STUDY OF CHANGES IN THE GROUND WATER IN GAZA STRIP DURING THE LAST TWENTY YEARS

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ملخـــــــص

يعتمد معظم السكان في قطاع غزة على الابار الجوفية لسد احتياجاتهم من المياه . وخلال الاعوام الاخيرة وبسبب ازدياد الاستهلاك المحلي وتسرب المياه المالحة من البحار المحيطة "بواسطة الضغط الهيدروليكي" بدات نوعية المياه في الابار تتدنى . في هذه الورقة العلمية ، تم اجراء عدة فحوصات كيميائية على العديد من العينات والتي اخذت من آبار مختلفة ومتواجدة في جميع انحاء قطاع غزة ، ولقد اثبتت النتائج انه بالفعل هناك تدني مستمر في نوعية المياه المستخرجة .

ABSTRACT

The inhabitants of the Gaza Strip depend heavily on underground resources for their water supplies. This is due, partly, to the scarcity of rain falls in that region and, also, to the limited number (three) of streams and the inadequate quantities of water which can be drwan from them. Chemical analysis of the water (for irrigation and domestic purposes) obtained from several wells and the comparison of the results, with those previously performed, on the same wells, showed, conclusively, that there exist a gradual change in the quality of water attainable from these wells. This has been attributed to the intrusion of the mediterranean salty water into the main aquifer (plio-pleistocence aquifer) of the area.

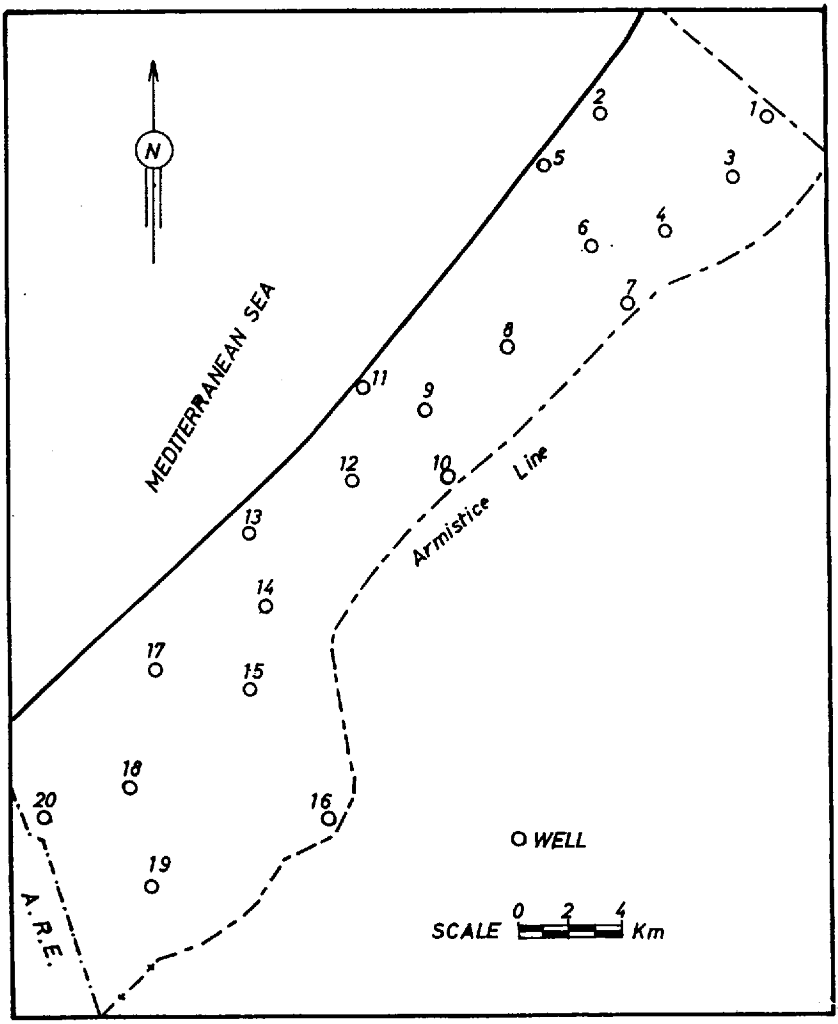
INTRODUCTION

Throughout the civinity of the Gaza Strip (approx : 360Km), there exist around two thousands wells. Most of these wells (Fig 1) lie outside the western perimeter (sand dunes area). Wells in the later area are tap free water from a calcareous salty sand stone bed (continental kurkar). However, the remaining wells (deeper than 60 meters) are tap confined water from the marine kurkar (plio - pleistocene aquifer). The later wells represent the main aquifer in the area. The marine kurkar is highly porous, and its permeable bed consists of shell fragments and course sands cemented by calcareous materials. Due to the seaward dip of this type of aquifer, the hydraulic equilibrium between the fresh water contained and the saline water of the sea depends on the input and output of the fresh water. Twenty years ago, this hydraulic equilibrium was somewhat stable, the input of the fresh water was nearly equal to the output, however, because of the increased demand for water, the output of the fresh water exceeded that of the input by 40 million cubic metres. Also, the average annual depession of the water level measured in the wells of the area, is about 24 cm. Consequently, this irigular hydraulic relationship caused the invasion of the salt water of the mediterranean into the main aquifer of the area and changes the groundwater quality.

The present study is mainly concerned with determining the changes that occurred in the quality of underground water in the Gaza Strip during the past two decades. The data obtained is then used to postulate the trend of further changes which is expected to occur in the future.

EXPERIMENTAL

The samples used for this investigation, are obtained from selected wells, distributed throughout the whole area of the Gaza strip. (Fig. 1) These samples were chemically tested and the results analysed to determine the



(Text-fig.1) GAZA STRIP, LOCATION OF WELLS

Table I. Chemical analysis of hrundwater in Gaza Strip

Sample No.	E.C. m mhos 25°	T.D.S	hard. epm	pH	Cations								Anions								
					K^+		Na^+		Ca^{++}		Mg^{++}		Cl^-		SO_4^{--}		NO_2^-	NO_3^-	F^-	HCO_3^- + CO_3^{--}	
					ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	ppm	ppm	ppm	epm
1	1650	1312	26	8.0	20.8	0.52	282	12.26	69.6	3.48	49.5	4.13	310	8.73	140	2.92	-	21.2	1.8	390	7.68
2	620	560	17	7.95	23.8	0.61	64.4	2.8	71.5	3.58	23.7	1.98	118	3.32	54	1.13	-	1.7	1.1	186	3.66
3	1490	1085	18	8.0	25.0	0.64	212	9.2	24.4	1.22	44.2	3.7	210	5.9	131	2.73	-	2.5	2.0	356	7.00
4	970	680	10	8.1	22.8	0.57	235	10.2	33.0	1.65	16.0	1.33	211	5.94	22.6	0.47	0.001	8.5	1.05	226	4.45
5	1300	960	12	7.75	25.0	0.64	232	10.1	32.6	1.63	22.2	1.85	212	5.96	16.2	0.34	0.1	51.3	0.66	353	6.96
6	3580	3000	72	7.15	25.7	0.66	725	31.5	161.0	8.05	151.0	12.58	1146	32.28	389.0	8.10	-	92.0	1.5	244	4.80
7	4200	3350	21	7.5	28.9	0.74	1037	45.1	46.2	2.31	45.7	3.81	1228	34.59	345	7.19	-	17.0	2.0	575	11.31
8	2530	2153	32	7.85	15.6	0.40	596	25.9	84.1	4.21	61.6	5.13	681	19.18	414	8.62	-	29.0	1.25	266	5.24
9	3950	2850	58	7.35	25.0	0.64	697	30.3	184.7	9.24	99.8	8.32	1200	33.80	420	8.75	-	11.0	1.35	202	3.98
10	3320	2680	38	7.1	26.9	0.69	747	32.5	84.1	4.21	78.6	6.56	1070	30.14	395	8.23	-	16.0	1.9	246	4.84
11	2280	1860	35	7.8	25.0	0.64	462	20.1	84.9	4.25	69.8	5.82	788	22.20	223	4.65	0.001	47.0	1.3	156	3.07
12	3460	2767	30	7.4	50.3	1.29	796	34.6	80.9	4.05	58.6	4.88	1034	29.13	408	8.50	-	8.8	2.0	260	5.12
13	1980	1590	18	7.8	24.0	0.6	414	18.0	40.2	2.01	37.3	3.11	301	8.48	468	9.75	-	41.0	0.8	235	4.62
14	3150	2520	42	8.3	26.9	0.69	593	25.8	148.0	7.40	67.4	5.62	877	24.71	527	10.98	0.001	94.0	1.4	122	2.40
15	3910	3160	23	7.8	26.5	0.68	1035	45.0	52.1	2.61	47.5	3.96	1181	33.27	614	12.79	-	8.7	3.4	164	3.23
16	5000	4730	74	8.1	23.2	0.59	1240	53.9	226.5	11.33	134.0	11.18	1791	50.45	1042	21.7	0.002	41.0	2.8	209	4.11
17	1160	920	19	8.15	3.2	0.08	202.4	8.8	52.1	2.61	35.9	2.99	331	9.32	99.2	2.07	0.001	24.0	1.25	148	2.91
18	870	720	16	7.95	25.4	0.65	122.0	5.3	54.5	2.73	24.6	2.05	245	6.90	70.6	1.47	-	14.5	0.9	136	2.83
19	4400	4000	66	8.2	23.1	0.59	1041	45.3	178.8	8.94	127.0	10.58	1451	40.87	897	18.69	-	18.0	3.4	256	5.04
20	1300	910	22	7.85	26.1	0.67	182	7.9	50.5	2.53	45.6	3.80	320	9.01	79.2	1.65	-	8.2	1.4	188	3.70

metalic and nonmetalic (inorganic) constituents in them (Table 1).

1. Determination of metals: Automic absorption spectrophotometric method was used for the determination of calcium, iron, magnesium and manganese and flame photometric method was used for the determination of potassium and sodium. The hardness was computed from results of the calcium and the magnesium determinations.

2. Determination of inorganic constituents[1] *:*

Chloride was determined by the potentiometric methods, fluoride by electrode method, sulphate by gravimetric and turbidimetric methods and the carbonate and bicarbonate were determined stoichiometrically by titration.

RESULTS AND DISCUSSION

Evaluation of Gaza.s irrigation waters: There are a number of procedures[3,11] which can be used to determine the degree of suitability of underground water for irrigation purposes. Most of the reported procedures make use of the following factors to determine the class of water being investigated:

1) Total salinity (electrical - conductivity) of water.
2) Percentage of Na (to the total cations).
3) Concentration of boron.
4) Concentration of chlorides and sulphates.

In general, most cakssification procedures yield that, irrigation waters can be subdivided into 3 - 5 classes.

Evaluation of the groundwater (for irrigation purposes) of Gaza Strip, using Wilcox[11] classification and the comparison of the results obtained, with those previously reported[4] two decades ago (on the same wells & using the same approach, yields that there has been a considerable depreciation in the quality of groundwater as indicated in Table 2.

Table 2. Evaluation of the ground water in Gaza. Classification is based on Wilcox[11]

Classification	El-Nakhal & Himida (1964)	Present Study (1984)
Samples of medium salinity hazard and low sodium hazard.	20 %	5 %
Samples of high salinity hazard and low sodium hazard.	20 %	15 %
Samples of high salinity hazard and medium sodium hazard	10 %	20 %
Samples of high salinity hazard and high sodium hazard.	---	5 %
Samples of very high salinity hazard and medium sodium hazard.	20 %	---
Samples of very high salinity hazard and high sodium hazard.	15 %	25 %
Samples of very high salinity hazard and very high sodium hazard.	15 %	30 %

In general. the comparison shows that the groundwater of Gaza Strip tends to have a very high salinity and sodium hazards.

In Doneen[3] approach, the following factors are taken into account in the evaluaton of irrigation waters:

1) Potential (or effective) salinity.
2) Permeability (or sodium) index.
3) Concentration of toxic substances.

Doneen, using the following equation to calculate the potential salinity (P) of several water samples (for irrigation purposes) $P = Cl + 1/2\ SO_4$ (meq/L), has divided irrigation water into three classes as shown in Table 3 (see also Fig. 2).

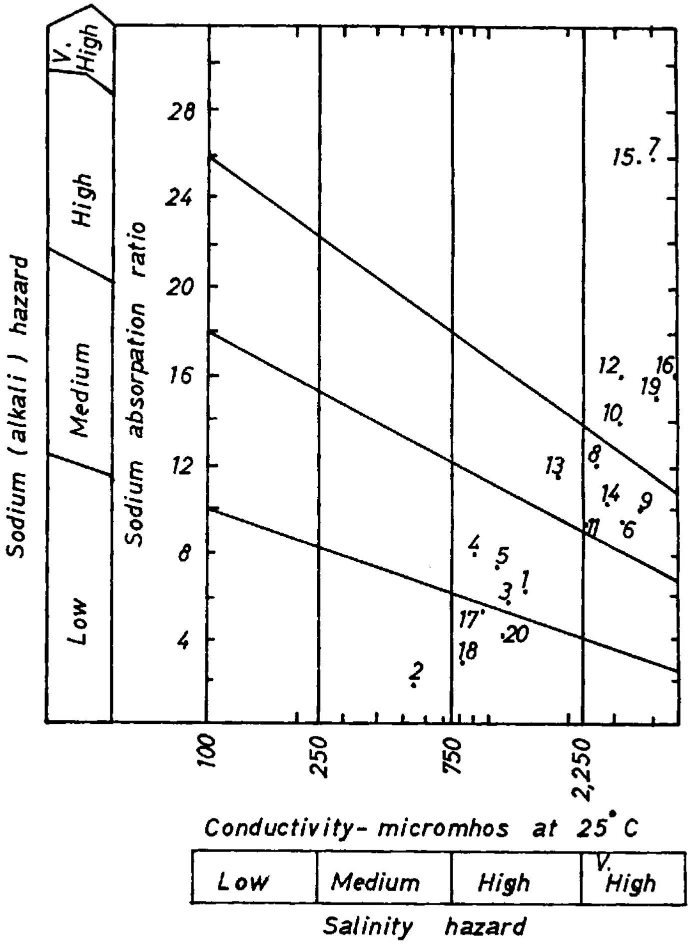
Table 3. Classes of irrigation water based on potential salinity.

Soil Characteristics	*Class I meq/L*	*Class II meq/L*	*Class III meq/L*
Soil of low permeability	*Less than 3*	*3 - 5*	*More than 5*
Soil of medium permeability	*Less than 5*	*5 - 10*	*More than 10*
Soil of High permeability	*Less than 7*	*7 - 15*	*More than 15*

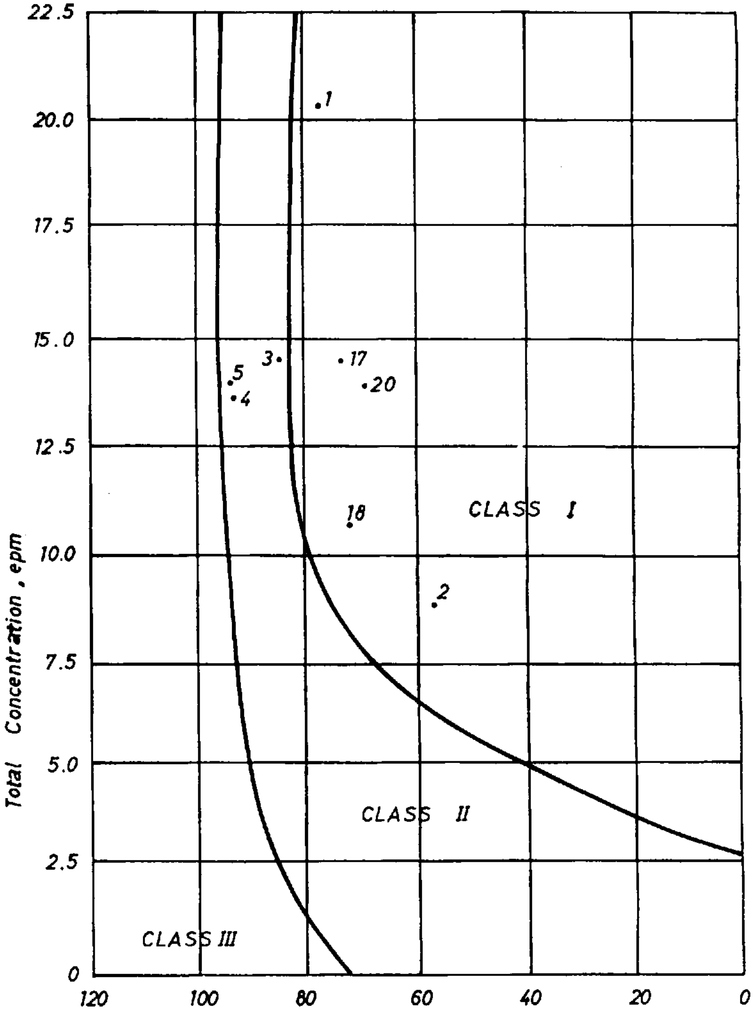
Also by estimating permeability (or sodium) index from the following equation: ,he permeability index =

$$\frac{Na + HCO_3}{Na + Mg + Ca} \times 100 \text{ Meq/L}$$

and combining the values obtained with those of the total salinity for the same samples, and by using Doneen 3 a graph irrigation water, may again, divided into three divisions (Fig 3). In the present investigation, the salinity of Gaza water samples was found to range between 3.885 Meq/L (well No. 2) and 61.30 Meq/L (well No. 16). Also the results of calculations involving the permeability index, when superimposed on Doneen graph yeild that: 25% of the selected samples may be regarded as a first class water, 15% as asecond class, and 60% as third class. Comparison of the present results with those previously reported[4] (performed under similar conditions) indicates that the Gaza water tends to be a third class water as shown in Table 4



(Fig.2) : Classification of the Ground Water in Gaza Strip for Irrigation Using Wilcox (1955) Diagram



Permeability Ir. dex

(Text-fig.3) Classification of the Ground Water in Gaza Strip for Irrigation, Using Doneen Diagram (for soil of medium permeability)

Table 4. Evalution of irrigation water based on permiability index and potential salinity.

A. Permiability index

Classification	El-Nakhal & Himida Analysis (1964)	Present Study Analysis (1984)
First Class	30%	25 %
Second Class	15%	15%
Third Class	55%	60%
B. Potential Salinity		
First Class	30%	5%
Second Class	15%	35%
Third Class	55%	60%

There are no reported litearature dealing with the classification of Gaza irrigation water according to the level of concentration of toxic substances (boron is the most important[1]). Therefore, this approach has not been adopted in this investigation.

Evaluating the groundwater of Gaza Strip for domestic uses: Idealies, water used for domestic purposes must be colorless, odorless and have an acceptable taste. All the analysed samples in the present study, are colorless as well as odorless but, 70% of these samples have a salty taste. This is due to the presence of sodium chloride in high concentration and because these samples contain a total of more than 1000 ppm dissolved solids.

No universal classification have yet been provided for evaluating the chemical characteristics of water used for domestic purposes. However, several attempts of local importance have appeared in different parts of the would.

According to the U.S.A. standards, water should not contain any of the following ingredients in amounts exceeding the shown concentrations[2] :

Fluoride	1.500 ppm.	Chromium	0.050 ppm.
lead	0.050 ppm.	Copper	1.000 ppm.
Arsenic	0.050 ppm.	Iron & Manganese	0.500 ppm.
Selenium	0.010 ppm.	Phenol	0.001 ppm.

And in the desert areas of the USSR, the following are two of the applied classifications which are similar, to some extent, to Gaza Strip[6] (Table 5).

Tables 5. Classification of water for domestic purposes[6]

a. The Classification Used in Northern Caucasus Region

Characteristics of water	Total dissolved solids (ppm)	Concentration of ions Cl (ppm)	SO_4 (ppm)	Total hardness (epm)
Good	500 - 1000	8 - 200	160 - 480	20 - 30
Acceptable	1000 - 2000	200 - 300	480 - 720	30 - 40
Permissible	2000 - 2500	300 - 400	720 - 960	40 - 50
Unsuitable	2500 - 3000	400 - 500	960 - 1200	50 - 60

b. The classification used in Middle Asia (U.S.S.R.): 6

Characteristics of water	Total dissolved solids (ppm)	Concentration of ions (ppm.) Na	Ca	Mg	Cl	So_4	Total hardness (epm)
Good	1500	400	150	75	600	600	30
Acceptable	2000	500	250	100	700	800	45
Permissible	2500	700	300	125	800	900	60
Unsuitable	300	800	350	150	900	1000	80

According to the available standards, it has been proved that several samples of Gaza Strip groundwater contain unsuitable amounts of certain ingredients and this is shown as follows:

1. Total dissolved solids: The concentration of the total dissolved solids, in the studied samples between 560 and 4730 ppm. By using the classification applied in U.S.S.R., the analysed samples can be evaluated as follows as shown in Table 6

Table 6. Comparison between El-Nakhal and Himida evaluation of the groundwater of Gaza Strip and the present study evaluation, based on the total dissolved solids in U.S.S.R. Classification:

Characteristics of water	*El-Nakhal & Himida analyses (1964)*	*The Present study Analyses (1984)*
Good	*40*	*30*
Acceptable	*20*	*20*
Permissible	*20*	*5*
Unsuitable	*20*	*45*

It is obvious that the groundwater of Gaza Strip tends to become unsuitable for domestic uses due to the tendency of increasing concentration of total dissolved solids.

2. Sodium: The concentration of sodium in Gaza Strip groundwater ranges between 64 and 1240 ppm. The analysed samples are classified as follows as shown in Table 7

Table 7. Comparison between El-Nakhal and Himida evaluation of the groundwater of Gaza Strip and the present study evaluation with regard to the concentration of sodium:

Characteristics of water	*El-Nakhal & Himida Analyses (1964)*	*The Present Study Analyses (1984)*
Good	*55 %*	*40 %*
Accdeptable	*25 %*	*10 %*
Permissible	*5 %*	*15 %*
Unsuitable	*15 %*	*35 %*

It is obvious that the groundwater of Gaza Strip tends to be unsuitable for domestic uses due to the tendency of increasing concentration of sodium.

3. Calcium: The concentrations of Calcium in Gaza Strip groundwater ranges between 24.4 and 226.5 ppm., and hence all the analysed samples have good quality.

4. Magnesium: The concentration of Magnesium in Gaza Strip groundwater ranges between 16 and 151 ppm. The analysed samples are classified as shown in Table 8.

Table 8. Comparison between El-Nakhal and Himida evaluation of the groundwater of Gaza Strip and the present study evaluation with regard to thr concentration of magnesium:

Characteristics of water	*El-Nakhal & Himida analyses (1964)*	*The present study analyses (1984)*
Good	*100 %*	*75 %*
Acceptable	-	*10 %*
Permissible	-	-
Unsuitable	-	*15 %*

The comparison shows the tendency of increasing concentration of magnesium in Gaza Strip groundwater.

5. Iron and Manganese: With regard to the U.S.A. standards, the highest acceptable limits of iron and manganese is 0.5 ppm. On this basis 95% of the studied samples are of good quality and 5% of the studied samples are unsuitable. Whereas in El-Nakhal and Himida[4] analyses all the samples were of good quality.

6. Chlorides: The concentrations of the chlorides, in the present study, ranges between 118 and 1791 ppm. On the basis of U.S.S.R. standards, Gaza Strip groundwater is classified as shown in Table 9.

Table 9. Comparison between El-Nakhal and Himida evaluation of the groundwater of Gaza Strip and the present study evaluation with regard to the concentration of chlorides

Characteristics of water	El-Nakhal & Himida Analyses (1964)	The Present Study Analyses (1984)
Good	40 %	5 %
Acceptable	05 %	25 %
Permissible	05 %	15 %
Unsuitable	50 %	55 %

The comparison shows the tendency of increasing concentration of chlorides in Gaza Strip groundwater.

7. *Fluouides:* With regard to U.S.A. standards, water containing fluorides in concentration higher than 1.5 ppm. is considered to be harmful to children whereas, concentrations exceeding 4ppm. are hazardous to adults. In Gaza Strip, nine of the samples (nos. 1, 3, 6, 12, 10, 7, 16, 15 and 19) (Table 1), contain fluoride in concentrations higher than 1.5 ppm. (but less than 4ppm.). The water of these wells should not be used for children. The present analyses shows the tnedency of increasing concentration of fluorides in Gaza Strip groundwater.

8. *Sulphates:* The concentration of sulphates in the analysed samples ranges between 16.2 and 1042 ppm. On the basis of U.S.S.R. standards, Gaza Strip groundwater is classified as shown in Table 10.

Table 10. Comparison between El-Nakhal and Himida evaluation of the groundwater of Gaza Strip and the present study evaluation with regard to the concentration of sulphates

Characteristics of water	El-Nakhal & Himida analyses (1964)	The present study analyses (1984)
Good	85 %	80 %
Acceptable	15 %	10 %
Permissible	-	5 %
Unsuitable	-	5 %

The comparison shows the tendency of increasing concentration of sulphates in Gaza Strip groundwater.

9. *Nitrates:* According to U.S.A. standards, the highest acceptable limits for nitrates (as nitrogen) is 10 ppm.[10] . Eighty percent of the studied samples contain less than this limit and are considered of good quality. The water of the wells nos. 5, 5, 11 and 14 should not be used for infants because water containing more than 10 ppm. of nitrates (as nitrogen) produces methemelglobinemia or cyanosis (blue baby).

In summary, the combined evaluation (for domestic purposes) of Gaza Strip groundwater by using the available standards of both U.S.A. and U.S.S.R. proved that 25% of the samples (no. 2, 4, 5, 17 and 18) are of good quality for domestic uses, and 75% of the samples (nos. 1, 3, 6, 7, 8, 9, 10, 11, 12,13, 14, 15, 16, 19, and 20) are unsuitable for domestic uses due to the presence of one or more ingredients in objectionable amounts.

It should be pointed out at this stage that, for industrial purposes, the quality of water used depends on the nature of the industry itself. However, only simple industries such as pottery and building works, have been established in Gaza Strip. Consequently, water with special characteristics is not needed.

For building works, water should not contain sulphates in concentrations exceeding 800 ppm. On this basis, 90% of the analysed samples are suitable for building purposes. Based on this, the water of the wells nos. 16 and 19 should not be used for this indusry.

SUMMARY AND CONCLUSIONS:

Twenty groundwater samples, representing the wells of Gaza Strip have been chemically analysed and evaluated by using several approaches.

This study proved the development of the salt water intrusion into the main aquifer (Plio - Pleistocene aquifer) of the area. This intrusion has changed the groundwater quality of the area duting the last two decades as well as their evaluation for irrigation, domestic uses and local industry (Table 11).

Table 11. changes in groundwater quality in the last 20 years.

Classification	El-Nakhal & Himida analyses (1964)	The Present study analyses (1984)
Evaluation for Irrigation:		
Samples of the first class and are excellent to good for irrigation	20%	5%
Samples of the second class and are good to permissible for irrigation	20%	25%
Samples of the third class and are doubtful to unsuitable for irrigation.	60%	70%
Evaluation for domestic uses:		
Samples good for domestic uses	40%	25%
Samples unsuitable for domestic uses	60%	75%
Samples contain undesirable amount of the total dessolved solids	20%	45%
Samples contain unsuitable amounts of sodium	15%	35%
Samples contain unsuitable amounts of calcium	--	--
Samples contain unsuitable amounts of agnesium	--	15%
Samples contain unsuitable amount of iron and manganese	--	5%
Samples contain unsuitable amounts of chlorides	50%	55%
Samples contain unsuitable amount of fluorides	30%	45%
Samples contain unsuitable amounts of suphates	--	5%
Samples contain unsuitable amounts of nitrates	10%	20%
Evaluation for local industry:		
Samples unsuitable for building works	--	10%
Samples unsuitable for other local industries	--	--

These changes in quality can be attributed to the increasing withdraw of the fresh water from the main aquifer of the area. As the necessary of the fresh water of different uses vegorously increases: it is necessary to develop the fresh water from 'the older formations (Eocene and Cretaceous) in order to eliminate the problem of deficiency of the fresh water in the future.

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