high permeability property. While as, the hydraulic diffusivity " D " values ranged between 6.514E10^6 m^2/day and 7.968E10^{28} m^2/day. Therefore, El Kharrouba area is characterized by high estimated values of hydraulic diffusivity, which reflects suitable conditions for sustainable reclamation projects under modern irrigation systems. On the other hand, twelve step-tests were carried out and analyzed to evaluate well characteristics and design criteria, using manual, graphical and software analysis methods. The well characteristics within studied area pointed generally to bad design criteria which lead to a well failure. As, wells of numbers (23 and 25) have very bad design criteria because, they have very high values of well loss percent (56.30% and 56.72% respectively) with low values of efficiencies (43.70% and 43.28% respectively). Also, wells of order (20, 22 and 28) reasonable (moderate) design criteria. also, wells of numbers (19 and 30) have good design criteria. While, the rest wells of orders (21, 24, 26, 27 and 29) have abnormal hydraulic behavior because they have unusual values of productivity (5.56%, 2.53%, 2.02%, 4.39% and 4.17% respectively) in spite of they have moderate to good values of efficiencies (56.77%, 97.22%, 81.88%, 51.07% and 69.15 respectively) and low to moderate values of well loss percent (43.23%, 2.78%, 18.12%, 48.93% and 30.85% respectively). So, more and deep studies are highly recommended to explain and investigate this abnormal hydraulic behavior.

Keywords: Aquifer hydraulic parameters, Water level, Transmissivity, Hydraulic conductivity, Storativity, Diffusivity, Well characteristics**.**

1. Introduction

The present work is an approach to evaluate the sustainability of water resources in the promising study area. Water demands are increasing and the groundwater potentialities could be used as a main potential source for all different activities. The success of suggested development practices is dependent on the availability and reliability of basic hydrological and well managements as an integrated method. The first part of study focused on hydrological aspects of study aquifers, so key map and distribution maps of different tests for selected wells and all aquifer hydraulic parameters contour maps were prepared. Furthermore, the second part of study gave more attention to well operation, well characteristics and its design criteria, to get proper and suitable management plans for present and future investments.

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Site Description

The study area occupies an important part of northeastern coast of Sinai Peninsula, between El-Arish city and El-Sheikh Zowyed city. It covers the area between latitudes 31º 06' 00" to 31º 12' 00" N and longitudes 33º 55' 00" to 34º 01' 00" E, (Fig. 1).

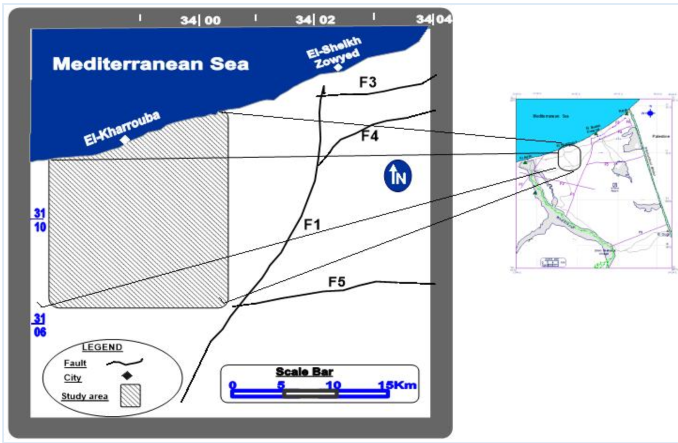

Fig. 1: Key map of the study area

Geomorphologically

The study area is characterized by desert and arid conditions. This appears in a number of land features. It is represented by accumulation of drift sand, the development of yellow desert soils and the lack of natural vegetation. The area under investigation is characterized by moderate relief with elevation varying from about Sea level to less than 1000m. From Geomorphologic point of view, Sinai Peninsula includes the following main units Fig. (2):

1 – The Southern Mountainous Region, which is composed of igneous and metamorphic rocks of Precambrian age.
2 – The Central Table Lands, which include two plateaux:
  a – El Tih plateau is composed of Cretaceous limestone, with shale and sandstones at the base, Hammad, (1980).
  b – El Egma plateau, chalky carbonate rocks of Eocene age
3 – The Mediterranean coastal plain, where the investigated area lies within it and extends in the entire width of northern Sinai. This unit is bounded on the north by the Mediterranean Sea and on the south by the central high lands.

The Digital Elevation Model (DEM)

The DEM of the investigated area showed that this area lies within a low land area, Fig. (3), discusses minimum and maximum values. Where, the minimum and maximum elevation values measured are 19.98m and 68.7m respectively.

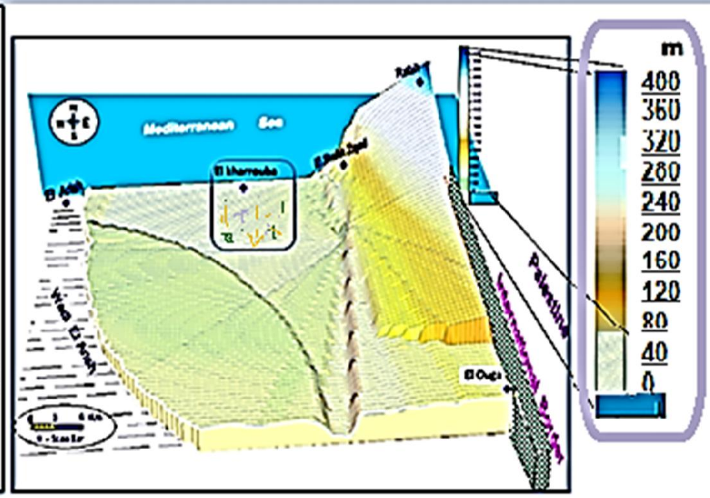

Fig. 2: Geomorphological map of Northeast Sinai Peninsula.

Fig. 3: The Digital Elevation Model (DEM) Northeast Sinai Peninsula.

Geologically

There are many studies and publications investigated the geology of Sinai Peninsula. The geological structure, distribution of major formations and their stratigraphy and lithology may have direct implications on the hydrogeological conditions in the area. According to Jica 1992, [8]. The study area is covered by Quaternary deposits which consist of sand dunes, old beach sand and calcareous sand stone (Kurkar formation), Fig. (4).

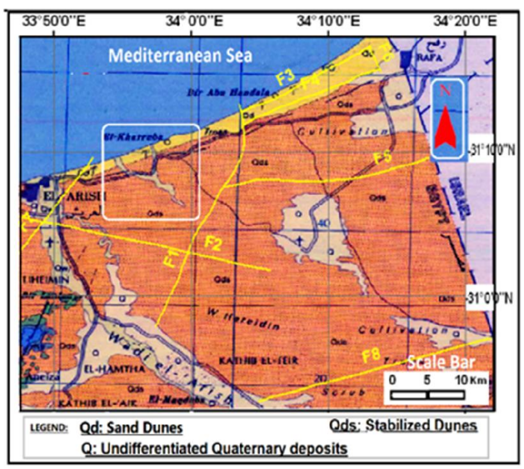

Fig. 4: Geological map of North East Sinai (after RIWR, 1988).

The thickness of these deposits is about 80–100m. The structural elements were given by RIWR (1988). It is considered as a base map in the present study for detecting the main faulting and folding systems Fig. (5).

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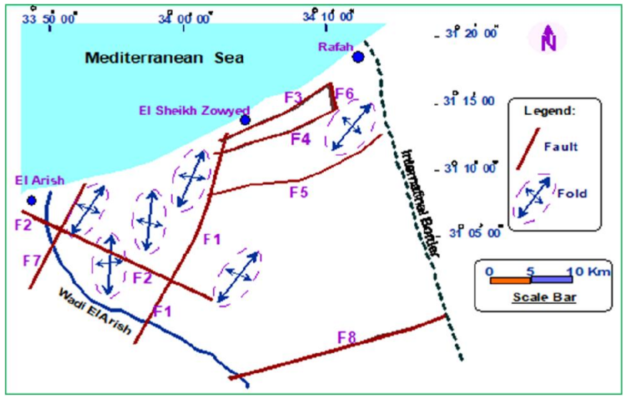
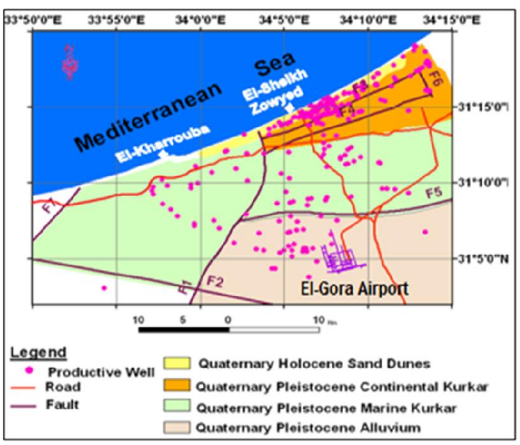


Fig. 5: Major structural elements in El-Arish-Rafah area (after RIWR, 1988).

Hydrogeologically

The area of study (El-Kharrouba) is characterized by an aquifer system belonging to the Quaternary (Holocene and Pleistocene), Fig. 6. The Pleistocene aquifer (The Calcareous Sand Stone (Kurkar Aquifer), is the main aquifer. It is considered as a type of calcareous sand deposits broadly distributed in the coastal plain. This aquifer is represented by 25 drilled water points within the study area (El-Kharrouba). This aquifer is characterized by unconfined to semi-confined conditions, where the depth to water varies from 12.4 m to 68.65 m. Water level ranges from +3.3 to +48.17m, see Figure 7.



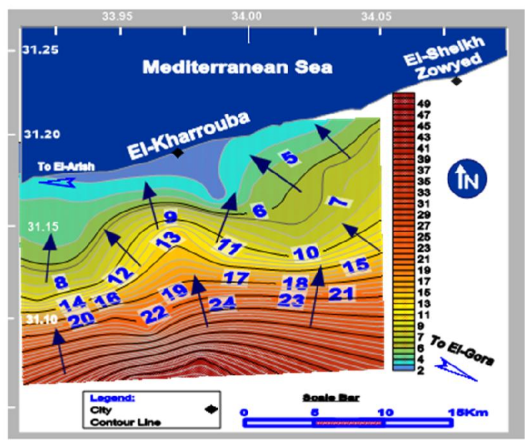


Fig. 6: Aquifer types in the study area **Fig. 7:** Water level contour map within the study are

Moreover, the Kurkar unit is underlained by the Pre-quaternary sediment mainly consisting of shale, sandstone, and /or limestone. Also, the Kurkar is overlained by a thick bed of clays where a confined aquifer conditions are developed. It occupies the most part of the bottom of the Quaternary in the study area. However, the extension of the clay bed is limited, so the hydraulic connection between the Kurkar aquifer and the overlying aquifer is observed. Generally, From Water Level (WL) contour map Fig. 7, the ground water flows northward towards the Mediterranean Sea.

Impact of the structures on groundwater occurrence

The previous studies elucidated that the structural setting has a direct impact on the occurrence and flow direction of groundwater. So, it's urgent to draw a general view of the hydrogeological setting of the study aquifers, Fig. 8.

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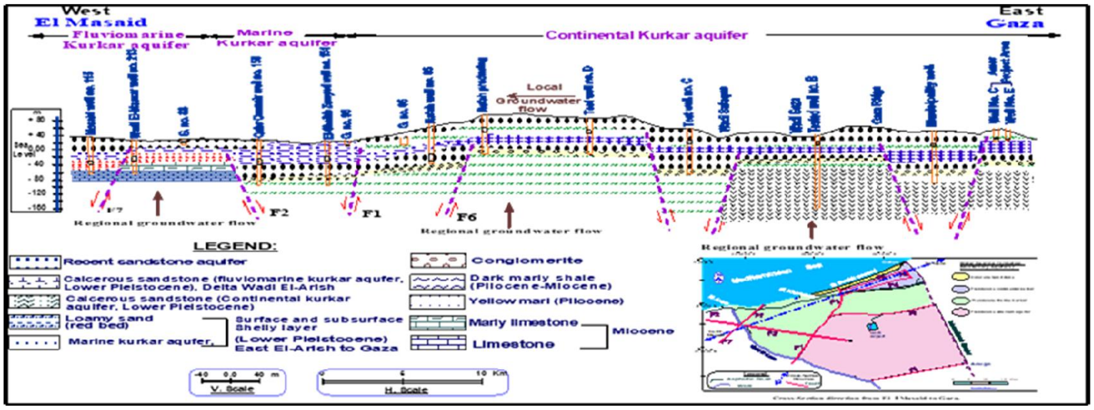

Fig. 8: Hydrogeological cross section from West to East (after Gedamy, 2004).

Materials and Methods

Several field trips were arranged to perform in field works, this included the following:

1- Collecting the hydrological data in the study area.
2- Collecting the wells lithological data and well design parameters (total depth, screen length, well design assembly and well diameter) within study area.
3- Measuring the SWL and well drawdown (by using the sounder instrument).
4- Determine the location & ground elevation (by using GPS instrument),
5- Carrying out twelve step tests for available productive wells and eight pumping and six recovery tests of main aquifer, Fig. (9).

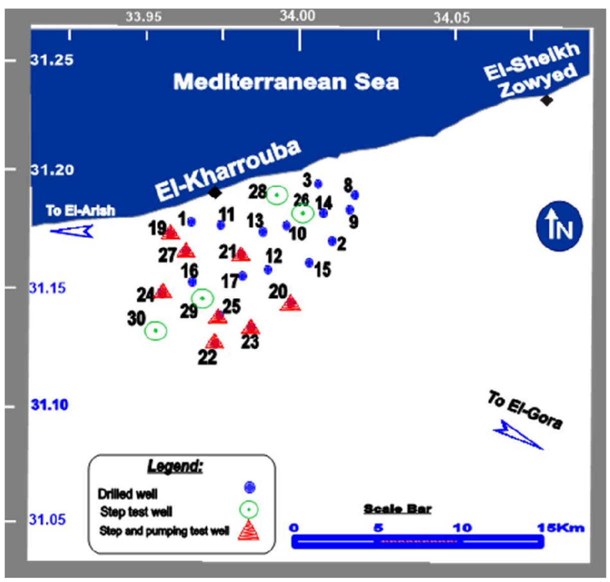

Fig. 9: Shows the selected wells for pumping test (also step and recovery tests).

6- Detecting errors of field data and/or calculation procedures, by which, the designer can use next equation as a check way for the field data or/and calculations, $[\, s_W\% + \eta_W \,] = 100\% = 1$
7- Analyzing the tests data of tested wells by using both of software (such as GWW software), manual analysis methods also, Rorabough method,
8- Preparing of distribution maps and/or tables of hydraulic parameters assessment.
9- Evaluating and assessment both of well characteristics (well hydraulic parameters) and design criteria using (different classification methods such as Zekai Sen 1995 and Hawash 2012).
10- Detecting the state of wells design criteria; if bad, moderate or good.
11- Redesigned cases for some wells of bad design criteria, using more scientific and ideal procedures.
12- To get the main equation factors B and C values, it's urgent to solve the main equation as follows;

-First: Manual Graphical Method (see Fig. 16); this method didn't use any value of correction factor to get best fitting line. Now, to get the main factors B and C values (Table 2), it's urgent to solve the main equation as follows;

Total drawdown calculated $\mathbf{s = (B\,Q + C\,Q^2)}$ ……………………………………………………......1

divide by Q to get linear relation**;** then, Specific drawdown $\mathbf{(s/Q) = (B + C\,Q)}$ ……………..….2

So, plot (s/Q) versus Q, to get best fitting line, (Jacob & Bierschink 1964)**,**
Where, B: is the line intercept with Y axis and C: is the line slope.

-Second: GWW software Method (see Fig. 17);, this method always use correction values about 15%-20% of correction factor to get best fitting line.

plot (s) versus (Q), to get B & C then; well loss (s_w) and formation loss (s_f) also well efficiency (η_w)……..(Gww version 1998)**,**

-Third: Rorabough Method (see Fig. 18),

$s = (B\,Q + C\,Q^n)$ … divide by Q …. $(s/Q) = (B + C\,Q^{n-1})$ … then;
Log[(s/Q) – B] = (n-1) Log(C Q) .... Log[(s/Q) – B]= (n-1) Log(C)+ (n-1) Log (Q)
So, plot [(s/Q) -B] versus Q in Log-Log paper as assuming B values to get best fitting line.
……….Where, Line Slope = (n-1) and C = Line intercept with Y axis.

3. Results and Discussion

3.1. Aquifer hydraulic parameters

During the present work, an approach was made to determine and evaluate the hydraulic parameters of the water bearing formations. In order to achieve this goal, eight pumping tests and six recovery tests were carried out on selected wells, Fig. 9. So, the field data were analyzed by two different methods, by applying Cooper and Jacob analyzing method. Also by applying Aquifer Test Pro. software (Waterloo). The resultant values of different methods and average values were showed in Figures from 10 to 13 and Tabulated in Table 1.

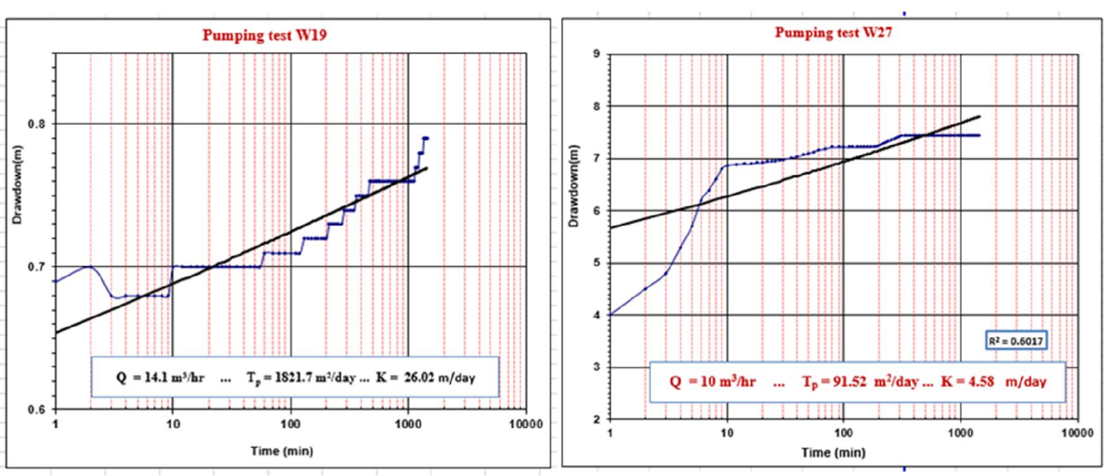

Fig. 10: Analyzing pumping test field data by applying Cooper-Jacob method, W19 & W27.

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- *Pumping test of Well 19*

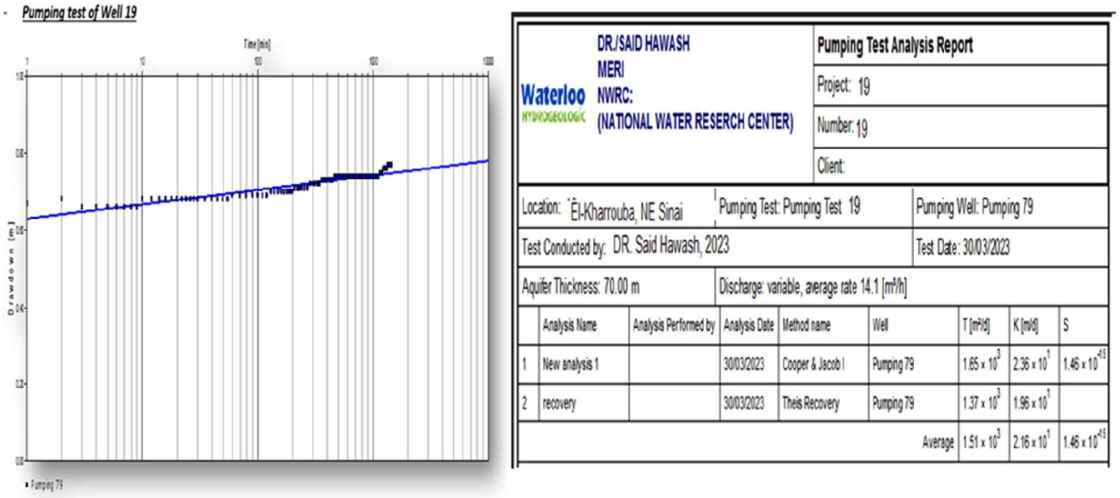

Fig. 11: Analyzing pumping test field data by applying Aquifer test pro. Software, W19.

- *Pumping test Well 27*

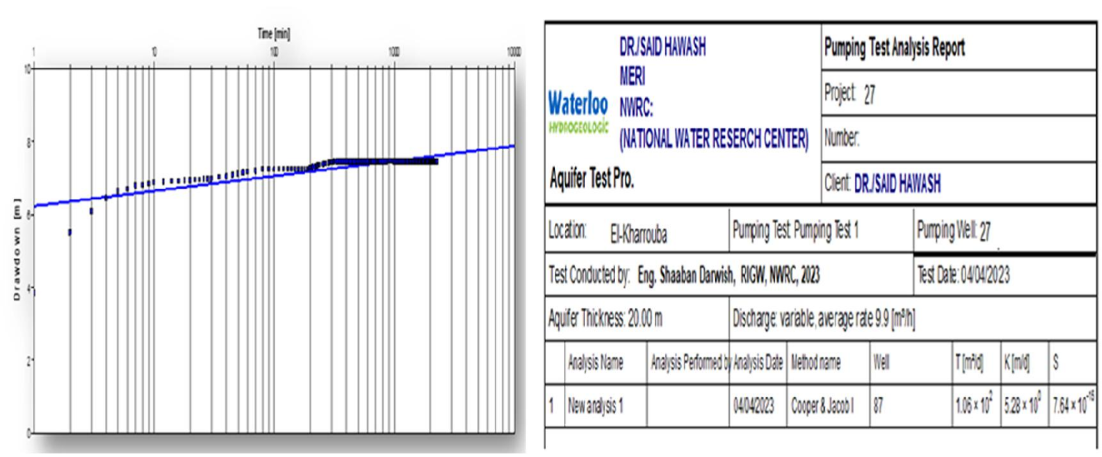

Fig. 12 : Analyzing pumping test field data by applying Aquifer test pro. Software, **W27.**

- ***Recovery test W19***

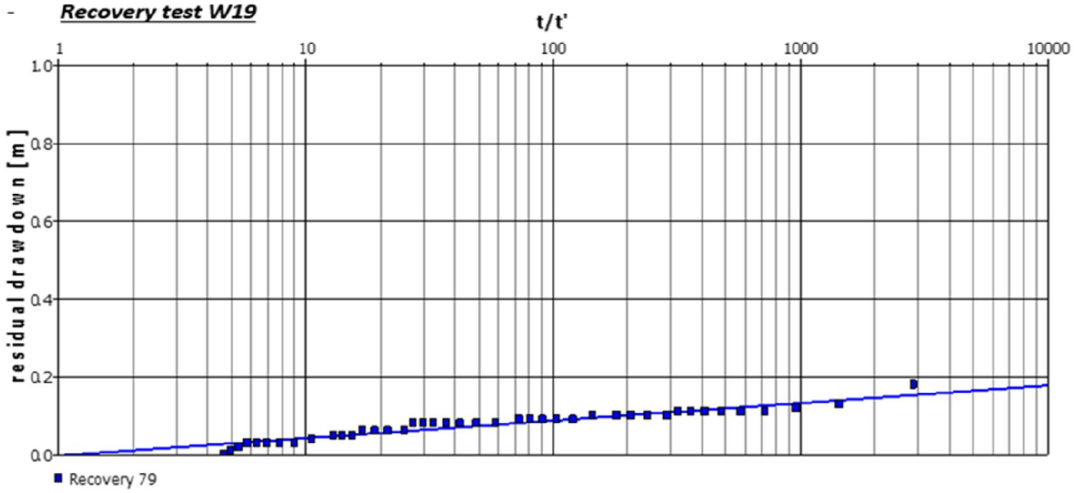

Fig. 13: Analyzing recovery test data by applying Aquifer test pro. Software, W19.

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Table 1: The average calculated hydraulic parameters of the studied aquifer

well no.	Q m^3/day	$T_{average}$ (m^2/day)	$K_{average}$ (m/day)	S .... avarage	D diffusivity = (T / S)average
19	141	1632.3	27.7	$1.46*10^{-15}$	$1.118*10^{+18}$
20	240	651.4	16.3	$1*10^{-4}$	$6.514*10^{+6}$
21	233	7789.7	121.5	$4.17*10^{-5}$	$1.868*10^{+8}$
22	233	740.9	24.7	$2.71*10^{-20}$	$2.734*10^{22}$
23	140	612.7	12.2	$7.68*10^{-27}$	$7.978*10^{+28}$
24	130	343.2	6.8	$1*10^{-21}$	$3.433*10^{+23}$
25	383	1097.4	47.5	$1.75*10^{-10}$	$6.271*10^{+12}$
27	99	65.8	3.28	$7.64*10^{-15}$	$8.6178*10^{+15}$

- Furthermore, the values of the hydraulic parameters by the present work, used for compiling distribution maps of aquifer different hydraulic parameters such as; Transmissivity (T), Fig. 14, Storage coefficient (S), Fig. 15, hydraulic conductivity (K), Fig. 16 and Diffusivity (D), Fig. 17.
-

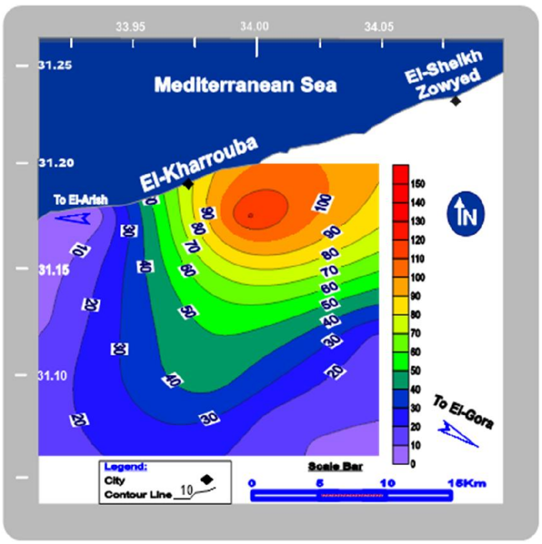

Fig. 14: Transmissivity (T) contour map

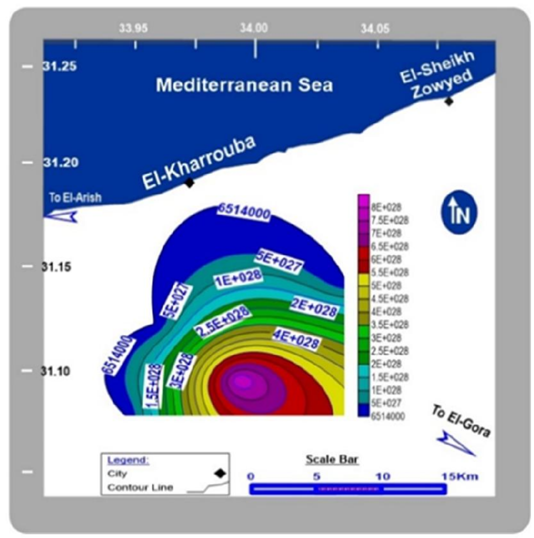

Fig. 15: Storativity (S) contour map

Moreover, the higher Transmissivity values tend to be indicative of higher aquifer potentiality, (Jacob, 1944), [9]. These phenomena could be attributed to the impact of structural setting, variations of aquifer thickness and heterogeneity of aquifer sediments. Because of the marine Kurkar aquifer reflect wide range of Transmissivity (612.7 to 7789.73 m^2/day), the Marine Kurkar aquifer is of high potentiality, based on classification of Georhage, 1979, [3], Table 2. The storage coefficient "S" values of the Marine Kurkar aquifer ranged between 7.68E-27 and 1.68E-04, in addition, the increases of "S" directions may be attributed to the decrease of clay content in these directions, which gives a good chance of high Storativity.

Table 2: Classification of Aquifer potentiality (Georhage,1979)

Potentiality of the aquifer	Transmissivity (m^2/day)
High	> 500
Moderate	50 - 500
Low	5 - 50
Very low	0.5 – 5

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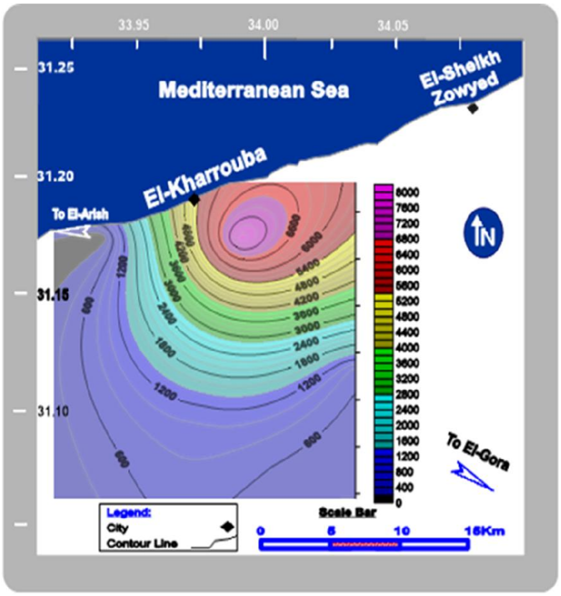

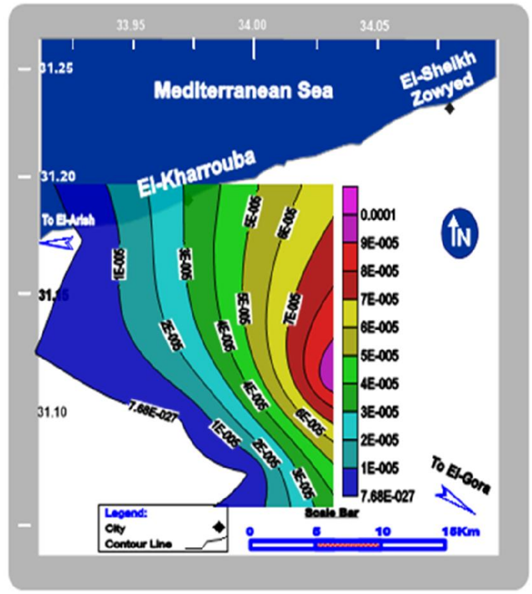

Fig. 16: Hydraulic Conductivity (K) contour map **Fig. 17:** Diffusivity (D) contour map

On the other hand, the hydraulic conductivity "K" values of the Marine Kurkar aquifer vary from a well to another. It ranges from 3.287 m/day to 121.617m/day, which pointed to high permeability property of kurkar aquifer. In addition, the hydraulic diffusivity D is the result of dividing the Transmissivity (T) by Storativity (S) (Kranz et al., 1990). The hydraulic diffusivity "D" values of the Marine Kurkar aquifer ranged between $6.514E10^{6}$ m^2/day and $7.968E10^{28}$ m^2/day. So, El Kharrouba area is characterized by high estimated values of hydraulic diffusivity and this reflects suitable conditions for sustainable reclamation projects under modern irrigation systems.

2- Well Hydraulic parameters and performances

In order to determine and evaluate well hydraulic parameters twelve step drawdown tests were carried out on available productive wells, Fig. 9. So, the field data were analyzed by three different methods, by applying manual or graphical method and by applying GWW software also by applying Rorabough method respectively. The resultant values of different methods and average values were showed in Figures from 18 to 21 and Tabulated in Tables from 3 to 6.

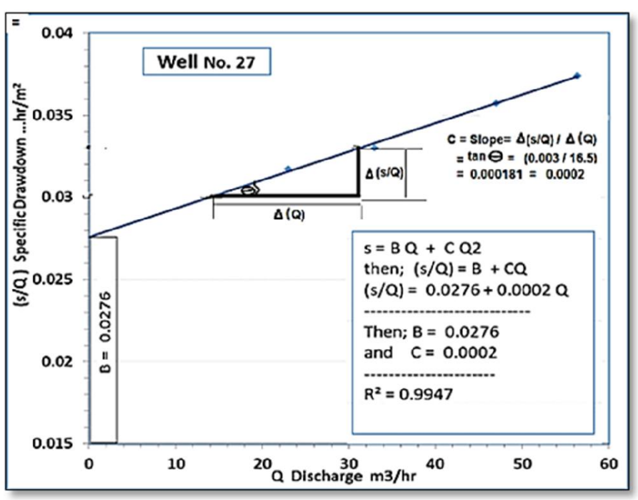

Fig. 18: Graphical or Manual method and its different parameters for well no. 27.

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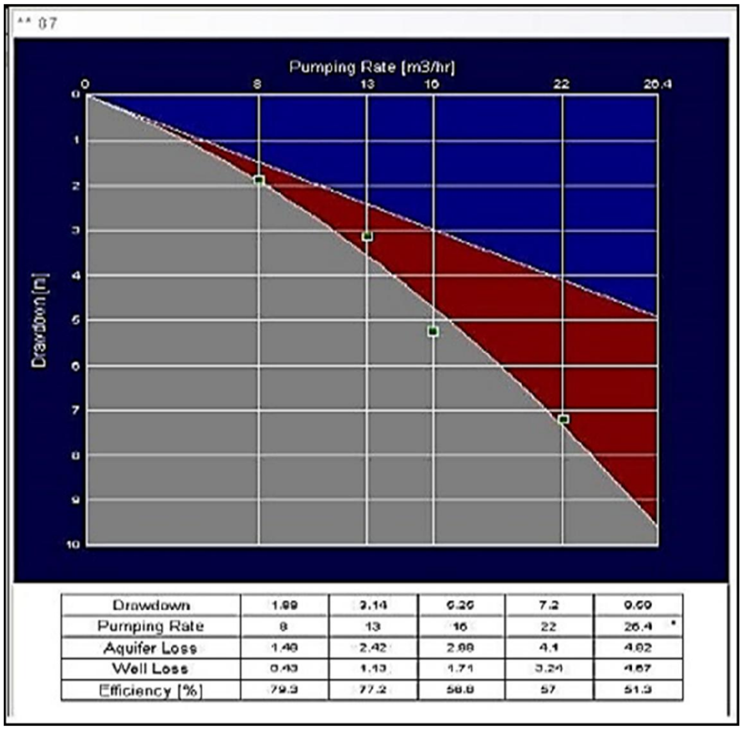

Fig. 19: GWW software method and its different parameters for well no. 27.

Table 3: Rorabough method and its calculation procedures for well no. 27

Step	s	Q	s/Q	B = 0.08	B = 0.12	B = 0.16	B = 0.20	B = 0.22
1	1.88	8	0.235000000	0.155000000	0.115000000	0.075000000	0.035000000	0.015000000
2	3.14	13	0.241538462	0.161538462	0.121538462	0.081538462	0.041538462	0.021538462
3	5.25	18	0.291666667	0.211666667	0.171666667	0.131666667	0.091666667	0.071666667
4	7.2	22	0.327272727	0.247272727	0.207272727	0.167272727	0.127272727	0.107272727
		Line No.		1	2	3	4	5

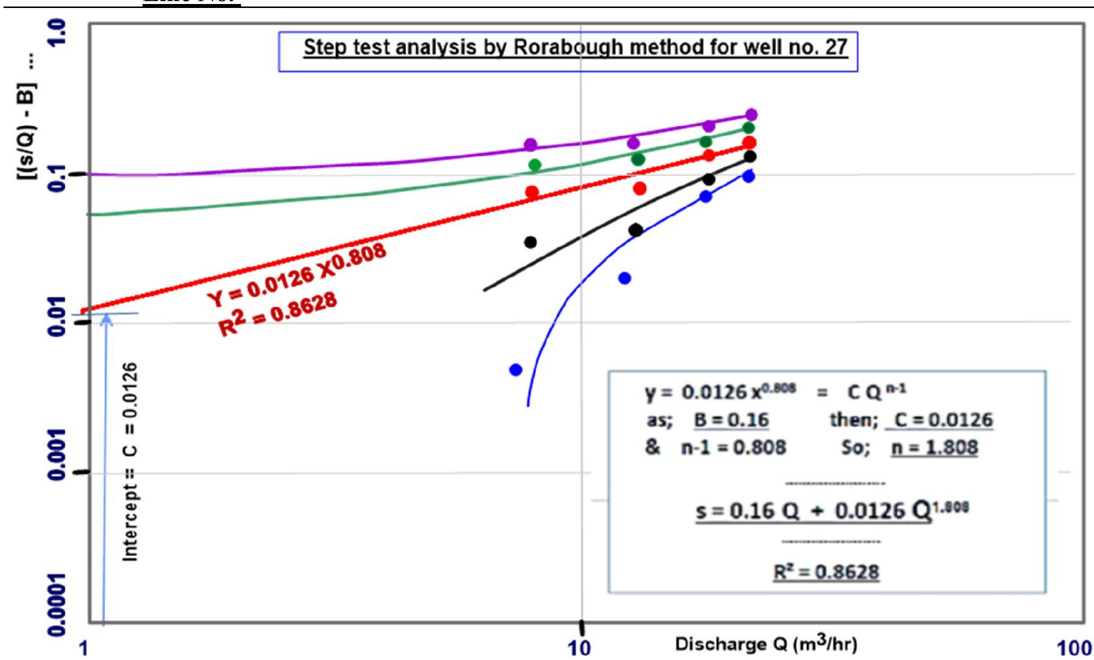

Fig. 20: Rorabough method and its different parameters for well no. 27.

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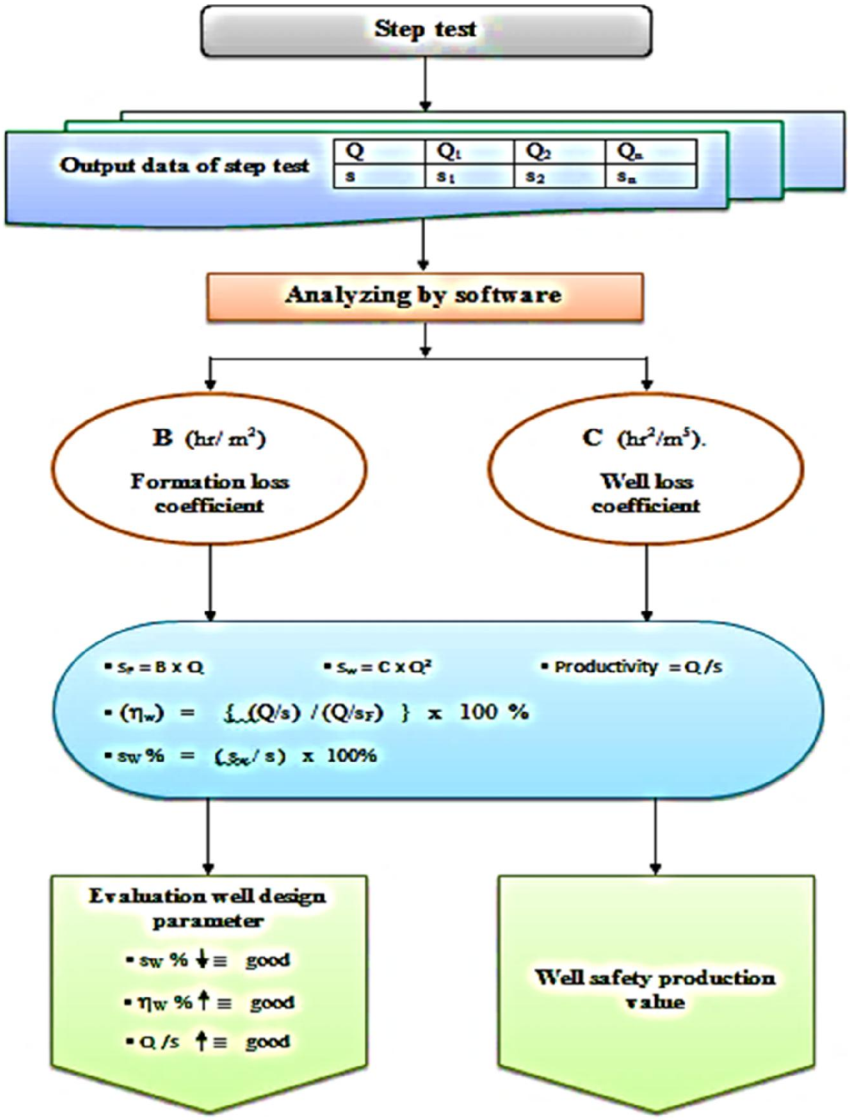

Fig. 21: Flow-chart elucidates evaluation well design parameters for different results of step test analysis method and its procedures (after Rabi, 2021).

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Table 4: Different hydraulic coefficients (B & C) for some studied wells.

NO:	Step No:	D.D. s m	Discharge Q (m^3/hr)	Specific D.D (s/Q) hr/m^2	Manual Method B hr/m^2	Manual Method C hr^2/m^5
W19	1	0.28	8.00	0.035000	0.02320	0.00022
	2	0.74	13.00	0.056923	0.02320	0.00022
	3	1.23	18.20	0.067582	0.02320	0.00022
	4	1.52	21.80	0.069725	0.02320	0.00022
	5	1.76	24.40	0.072131	0.02320	0.00022
W29	1	2.21	5.00	0.442000	0.34270	0.01510
	2	4.22	9.20	0.458696	0.34270	0.01510
	3	6.28	12.50	0.502400	0.34270	0.01510
	4	8.3	14.80	0.560811	0.34270	0.01510
	5	9.78	15.86	0.616646	0.34270	0.01510
W30	1	1.35	19.00	0.071053	0.06060	0.00050
	2	2.25	29.40	0.076531	0.06060	0.00050
	3	3.35	40.60	0.082512	0.06060	0.00050
	4	4.4	50.00	0.088000	0.06060	0.00050

Table 4: Continued

NO:	Step No:	D.D. s m	GWW Software B hr/m^2	GWW Software C hr^2/m^5	Rorabough Method B hr/m^2	Rorabough Method C hr^2/m^5	Average Value B hr/m^2	Average Value C hr^2/m^5
W19	1	0.28	0.03061	0.00177	0.02800	0.00030	0.02727	0.000766
	2	0.74	0.03061	0.00177	0.02800	0.00030	0.02727	0.000766
	3	1.23	0.03061	0.00177	0.02800	0.00030	0.02727	0.000766
	4	1.52	0.03061	0.00177	0.02800	0.00030	0.02727	0.000766
	5	1.76	0.03061	0.00177	0.02800	0.00030	0.02727	0.000766
W29	1	2.21	0.07673	0.00155	0.10000	0.00140	0.17314	0.006017
	2	4.22	0.07673	0.00155	0.10000	0.00140	0.17314	0.006017
	3	6.28	0.07673	0.00155	0.10000	0.00140	0.17314	0.006017
	4	8.3	0.07673	0.00155	0.10000	0.00140	0.17314	0.006017
	5	9.78	0.07673	0.00155	0.10000	0.00140	0.17314	0.006017
W30	1	1.35	0.06028	0.00055	0.02400	0.00020	0.04829	0.000418
	2	2.25	0.06028	0.00055	0.02400	000020	0.04829	0.000418
	3	3.35	0.06028	0.00055	0.02400	0.00020	0.04829	0.000418
	4	4.4	0.06028	0.00055	0.02000	0.00020	0.04829	0.000418

Table 5: Well characteristics resulted in all methods and its calculation procedures for all tested wells

Well NO:	Step No:	Measured D.D. s m	Q (m3/hr)	Discharge (s/Q) hr/m2 B hr/m2	Specific D.D... C hr2/m5	C*Q2 sw	Average Value ...(m) sF	sf=B*Q ...m s sw %	Well Loss (sw+sF)...m Effi)w %	Formation Loss sW% = (sw / s) (m2/hr)	Total loss (sF / s) (m2/hr) Effi)w %	Well loss percent Q/s	well efficiency Q/sF	(Q/s)
W19	1	0.28	8.00	0.0350000	0.027270	0.000766	0.0490240	0.2181600	0.2671840	18.35	81.65	29.942	36.670	81.6
	2	0.74	13.00	0.0569231	0.027270	0.000766	0.1294540	0.3545100	0.4839640	26.75	73.25	26.862	36.670	73.2
	3	1.23	18.20	0.0675824	0.027270	0.000766	0.2537298	0.4963140	0.7500438	33.83	66.17	24.265	36.670	66.1
	4	1.52	21.80	0.0697248	0.027270	0.000766	0.3640338	0.5944860	0.9585198	37.98	62.02	22.743	36.670	62.0
	5	1.76	24.40	0.0721311	0.027270	0.000766	0.4560458	0.6653880	1.1214338	40.67	59.33	21.758	36.670	59.3
W 20	1	0.67	7.20	0.0930556	0.080040	0.002026	0.1050451	0.5762880	0.6813331	15.42	84.58	10.568	12.494	84.5
	2	1.57	13.42	0.1169896	0.080040	0.002026	0.3649353	1.0741368	1.4390721	25.36	74.64	9.325	12.494	74.6
	3	2.355	19.08	0.1234277	0.080040	0.002026	0.7376794	1.5271632	2.2648426	32.57	67.43	8.424	12.494	67.4
	4	3.29	23.99	0.1371405	0.080040	0.002026	1.1661956	1.9201596	3.0863552	37.79	62.21	7.773	12.494	62.2
W 21	1	2.29	18.36	0.1247277	0.109233	0.002320	0.7820479	2.0055240	2.7875719	28.05	71.95	6.586	9.155	71.9
	2	4.23	32.48	0.1302340	0.109233	0.002320	2.4474849	3.5478987	5.9953836	40.82	59.18	5.418	9.155	59.1
	3	6.29	45.36	0.1386684	0.109233	0.002320	4.7734687	4.9548240	9.7282927	49.07	50.93	4.663	9.155	50.9
W 22	1	1.25	10.23	0.1221896	0.071400	0.002175	0.2276549	0.7304220	0.9580769	23.76	76.24	10.678	14.006	76.2
	2	2.05	15.23	0.1346028	0.071400	0.002175	0.5045749	1.0874220	1.5919969	31.69	68.31	9.567	14.006	68.3
	3	2.73	19.30	0.1414508	0.071400	0.002175	0.8102899	1.3780200	2.1883099	37.03	62.97	8.820	14.006	62.9
	4	3.57	23.70	0.1506329	0.071400	0.002175	1.2218630	1.6921800	2.9140430	41.93	58.07	8.133	14.006	58.0
W 23	1	0.5	8.10	0.0617284	0.039247	0.003006	0.1972018	0.3178980	0.5150998	38.28	61.72	15.725	25.480	61.7
	2	0.86	13.00	0.0661538	0.039247	0.003006	0.5079577	0.5102067	1.0181643	49.89	50.11	12.768	25.480	50.1
	3	1.25	17.20	0.0726744	0.039247	0.003006	0.8891964	0.6750427	1.5642391	56.85	43.15	10.996	25.480	43.1
	4	1.98	22.00	0.0900000	0.039247	0.003006	1.4547427	0.8634267	2.3181693	62.75	37.25	9.490	25.480	37.2
W 24	1	1.51	4.00	0.3775000	0.386833	0.000756	0.0121030	1.5473333	1.5594363	0.78	99.22	2.565	2.585	99.2
	2	4.55	11.00	0.4136364	0.386833	0.000756	0.0915288	4.2551667	4.3466955	2.11	97.89	2.531	2.585	97.8
	3	6.37	15.70	0.4057325	0.386833	0.000756	0.1864541	6.0732833	6.2597374	2.98	97.02	2.508	2.585	97.0
	4	7.39	18.20	0.4060440	0.386833	0.000756	0.2505621	7.0403667	7.2909287	3.44	96.56	2.496	2.585	96.5
W 25	1	0.6	11.50	0.0521739	0.038973	0.001032	0.1365217	0.4481933	0.5847150	23.35	76.65	19.668	25.659	76.6
	2	1.38	24.30	0.0567901	0.038973	0.001032	0.6095628	0.9470520	1.5566148	39.16	60.84	15.611	25.659	60.8
	3	2.5	38.70	0.0645995	0.038973	0.001032	1.5460654	1.5082680	3.0543334	50.62	49.38	12.671	25.659	49.3
	4	4.45	56.80	0.0783451	0.038973	0.001032	3.3304476	2.2136853	5.5441329	60.07	39.93	10.245	25.659	39.9
	5	5.84	65.52	0.0891331	0.038973	0.001032	4.4315301	2.5535328	6.9850629	63.44	36.56	9.380	25.659	36.5
W 26	1	4.85	6.80	0.7132353	0.408733	0.009064	0.4191348	2.7793867	3.1985214	13.10	86.90	2.126	2.447	86.9
	2	6.42	8.70	0.7379310	0.408733	0.009064	0.6860794	3.5559800	4.2420594	16.17	83.83	2.051	2.447	83.8
	3	7.68	10.24	0.7500000	0.408733	0.009064	0.9504642	4.1854293	5.1358936	18.51	81.49	1.994	2.447	81.4
	4	8.7	12.40	0.7016129	0.408733	0.009064	1.3937319	5.0682933	6.4620252	21.57	78.43	1.919	2.447	78.4
W 27	1	0.73	23.00	0.0317391	0.124700	0.002718	1.4378220	2.8681000	4.3059220	33.39	66.61	5.341	8.019	66.6
	2	1.09	33.00	0.0330303	0.124700	0.002718	2.9599020	4.1151000	7.0750020	41.84	58.16	4.664	8.019	58.1
	3	1.68	47.00	0.0357447	0.124700	0.002718	6.0040620	5.8609000	11.8649620	50.60	49.40	3.961	8.019	49.4
	4	2.11	56.40	0.0374113	0.124700	0.002718	8.6458493	7.0330800	15.6789293	55.14	44.86	3.597	8.019	44.8
W 28	1	0.92	16.75	0.0549254	0.042057	0.000641	0.1799434	0.7044492	0.8843926	20.35	79.65	18.940	23.777	79.6
	2	1.91	32.40	0.0589506	0.042057	0.000641	0.6732811	1.3626360	2.0359171	33.07	66.93	15.914	23.777	66.9
	3	3.7	56.16	0.0658832	0.042057	0.000641	2.0228356	2.3619024	4.3847380	46.13	53.87	12.808	23.777	53.8
	4	4.65	67.39	0.0690013	0.042057	0.000641	2.9127103	2.8341988	5.7469091	50.68	49.32	11.726	23.777	49.3
W 29	1	2.21	5.00	0.4420000	0.173143	0.006017	0.1504333	0.8657167	1.0161500	14.80	85.20	4.921	5.776	85.2
	2	4.22	9.20	0.4586957	0.173143	0.006017	0.5093071	1.5929187	2.1022258	24.23	75.77	4.376	5.776	75.7
	3	6.28	12.50	0.5024000	0.173143	0.006017	0.9402083	2.1642917	3.1045000	30.29	69.71	4.026	5.776	69.7
	4	8.3	14.80	0.5608108	0.173143	0.006017	1.3180367	2.5625213	3.8805580	33.97	66.03	3.814	5.776	66.0
	5	9.78	15.86	0.6166456	0.173143	0.006017	1.5135976	2.7460533	4.2596509	35.53	64.47	3.723	5.776	64.4
W 30	1	1.35	19.00	0.0710526	0.048293	0.000418	0.1507175	0.9175733	1.0682908	14.11	85.89	17.785	20.707	85.8
	2	2.25	29.40	0.0765306	0.048293	0.000418	0.3608703	1.4198240	1.7806943	20.27	79.73	16.510	20.707	79.7
	3	3.35	40.60	0.0825123	0.048293	0.000418	0.6881903	1.9607093	2.6488996	25.98	74.02	15.327	20.707	74.0
	4	4.4	50.00	0.0880000	0.048293	0.000418	1.0437500	2.4146667	3.4584167	30.18	69.82	14.457	20.707	69.8

Table 6: Well hydraulic Parameters (s_F, s_W, s, η and s_W%) for some studied wells

Well	D.D.	Q	B	C	Well Loss	Format-ion Loss	Total loss	well	well loss
NO	m	m3/hr	hr/m2	hr2/m5	sw = C*Q2 ...(m)	Sf =B*Q ...m	s =(sw+sF) m	efficiency η %	percent s_w %
	Measured				sw	s_F	s	(s_F / s)	
W19	0.28	8.0	0.027270	0.000766	0.04902	0.21816	0.2671	81.65	18.35
	0.74	13.0	0.027270	0.000766	0.12945	0.3545	0.4839	73.25	26.75
	1.23	18.2	0.027270	0.000766	0.25372	0.49631	0.7500	66.17	33.83
	1.52	21.8	0.0273	0.0008	0.3640	0.5945	0.9585	62.02	37.98
	1.76	24.4	0.0800	0.0020	0.4560	0.6654	1.1214	59.33	40.67
W 29	2.21	5.0	0.1731	0.0060	0.1504	0.8657	1.0162	85.20	14.80
	4.22	9.2	0.1731	0.0060	0.5093	1.5929	2.1022	75.77	24.23
	6.28	12.5	0.1731	0.0060	0.9402	2.1643	3.1045	69.71	30.29
	8.3	14.8	0.1731	0.0060	1.3180	2.5625	3.8805	66.03	33.97
	9.78	15.86	0.0483	0.0004	1.5136	2.7461	4.2596	64.47	35.53
W 30	1.35	19.0	0.0483	0.0004	0.1507	0.9176	1.0682	85.89	14.11
	2.25	29.40	0.0483	0.0004	0.3609	1.4198	1.7807	79.73	20.27
	3.35	40.60	0.0483	0.0004	0.6882	1.9607	2.6488	74.02	25.98

Assessment of well Productivity, well Efficiency and well loss percent to evaluate well design criteria or well hydraulic parameters

Assessment of Actual well specific capacity or well actual productivity $(Q/s)_{act}$.:

Based on Zekai Sen, classification (1995), Productivity (Q/s) assessment reflects that eleven values are moderate also, one value is good, this, see Table 7.

Table 7: Assessment of Well Actual Productivity$)_{max.}$ By Zekai Sen; 1995. [17],

Well	Average actual prod.	(Q/s) act. < 0.18	0.18≤ (Q/s)act.<1.8	1.8≤ (Q/s)act.<18	18 ≤ (Q/s)act.
NO:	(Q/s)act.	Very Low	Low	Moderate	Good
W19	25.11				Y
W 20	9.02			Y	
W 21	5.56			Y	
W 22	9.30			Y	
W 23	12.24			Y	
W 24	2.53			Y	
W 25	13.51			Y	
W 26	2.02			Y	
W 27	4.39			Y	
W 28	14.85			Y	
W 29	4.17			Y	
W 30	16.02			Y	

Based on Hawash, classification (2012), Productivity (Q/s) assessment illustrates that five values of actual productivity are low, while, two values are low-to-moderate, also four values of actual productivity are moderate, while last one indicated moderate-to-good value, see Table 8 also see Fig. 22.

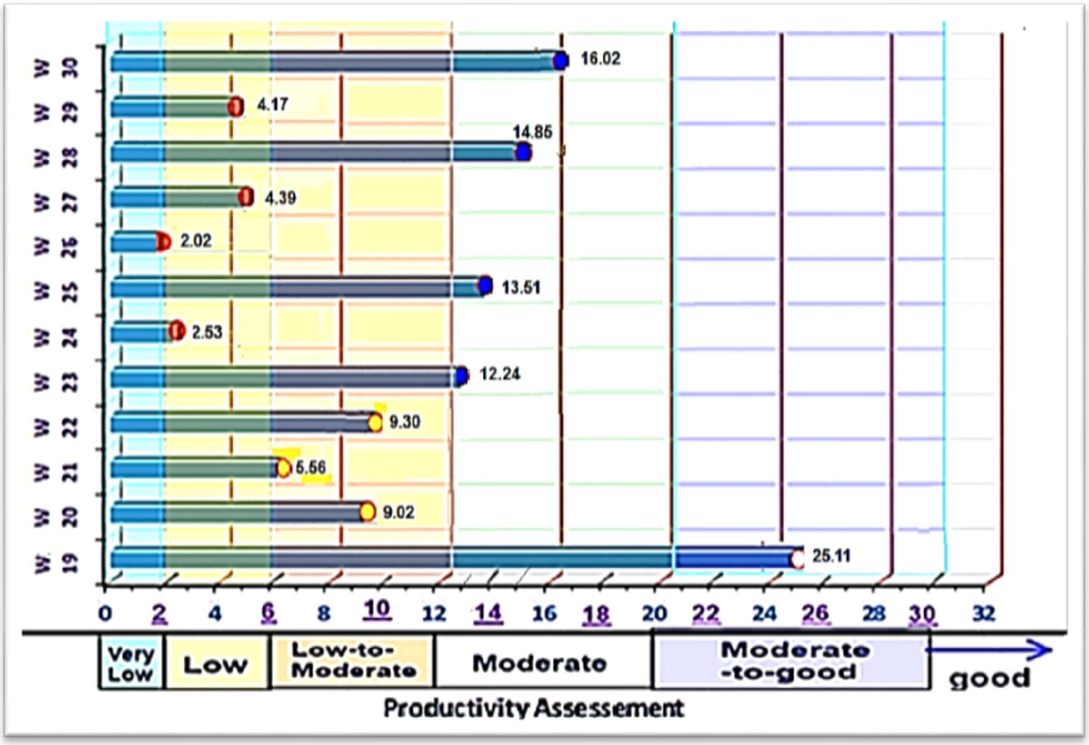

Fig. 22: Assessment of Well Actual Productivity based on classification of Hawash (2012).

Table 8: Assessment of Well Actual Productivity based on Hawash S. classification 2012

Well	Average actual prod.	$(Q/s)_{act.}<2$	$2\leq (Q/s)_{act.}<6$	$6\leq (Q/s)_{act.}<12$	$12\leq (Q/s)_{act.}<20$	$20\leq (Q/s)act.<30$	$30\leq (Q/s)act.$
NO:	(Q/s)act.	Very Low	Low	Low-to-Moderate	Moderate	Moderate-to-good	Good
W19	25.11					Y	
W 20	9.02			Y			
W 21	5.56		Y				
W 22	9.30			Y			
W 23	12.24				Y		
W 24	2.53		Y				
W 25	13.51				Y		
W 26	2.02		Y				
W 27	4.39		Y				
W 28	14.85				Y		
W 29	4.17		Y				
W 30	16.02				Y		

Assessment of well efficiency (ηw):

Based on Hawash, classification (2012), well efficiency (ηw) could be assessed immediately by Hawash, (2012) Classification, see Table 9 and Figure 23 respectively.

Table 9: Assessment of well efficiency based on classification of Hawash, (2012).

Well	Efficiency (%)	0 to 15	15 to 30	30 to 45	45 to 55	55 to 65	65 to 80	80 to 90	90 to 100
No.	η)average	Very Low	Low	Low to Moderate	Moderate	Moderate to good	good	Very Good	Excellent
W19	65.03						Y		
W 20	68.23						Y		
W 21	56.77					Y			
W 22	63.88					Y			
W 23	43.70			Y					
W 24	97.22								Y
W 25	43.28			Y					
W 26	81.88							Y	
W 27	51.07				Y				
W 28	55.65					Y			
W 29	69.15						Y		
W 30	65.70						Y		

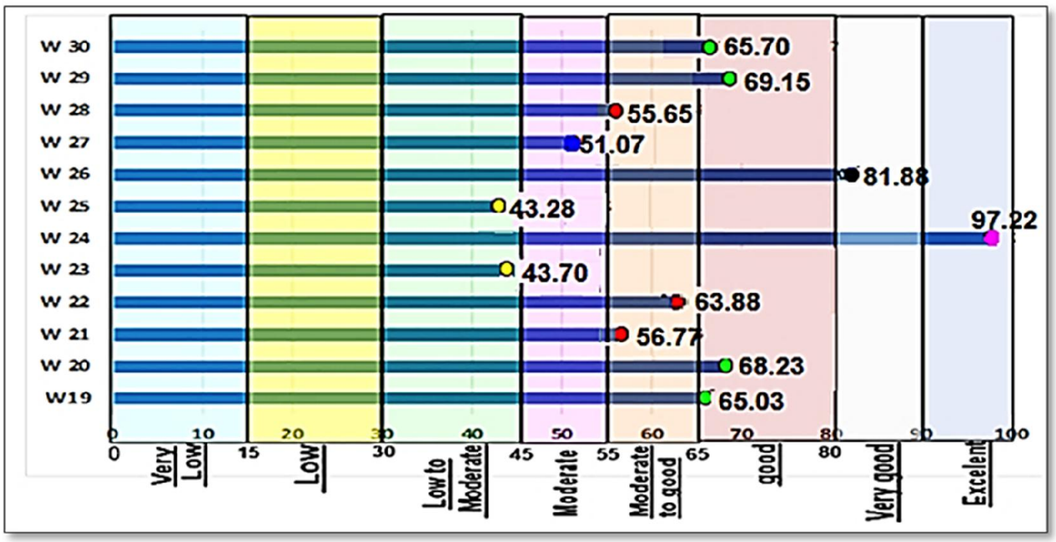

Fig. 23: Well efficiency (η_w%) assessement based on classification of Hawash, (2012).

-The results of efficiency classification (Table 8 and Fig. 23), may be as follows; two wells have low to moderate, one well has moderate value, three wells to good values, whereas five values are good, one value is very good and the last one is excellent. Generally, these values are classified as moderate (five values) and good (five values).

1- Well loss percent (sw%) assessment:

The values of well loss percent (sw%) for all the studied wells are calculated and classified as illustrated in Table 10 and Fig. 24.

As a classification result of well loss percent, the values showed that, most of wells (Seven values ranges between 30%–45% i.e. moderate), While one value is good and one is very good; which reflect moderate to good design criteria.

Table 10: Assessment of well loss percent s_W% based on Hawash S.; 2012 classification, [7],.

Well	Well loss percent	0 to 15	15 to 30	30 to 45	45 to 55	55 to 70	70 to 85	85 to 100
No.	sw %`	Very good	good	Good to moderate	Moderate	Moderate to bad	Bad	Very Bad
W19	34.97			Y				
W 20	31.77			Y				
W 21	43.23			Y				
W 22	36.12			Y				
W 23	56.30					Y		
W 24	2.78	Y						
W 25	56.72					Y		
W 26	18.12		Y					
W 27	48.93				Y			
W 28	44.35			Y				
W 29	30.85			Y				
W 30	34.30			Y				

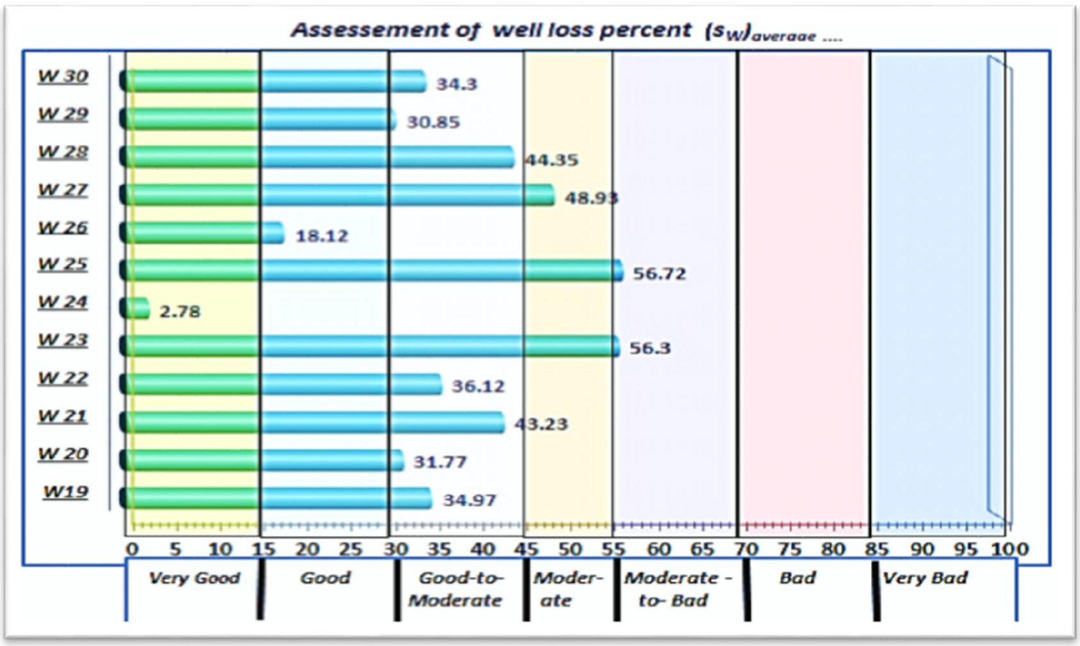

Fig. 24: Well loss percent assessment (sw%) based on Hawash, (2012) classification.

Final assessment of well characteristics or well hydraulic parameters

The average values of B and C, have been used in calculating all well hydraulic parameters (Well characteristics) Table 3, such as: -

Well loss (sw) -Formation loss (s_F), -Total losses (s) -Well Loss percent (s_w)% -Well efficiency (η)% - Specific capacity or productivity (Q/s).

Furthermore, the average values of main well hydraulic parameters can be stated as follows:
Well loss (s_w), (its min. value was 0.135 m while max. value was 4.762 m)
Formation loss (s_F), that varies from 0.4658 to 4.969 m
Total loss (s), it ranged between 0.7162 and 9.732 m.
Well productivity:
a. Well actual productivity $[(Q/s)_{actual}]_{average}$: (its min. value was 2.02 (m3/hr)/m while max. value was 25.11 (m3/hr)/m)

b. Theoretical productivity[$(Q/s)_{theo.}]_{average}$: (its min. value was 2.59(m3/hr)/m while max. value was 36.67 (m3/hr)/m)
Well efficiency $(\eta_w)_{average}$.: (its min. value was 43.28% while max. value was 97.22%)
Well loss percent $(s_w\ \%)_{average}$: (its min. value was 2.78% while max. value was 56.72%)

4. Conclusion

The hydraulic conductivity "K" values of the Marine Kurkar aquifer ranges from 3.287 m/day to 121.617m/day, which pointed to high permeability property of kurkar aquifer. Because of the marine Kurkar aquifer reflects wide range of Transmissivity (612.7 to 7789.73 m^2/day) > 500, the Marine Kurkar aquifer is of high potentiality, based on classification of Georhage, (1979). The storage coefficient values of the Marine Kurkar aquifer ranged between 7.68E-27 and 1.68E-04. The hydraulic diffusivity " D " values of the Marine Kurkar aquifer ranged between 6.514E106 m2/day and 7.968E1028 m2/day. So, El Kharrouba area is characterized by high estimated values of hydraulic diffusivity and this reflects suitable conditions for sustainable reclamation projects under modern irrigation systems. On the other hand, the well characteristics within studied area pointed generally to bad design criteria which lead to a well failure. The wells of numbers (23 and 25) have very bad design criteria because, they have very high values of well loss percent (56.30% and 56.72% respectively) with low values of efficiencies (43.70% and 43.28% respectively). Wells of order (20, 22 and 28) reasonable (moderate) design criteria. Wells of numbers (19 and 30) have good design criteria. The rest wells of orders (21, 24, 26, 27 and 29) have abnormal hydraulic behavior because they have unusual values of productivity (5.56%, 2.53%, 2.02%, 4.39% and 4.17% respectively) in spite of they have moderate to good values of efficiencies (56.77%, 97.22%, 81.88%, 51.07% and 69.15 respectively) and low to moderate values of well loss percent (43.23%, 2.78%, 18.12%, 48.93% and 30.85% respectively).

5. Recommendations

More and deep studies are highly recommended to explain and investigate the abnormal hydraulic behavior for wells of orders (21, 24, 26, 27 and 29) because they have unusual values of productivity ranged from 2.02% to 5.56%, in spite of they have moderate to good values of efficiencies ranged from 56.77% to 97.22%, and low to moderate values of well loss percent ranged from 2.78% to 48.93%.

- It’s very important to complete the present study (Quantitative evaluation) by carrying out (Qualitative study) for the same studied area.
- Well safe productivity should be controlled by both decreasing the closing number of drilled wells to prevent abstraction overlapping or/and prevent excessive drawdown.
- The redesigned wells so urgent for some wells of bad design criteria, using more scientific and ideal procedures.

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References

Cooper, H. H. and C.E. Jacob, 1946: A generalized graphical method for evaluating formation constants and summarizing well field history.”, Am. Geophys. Union. Trans., 27, 526-534.

Gedamy, Y. R. A., 2004. Geochemical studies of the groundwater in North-East Sinai area, Egypt.”, Ph.D. Thesis, Fac. Sci., Ain Shams Univ., Cairo, Egypt, 821p.

Georhage, A., 1979. In Processing and Synthesis of Hydrogeological Data.”, Abacus Press, 390p.

GWW Software, (Grounwater under windows), Version 1998, upgraded 2008.

Hammad, F. A., 1980. Geomorphological & hydrogeological aspects of Sinai Peninsula.", Ann. Geol. Survey of Egypt, Vol. X, 11p.

Hassan, E. M. S., 2009. Hydrological study on the Quaternary aquifer in El-Arish – Rafah area Sinai Peninsula –Egypt. M. Sc. Thesis Geology, Department of Geology, Faculty of Science, Al-Azhar University (Assiut Branch), 267 p.

Hawash, S. A. F., 2012. Water resources management by applying mathematical modeling techniques in northeastern portion of Sinai Peninsula, Egypt. Ph.D. thesis of Mechanical Engineering, Mechanical Power Department, Faculty of Engineering, Ain Shams University, 567 p.

Japan International Cooperation Agency (JICA), 1992. North Sinai groundwater resources study in the Arab Republic of Egypt. Final report submitted to the Research Institute for Water Resources, Egypt, 207p.

Jacob, C. E., 1944. Notes on determining permeability by pumping tests under water-table conditions. U.S. Geological Survey, Publisher: The Author, Jamaica, N.Y., 1944, OCLC Number / Unique Identifier: 28211298, 25p

Jacob, C. E. and W. H. Bierschenk, 1964. Determining well efficiency by multiple step-drawdown tests.", publication 64.1, International Association of scientific hydrology.

Kranz, R. L., J. S. Saltzaman, and J. Blacia, 1990. Hydraulic diffusivity measurements on laboratory rock samples using an oscillating pore pressure method. Elsevier Ltd. 90 : 9062-9270.

Rabi, A. M. A., 2021. Deterioration causes of some groundwater wells in the Eastern Sahara Desert", M.Sc. Degree, Faculty of African Postgraduate Studies, Cairo university, 2021.

Research Institute for Water Resources (RIWR), 1988. Groundwater management study in El Arish – Rafah plain area. Phase 1, Vol.11, Cairo, Egypt, 166p.

Rorabough, M. I., 1953: Graphical and theoretical analysis of step drawdown tests of artesian wells, Proc. ASCE, 79, 1.

Shlumberjer, 2016. Aquifer Test Pro. Software, Waterloo Inc., Version 2016.

Taha, A. A. M., 1968. Geology of the groundwater supplies of El Arish-Rafah area, northeast Sinai, U.A.R. M.Sc. Thesis, Fac. Sci., Cairo Univ., Egypt. 129p.

Zekai Sen; 1995. Applied Hydrogeology for Scientists and Engineers. Lewis publishers, C.R.C. Press, Inco., Florida, U.S.A., 301 p.