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Hydrogeophysical and Environmental Investigations of Groundwater Potentials in Al Sokhna Alluvium Aquifer in Zarqa – Jordan

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Abstract:

Sokhna basin is composed of alluviums and locates to the northern part of Zarqa Governorate in Jordan. The basin where many agricultural activities take place is recharged directly from the flowing streams of the effluent of As-samra WWTP and Zarqa River which is illegally the disposal site for the treated and untreated industrial waste water of some industries overlooking the flow path of the river. The basin was evaluated respecting its groundwater quality and quantity. Gravity method deduced depths to bedrock beneath the alluviums and found to range between 8 and 33 meters. The water was found not to fit for the WHO and local regulations for drinking water, where several pollution processes affected its quality. Annual throughput amounts were calculated to be less than 0.66 MCM.

Key words: Sokhna Basin, groundwater, depth to bedrock, environmental impacts.

Introduction

Jordan is one of the world's ten most water scarce countries (Global water assessment report, 2003). The country depends on groundwater to cover the increasing demands, where surface water resources are relatively absent. Pollution processes from different sources are degrading the water quality and exposing the annual water budget between demanded and available quantities to deficiency. (Water Ministry 2004).

This study comes in the context of the efforts paid towards evaluating the available water resources in the region. The study area is a small scale unconfined aquifer composed of sub-rounded poorly sorted clasts of sedimentary rocks and basalt of (Holocene-Recent) collected as wadi sediments in Wadi Al Sokhna basin which takes a narrow meandering extended shape with a length of about 30 km and a width ranges about 200 meters (Fig. 1).

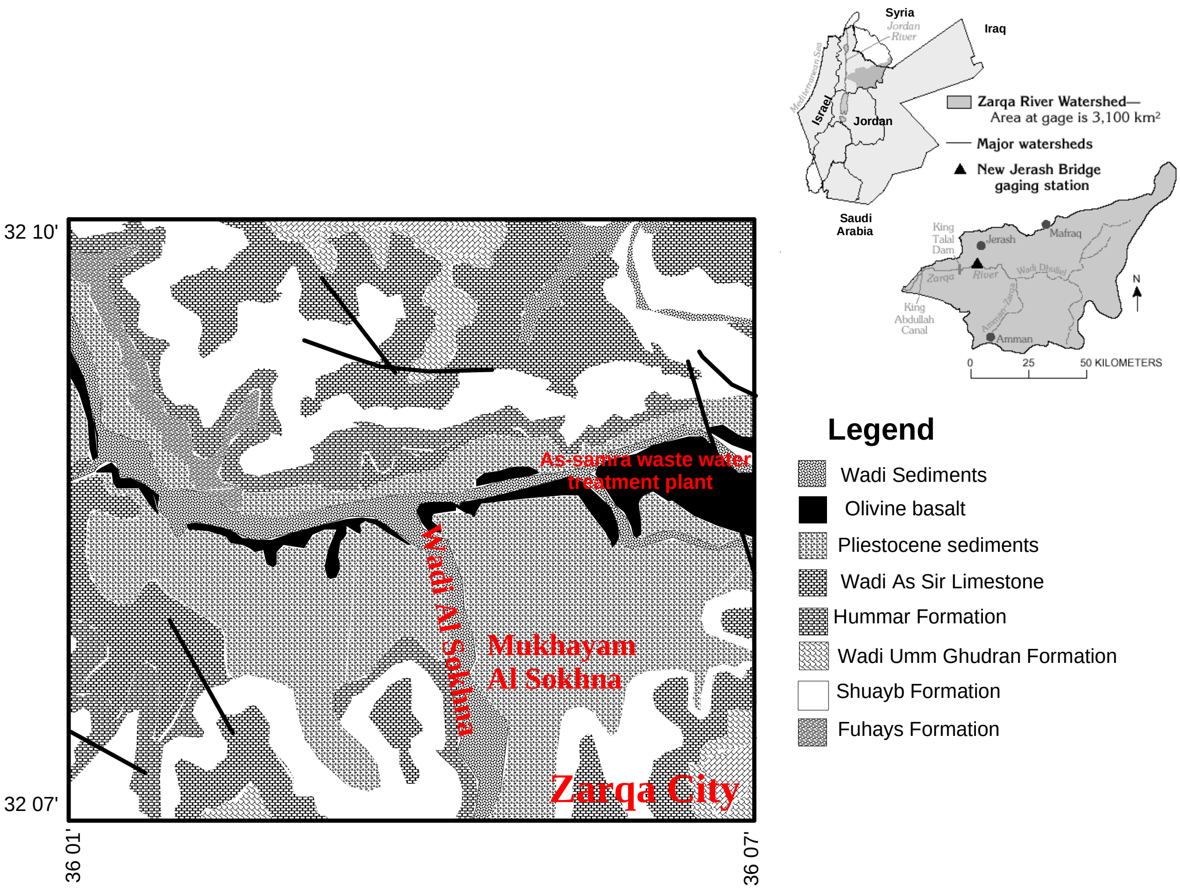


Fig. 1: Location and geological maps of the study area.

Two water streams meet and at the northern part of the wadi get mixed and continue flowing as one stream along the aquifer, these are Zarqa River (recently classified as a stream due to the lack of water) and the effluent of As-samra waste water treatment plant. This mixture of water is considered as the main source to recharge the aquifer (Fig. 2).
The study aims at defining the potentials and boundaries of the aquifer, evaluating the quality of the groundwater and assessing the human impacts on it.

Methodology

The study stood under need for several methods and included:

1- Applying gravity survey along one profile with about 5-10 meters spacing, and modeling the results using a new written software (Al Farajat & Mashagbeh 2004) to locate the depth to the bed rock and accordingly the thickness of the unconsolidated sediments.
2- Measuring the available wells on their hydraulics to build a simple groundwater flow model.
3- Sampling the wells on their water and exposing the samples for chemical analysis, and modeling the results using HYDROWIN Software. The American Standard Method

for Water Analyses and German DI- Norms were used in analyses of different parameters.

Fig 2: General view of the study area shows the basin and agricultural activity with a shallow groundwater well.

Hydro-geophysics

A precise gravity survey was carried out in the study area, where some 33 gravity stations were measured a long 4 profiles for each one in different locations of Wadi Al Sokhna. The field study was carried out using Sodin Gravimeter (with a limited contour range of about 1000 scale division), simultaneously a leveling instrument with an accuracy of 0.5 cm. The obtained gravity data was corrected for variation in drift, latitude and elevation in order to separate the local anomalies from the regional one.

A program written using Visual Basic was designed to calculate the above corrections, Drift, Free-air, Bouguer and latitude corrections (Al Mashaqbah, 1996). Another MS Excel program was designed by the authors to be used in modeling the corrected data.

The gravity stations were measured in linear profile with lengths ranged around 300 meters, where a reading was taken each 10 meter, while the elevation of each station was measured using a leveling instrument. A base station reading was taken each 30 minute in order to calculate the drift correction. The first step in the interpretation is to model the Bouguer anomalies. Interpretation in gravity can proceed using several different methods. The two primary methods are to use either a form of forward modeling, or to use inversion techniques (Reynolds, 2000). With forward modeling (which was used in the study), one builds a scale model of the geological situation, solves for the gravitational attraction of that model, and then compares it with the Bouguer anomaly curve. After this former procedure, the model may be modified and recalculated one or more times. These models must be built with all available geological information, including rocks density information.

An Excel program was used to compare the Bouguer anomalies with a different calculated layer thickness. The model was run, where an enhancement was added to the supposed geological model until the curve of observed data in the field gave the best fit with that of the calculated data. From that the thickness of the first layer (alluvium) which is saturated with water was deduced, and found changeable; thin at the edge and thick at the middle of the profile with a thickness about 30-33 meters at the middle and about 6-8 meters at the edge Fig. 3 .

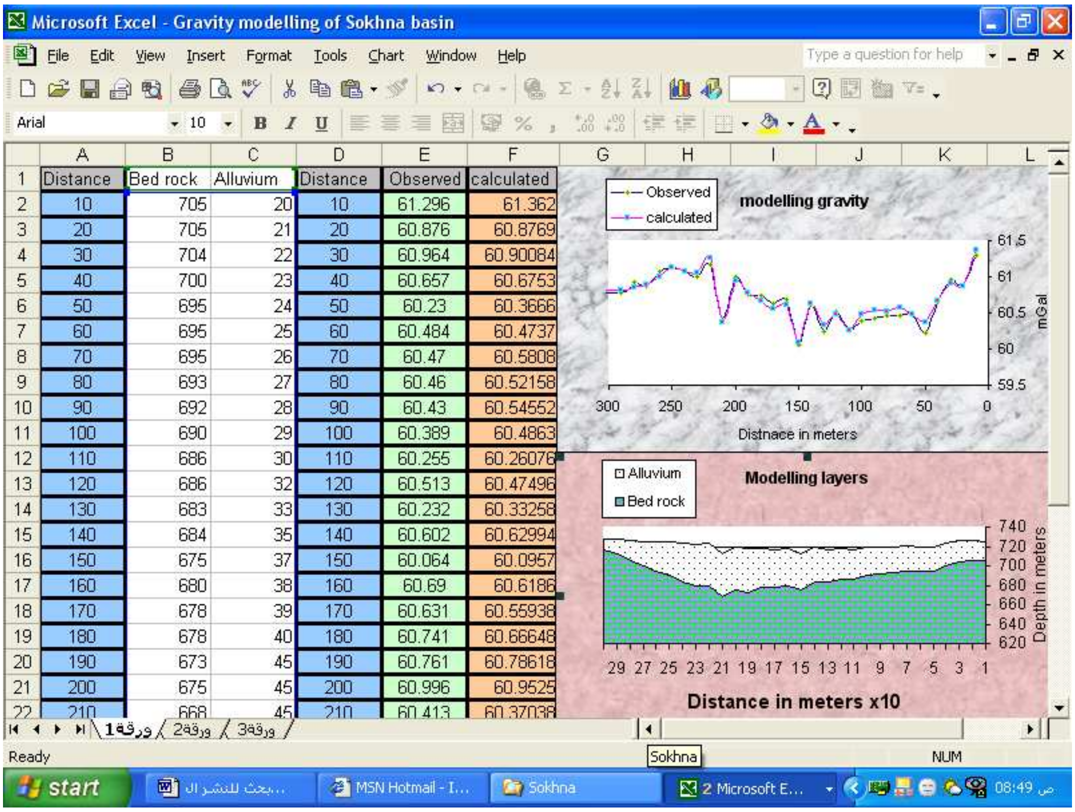


Fig. 3: Geological model of the study area built using gravity data resulted from one of the measured profiles.

Hydrogeology

Table 1 illustrates the locations and levels of the wells and the groundwater. The throughput amounts were calculated using the average of modeled cross sectional areas using gravity data (Fig. 4), and the saturated parts of them, which were found around 30000 m^2. The hydraulic gradient was calculated depending on the available wells considering the difference in the water heads and the distances in between and found to be around 0.04, and the permeability was estimated from the literatures of similar sediments and considering the field observations as 1.5 meter/day. Figure 5 represent the flow model of the groundwater in the aquifer.

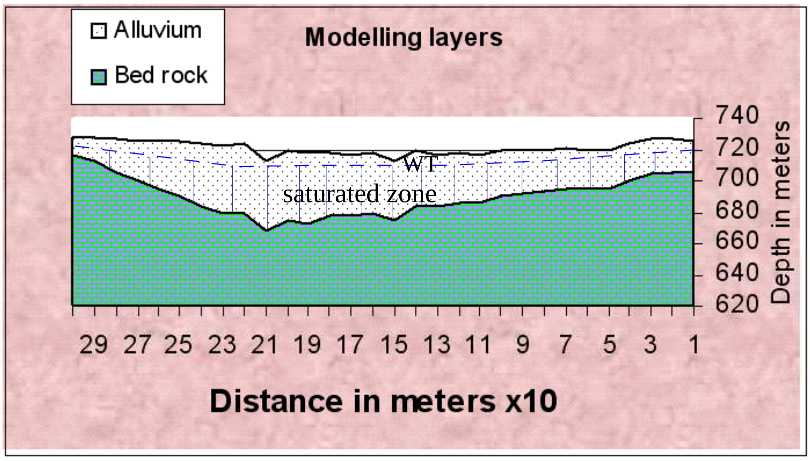


Fig. 4: Saturated thickness resulted from gravity modeling.

Table 1: Locations and levels of the wells and the groundwater.

source	date	distance m	x	y	Well Elv.	GWD	SWL
Murad	15/4/2004	0	36.0625	32.125	513	5	508
Radwan	15/4/2004	50	36.0625	32.1271	508.33	1.1	507.23
Dieb	15/4/2004	450	36.061	32.1291	508	3.23	504.77
Surface	15/4/2004		-	-	-	-	-

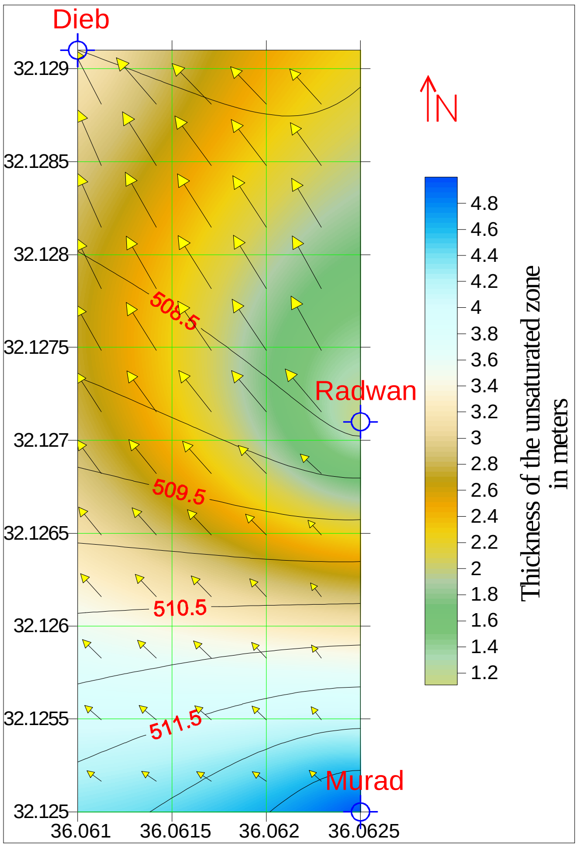


Fig. 5: simple flow model of the study area showing depth to groundwater and flow directions as arrows.

Water quality

The study area was sampled on its surface and groundwater. It was intended to sample the surface water in the stage they meet and get mixed, because the impact of this water type takes place along the aquifer as mixed water. Three wells were available in the area of the gravity survey. Also they were sampled on their water. These are the same wells measured on their hydrogeological aspects.

Figure 6 shows the correlation between the two water types (surface water and groundwater) in relation to the analyzed elements.

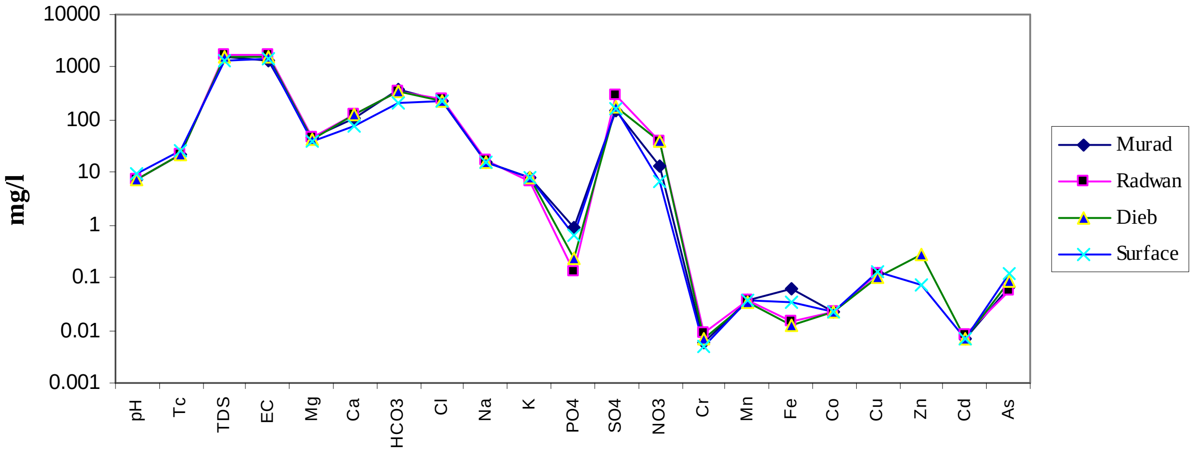


Fig. 6: showing the correlation between the two water types (surface and ground) in relation to the analyzed elements.

Results of the analyses on the major and minor elements of the ground and surface water types are listed in Tables 2 and 3. Statistics on water quality are illustrated in Table 4.

Table 2: Results of the hydrochmeical analyses of the surface and groundwater.

source	pH	Tc	TDS	EC	Mg	Ca	HCO3	CO3	Cl	Na	K	PO4	SO4	NO3
Murad	7.05	22	1520	1350	48.3	110.8	375.9	0	229.6	15	8	0.87	146.8	13.4
Radwan	7.15	21	1711	1772	44.8	132	335.6	0	252	17	7	0.13	297	40.8
Dieb	7.1	21.1	1603	1520	42.4	124.4	335.6	0	234	15	8	0.236	171.6	40
Surface	9.61	25	1316	1500	38.9	73.9	214.8	0	222.8	16	8	0.63	165.4	7

Table 3: Results of the analyses on the heavy metals in the surface and groundwater.

source	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	As	Pb
Murad	0.006	0.037	0.062	0.023	0	0.115	0	0.007	0.065	0
Radwan	0.009	0.036	0.015	0.023	0	0.118	0	0.008	0.058	0
Dieb	0.007	0.034	0.012	0.023	0	0.105	0.272	0.007	0.085	0
Surface	0.005	0.037	0.033	0.022	0	0.125	0.073	0.007	0.124	0

Table 4: Statistics on the water quality.

Item ppm	**Min**	**Max**	**Average**	**St. Dev.**
K^{+}	7.0	8.0	7.75	0.5
Mg^{++}	38.9	48.3	43.6	3.96
Ca^{++}	73.9	132.0	110.3	25.8
Na^{+}	15.0	17.0	15.75	0.96
Cl^{-}	222.8	252.0	234.6	12.5
$SO4^{--}$	146.8	297.0	195.2	68.68
$HCO3^{-}$	214.8	375.9	315.5	69.75
pH	7.01	9.61	7.81	1.21

Hydro-geochemistry

Stiff diagrams (Fig.7) were used to identify samples that have similar compositions. Mainly groundwater shapes are relatively of the same shape, indicating that they are clustering in one composition.

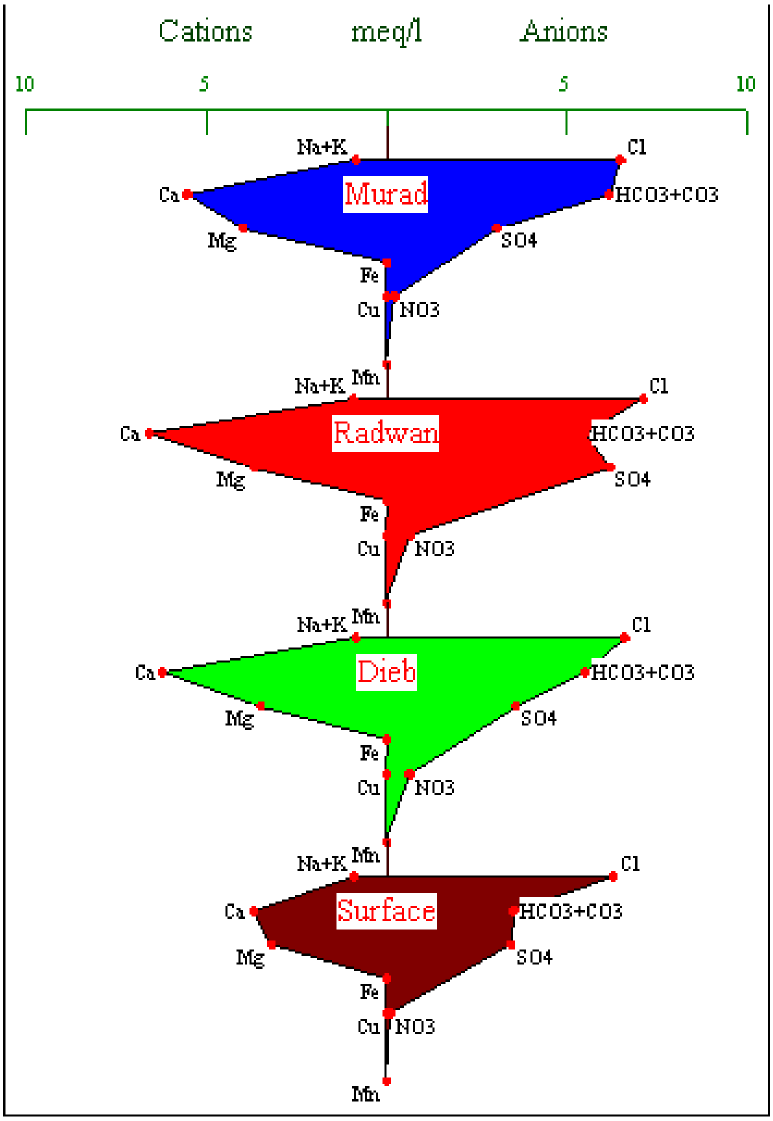


Fig. 7: Stiff diagrams shaping the different water samples.

Piper and Durov diagrams (Fig. 8, 9) were used. The plots revealed the dominant relationships for the water samples. They showed clustering groundwater samples points indicating they have relatively the similar compositions.

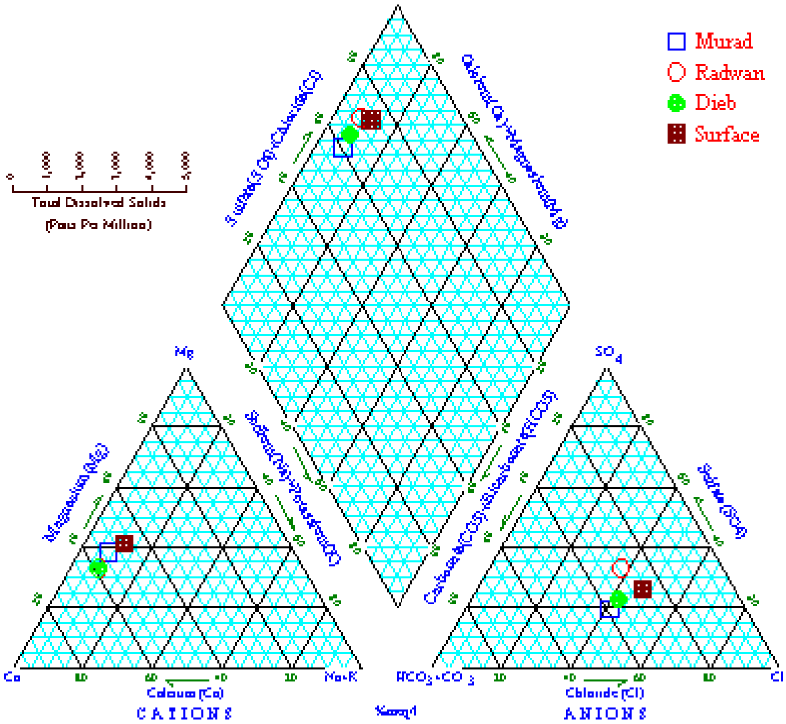
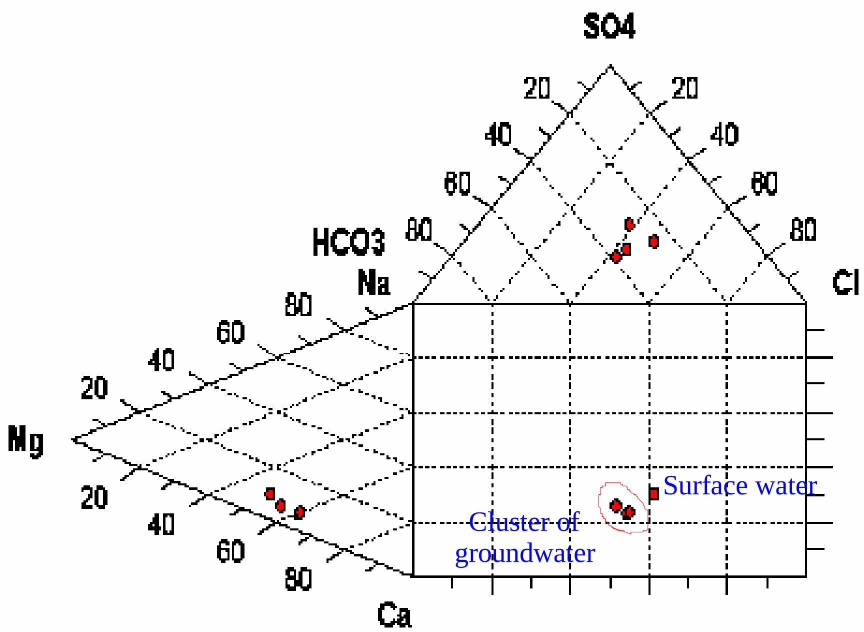


Fig. 8: Piper diagram shows the clusters of the water samples, both surface water and groundwater.

Fig. 9: Durve diagram illustrates the water clusters in the study area.



Depending on the classification of water due to its hardness expressed as $CaCO_3$ in mg/l, put by Sawyer and Mc-Carty 1967, the water fits in the class of very high hardness. Besides that, Table 5 illustrates the dissolved amounts of the minerals Halit, Dolomite and Anhydrite expressed in mg/l.

Table 5: The dissolved amounts of the minerals in mg/l.

ITEM	**WATER SOURCE**			
	Dieb	**Murad**	**Radwan**	**Surface mixture**
Water type	Ca-Mg-Cl-HCO3-SO4	Ca-Mg-Cl-HCO3-SO4	Ca-Mg-Cl-SO4-HCO3	Ca-Mg-Cl-HCO3-SO4
Total hardness mg/l as CaCO3	484.8	475.1	513.6	344.4
Total alkalinity mmol/l	5.5	6.16	5.5	3.52
Dissolved Halite mg/l	38.2	38.169	43.26	40.713
Dissolved Dolomite mg/l	321.1	365.8	339.3	294.6
Dissolved Anhydrite mg/l	243.3	208.2	421	234.5

Saturation indices represent the saturation of the ground water with respect to various minerals (LIOYD, 1985). They show the likelihood of a mineral dissolving or precipitating from solution. Interpretation of saturation indices from geochemical data can demonstrate the reactions taking place in the ground water. As a saturation index is of negative value, the mineral in question is being dissolved, and as a saturation index is of positive value, the mineral is precipitating. Table 6 illustrates the calculated values of the saturation indices of the different water sources, both groundwater and surface. HYDROWIN was used to model the indices. Figure 10 represents a correlation between the different values.

Table 6: The calculated saturation indices of the water.

mineral	Water source			
	Dieb well	Murad well	Radwan well	Surface mixture
Calcite	0.293	0.519	0.117	2.327
Aragonite	0.15	0.373	-0.027	2.183
Dolomite	0.465	1.072	0.106	4.72
Siderite	-1.77	-0.799	-1.859	0.931
Magnesite	-0.396	-0.101	-0.578	1.825
Gypsum	-1.267	-1.371	-1.05	-1.444
Anhydrite	-1.488	-1.602	-1.271	-1.665

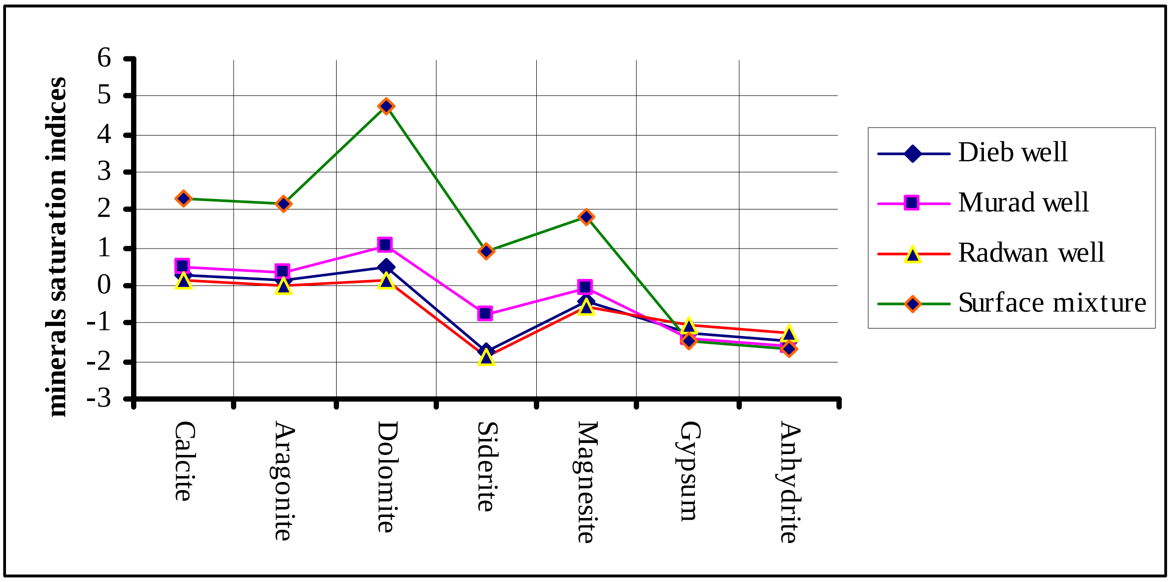


Fig. 10: Correlation between the saturation indices of the different water sources.

Drinking water quality

Depending on Table 7 and the WHO regulations of drinking water quality using HYDROWIN, both surface water and groundwater found not to fit for them. The listed items in the table exceeded the recommended values where some of them like As, Fe, Ca and TDS exceeded even the allowed maximum ranges.
Deserves mention here is that this water is used for the dominant agricultural activities in the area, while some of the farmers drink from it.

Table 7: Correlation between water samples and WHO regulations.

ITEM	**WHO REGULATIONS**		**WATER SOURCE**			
	Recommended	maximum	Dieb well	Murad well	Radwan well	Surface mixture
TDS	100-500	<1500	1603	1520	1711	1316
Mg	5-30	<50	42.4	48.3	44.8	38.9
Ca	40-100	-	124.4	110.8	132	73.9
Mn	<0.02	<0.05	0.034	0.037	0.036	0.037
Zn	<0.1	<5	0.272	0	0	0.073
Cu	<0.05	<1.5	0.105	0.115	0.118	0.125
Cl	<20	<200	234	229.6	252	222.8
SO4	10-50	<200	171.6	146.8	297	165.4
NO3	<25	<40	40	13.4	40.8	7
As	<0.002	<005	0.085	0.065	0.058	0.124
Fe	<0.05	<0.3	0.062	0.062	0.015	0.033

Table 8 shows that the water type is of medium to high salinity hazard, and of low sodium adsorption ratios.

Table 8: Irrigation possibilities of the water depending on SAR and conductivity.

ITEM	WATER SOURCE			
	Dieb well	**Murad well**	**Radwan well**	**Surface mixture**
Conductivity uS	792	750	858	655
group	C3		C3	C2
SAR	0.30	0.30	0.33	0.38
salinity	High salinity water		High salinity water	Medium salinity water

Discussion

Sokhna basin occupies about 537 square kilometers in area. The basin is consisting of a northwest-trending fluvial valley surrounded by mountains. It is best described as a water-table aquifer in the streambed alluvium. The Zarqa stream and the effluent of As samra waste water treatment plant are the main source of water in the basin. Direct recharge from precipitation and side wadis overlooking the basin is neglected comparing with that from the named streams. Total annual calculated throughput in the basin-fill sediments is about 0.66 million cubic meters.

In the upper reach of Sokhna basin the streambed alluvium is 0.1 to 1 kilometers wide. The streambed alluvium thickness ranges from several meters to as much as 33 meters in deeper sections. The streambed alluvium is very permeable where several irrigation wells yield up to 1000 cubic meters per day. Water levels in the streambed alluvium range from less than 3 meters to 8 meters below surface level.

Water in the basin-fill alluvium seems to be totally unconfined due to homogeneity in the permeability of the bed sediments in the basin-fill. Some non-extended clay layers (lenses) were noticed on the surface of the basin, these may be found within the alluviums and partially confine the aquifer. Increased consolidation with depth produces small well yields from the basin-fill. Water levels in the basin indicate groundwater movement to the northern west. Major components of recharge in the basin are attributed to the flowing streams of Zarqa River (stream) and As-samra WWTP's effluent. The chemical quality of water in the Sokhna basin is not suitable for drinking uses.

It is mentioned previously in the course of this study that the main source to recharge the aquifer is the flowing streams of Zarqa River and the effluent of As-samra WWTP. Industrial activities units overlook Al Zarqa River used to dispose industrial waste water into it. Recent environmental regulations prevented that, but still some illegal disposal actions take place. Recently the domestic and industrial waste water contributions to the inflows of the river are estimated at 50% of its discharge (Salameh, 1996). As-samra WWTP is overloaded,

accordingly the efficiency of the treatment process is not approached, BOD_5 of the effluent was in 1995 around 144 mg/l, which was much higher than the 30 mg/l value set by the guidelines (Salameh, 1996).
As noticed through the phases of the field survey in the study area, the farmers intensively make use from organic animal wastes (dung) as bio-fertilizers, especially that of poultry solid wastes. In addition to that, inorganic fertilizers are severely used. Hence, any pollution indicators of organic compounds, inorganic compounds and heavy metals should be attributed to the previous sources.

Mostly, the surface water seems of higher saturation values than the rest samples, this refers to the elevated pH value of this water type. In general, the groundwater tends to precipitate the carbonate minerals (Calcite, Aragonite and Dolomite) and to dissolve the sulfate minerals (Gypsum and Anhydrite) and Siderite and Magnesite.

Surface water was located in Durov and Piper diagrams in an area out of that of the groundwater cluster indicating that it pass through some reactions in the unsaturation zone during recharge process. Also the rock-water reactions change its quality when it percolates into the aquifer.

The resulted shape of the surface water using Stiff Diagrams is not far different from those of groundwater. As seen from the shapes, some development took place to the chemistry of the groundwater and is attributed as mentioned before to the rock-water interactions and the reactions inside the aquifer. These processes seem to enrich the chemical constituents of the surface water.

The throughput amounts were calculated as follows:
***Saturated** area* (m^2) x *hydraulic gradient* x *permeability* m/day x 365 days

$$=30000\ m^2 \times 0.04 \times 1.5\ m/day \times 365\ days$$

$$= (\ 0.66\ )\ MCM/year$$

This amount is considered as the total amount of groundwater flows annually through the aquifer. Depending on the obtained simple flow model shown in figure (5), the groundwater flows mostly to the north west, and the thickness of the unsaturated zone ranges from one to five meters, in other words this is the range of the depth to groundwater in the area. This emphasizes on the aquifers vulnerability against pollution potentials.

Total dissolved solids TDS ranged for all samples from about 1300-1500 PPM, this points to that the surface water and the groundwater are of brackish type. Surface water shows lower value of TDS than the groundwater, the excess in the groundwater refers to the rock-water interaction processes in the aquifer.
The correlation plot between surface and the groundwater indicates that the former one is originated from the mixed surface water. This takes place as some of the surface water leaks down into the permeable alluvium aquifer contributing to its recharge.

The water quality reflected the pollution potentials clearly, where some heavy metals exceeded or approached the maximum regulations of drinking water quality. Major ions represented also in TDS pointed to values higher than those specified by WHO regulations for drinking purposes.

Products of agricultural activities in the study area like potatoes, eggplant, cucumber, tomatoes, cabbage and carrot are transported to Amman Central Market of Vegetables, and from there they are distributed to the different areas in Jordan. The named agricultural products depend totally on the polluted groundwater as a source of irrigation.

Conclusions

The Sokhna aquifer was found to be very vulnerable to pollution potentials, where self purification processes are little or absent in the unsaturated zone, besides that, soil cover is absent. The main source found to recharge the Sokhna aquifer is the Zarqa River and As-samra WWTP. All agricultural activities taking place in the area and make use of the aquifer are using polluted water for irrigation. This can reflect sever impacts on the health of the consumers.

Acknowledgement

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