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Groundwater Geochemistry of Nile Delta-Desert Interface 1.Isotope Hydrology

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خلاصة

للحفاظ على المياه الجوفية وحمايتها بيئيا أهمية بالغة في التنمية المتكاملة للأقاليم الجافة وشبه الجافة بحوض النيل. تشير بيانات النظائر (أكسيجين 18 ـ ديتيريوم ـ تريتيوم) بالمياه الجوفية بغرب دلتا النيل الى مساهمة مياه جوفية حفرية (في حدود 10٪ الى 80٪ بمتوسط يبلغ 39٪ و 52٪ في التحرير والخطاطبة على التوالي) مع شحن شبه حديث من خزان الدلتا الرئيسي وحديث من شبكة قنوات الري بنطاق اتصال دلتا النيل بالصحراء. يقترح البحث موديل خلط نظائري (مبرمج في صورة جدول ثنائي المداخل باستخدام برنامج اكسل يمكن تشغيله على كومبيوتر آبل ماكنتوش) لتفسير التعارض الظاهري في التركيب النظائري للمياه الجوفية بمنطقتي الخطاطبة والتحرير بافتراض مساهمة قطبين مائيين حفريين مختلفي التركيب النظائري مع قطبين متشابهين نظائريا مصدرهما الخزان الجوفي الرئيسي للدلتا. كما تم تقدير افقار نظائري يبلغ ثلاثة من عشرة في الألف لقيمة دلتا اكسيجين 18 بكل عشرة كيلومترات في المياه الجوفية بالتجاه شمالا مع مسار النهر بامتداد فرع رشيد مع تدني شحن المياه الجوفية عبر مسافة الخمسة وسبعين كيلومترا الأولى من هذا الفرع. وتوعز النتائج كذلك بوجود شحن تحت حديث من خزان الدلتا الرئيسي أكبر نحو الخطاطبة عنه نحو التحرير، على حين يتلقى خزان التحرير شحنا معاصراً من شبكة الري/ الصرف والحقول المروية بالغمر مع تعرضه أكثر لمخاطر التلوث. أما خزان البحيرة فيتعرض لتداخل المياه البحرية الجوفية شمالا. ومن المتوقع استمرار انخفاض المناسب البيترومترية في المناطق الصحراوية التي أصبحت عرضة للضخ الجائر في العقود الأخيرة مما يستدعي دراسة الهيدرولوجيا النظائرية للإقليم بصورة مكثفة بغية كشف المزيد من المعلومات الضرورية عن طبيعة العلاقة بين المكونات المائية الحفرية والمتجددة لما لتلك المعلومات من أهمية فائقة في ترشيد الادارة

Abstract

Sustenance and environmental protection of groundwater supply is of major concern in the integral environmental development in the arid to sub-arid regions in the Nile basin. Isotope data (^{18}O, ^{2}H and ^{3}H) of groundwater in the west of the Nile Delta indicates the contribution of palaeo groundwater component (in the range 0.1 - 0.8 with means of 0.39 and 0.52 for Tahrir and Khatatbah, respectively) along with sub-recent recharge from the delta aquifer and recent recharge from irrigation conveyance canals in desert. Isotope mixing model (developed as Two-input Table using Excel™ spreadsheat on Apple Macintosh™) is proposed to explain the apparent discrepancies in groundwater isotopic composition of Khatatbah and Tahrir areas assuming the contribution of two isotopically different palaeo-poles with two isotopically similar main delta groundwater poles. About 0.30‰ $\delta^{18}O$ depletion per 10 km downstream is detected and low northward groundwater recharge is suggested along 75 km of the Western Strip of Rosetta Nile. Higher sub-recent recharge from the main Delta aquifer is believed to take place in Khatatbah than Tahrir whereas the last is believed to be replenished at present from the irrigation/ drainage network and irrigated fields with higher pollution risk for groundwater system in Tahrir. Behira aquifer is exposed to northern marine intrusion. Lowering of the piezometric level is to be expected in the newly exploited desertic areas under overpumping. Palaeo-hydrology of the studied region requires intensive isotopic monitoring to further delineate fossil/ renewable groundwater relations for rational environmental water management in the region.

Introduction

Detailed study of the available and potential water resources by several analytical techniques is needed for agricultural development and environmental protection under arid conditions. The nuclear techniques using the environmental stable isotopes $^{18}O/^{16}O$ and $^{2}H/^{1}H$ and radioactive isotope ^{3}H in groundwater, in its relation with surface water, provide adequate approach from which valuable pieces of information converning water origin, flow and mixing could be obtained. The newly introduced and potential agricultural and urban expansion in the desertic regions surrounding the Nile Delta depend on either water "importation" (power lifting of Nile water to distribution canals) or groundwater extraction from local aquifer(s). Sustainance of such development under arid conditions is controlled by both water supply and quality. A case study in some sites of the interface zone between the deltaic system and the adjacent western desert makes the subject of the present work.

Site, Hydrology and Sampling

The Nile in Egypt is an intrusive river and its related system (the alluvial valley and delta) are strongly contrasted with the surrounding deserts which are a part of the extensive north eastern belt of the Great Sahara (Hemdan, 1981). The major differences between the delta and these deserts are abundant surface water, low topography, presence of thick clay cap and long cultivation history in the first, in contrast with high aridity, absence of surface water resources, higher topography and scarce vegetation in the second. on the south western bank of Rosetta Nile runs a narrow (< lS km width) alluvial strip which is almost flat (slope 8.5 cm/km) with low topography (< 20 meters a. m. s. l.). This cultivated strip becomes much wider (~ 80 km) as it extends further in a north west direction towards the sea at ~ 80 km east of Alexandria. The border of this alluvial plain makes the western limit of the deltaic fan. Level difference between the western part of the deltaic fan and the Sahara together with the absence of surface water have always prevented westward agricultural expansion either in the southern sandy plains or the northern calcareous soils of this region. However, parts of this area have recently became the subject of cultivation outside the "old" cultivated Holo£ene alluvial soils which represent 4% of the whole land of Egypt. Four sites have been selected for studying groundwater

resources in some sectors of the desert / delta interface (Fig. 1) on the west of the Rosetta Nile, namely:

1. Khatatbah: recently cultivated (~ 10 years) desertic sandy area which occupies ~ 600 Km2 extending on the south west of the delta at moderate distance (20-40 km) from the river branch and runs in a northwest direction for ~ 30 Km. Drip and pivot irrigation methods are used.
2. South Tahrir: newly cultivated (~ 40 years) sandy desertic area which occupies ~ 1200 K m^2 at moderate to far distance (20-60 km) from the west of Rosetta branch and runs for ~ 30 km further to the

northwest from Khatatbah area. Conventional surface irrigation is practiced.

3. Western Strip: "old" cultivated alluvial narrow strip (<15 km in width) that occupies ~ 1200 Km^2 and runs to the northwest for 80 km along the western bank of Rosetta Nile.
4. Behira / Noubaria: occupies 2400 Km^2 to the far west and northwest of Rosetta Nile. It has a small to moderate width, 15-60 km, and runs for ~ 40 km in "old" cultivated alluvial soils in its eastern and north eastern sector contrasting with calcareous soils in its western and north western sector. These calcareous soils are irrigated by conventional methods since ~ 30 years, but would have been subjected to cultivation (or natural vegetation) few thousand years B.P.

The lithology of the desert to the south west of the Delta belong to the Pleistocene fluvial deposits: Protonile sediments (Ql-Idfu Formation, 690-650 thousand years B.P.) in Khatatbah and Prenile / Neonile interval sediments (Q2/Q3-Abbasia Gravel, 200-130 thousand years B.P., i.e. after the connection of the Egyptian Nile with its Equatorial and Ethiopian reaches) in Tahrir (Said, 1981). These exposures are similar to sediments making-up the Pleistocene aquifer of the main delta (Prenile, Q2-Qena sediments, 650-200 thousand years B.P.). The aquifer in the studied region rapidly changes from semi-confined (leaky) aquifer (in the Western Strip and Behira where some downward seepage takes place through shallow phreatic water-table in the alluvial Holocene clay cap due to frequent watering by the conventional surface ponding irrigation) to unconfined aquifer (in Tahrir, Khatatbah and Noubaria where the surface clay cap is completely absent). The main irrigation source in Tahrir and Khatatbah is local groundwater whereas surface water is abundant in the Western Strip, Behira and Noubaria. Groundwater in the deserts west of the Nile Delta is believed to have free contact with groundwater in the western part of the main Delta since these arid plains make parts of a greater delta built by powerful Pleistocene Nile systems (Said, 1981 and Elbaz, 1993). Nile water is permanently percolated form the river downward in the main delta aquifer and believed to outflow to the adjacent deserts due to favorable hydraulic gradient (RIGW, 1981). over than 50 water samples are used in the present study, namely: groundwater (47 samples) and surface water from main irrigation canals (7 conveyance canals). Groundwater is collected from production wells (in Khatatbah and Tahrir) or from deep observation piezometers (in the Western Strip, Behira and Noubaria). Most of the sampled power pumping wells (in Khatatbah and Tahrir) penetrate the aquifer partially and the screens are moderately deep (S5-6S m below surface), however, in some cases screens are shallower (40-54 m) or deeper (84-88 m, 120-125 m or even 144-149 m). The observation piezometers are moderately deep (55-65 m).

Medhods

The isotopic analyses were carried out by measuring the abundance of the rare (heavy) isotope after adequate gas preparation under vacuum. For ^{18}O, equilibrium of water sample with CO_2 gas was proceeded for 24 hours in water bath at 25 oc to permit isotopic exchange with H_2O and the $^{18}O/^{16}O$ ratio was measured out on VG^{TM}602C double-inlet gas mass spectrometer (Epstein, S. and Mayeda, 1953 and Sofer and Gat, 1972). For ^{2}H, the reduction of water sample into ^{2}H gas using hot uranium was used and the $^{2}H//^{1}H$ ratio measurement was accomplished on VG~602D double-inlet gas mass spectrometer (Godfrey, 1962 and Friedman and Hardcastle, 1970). $Beckman^{TM}$-LS100C liquid scintillation counter was used to obtain the 3H radioactive isotope content after electrolytic enrichment of water in 3H atoms (Swailem, 1969 and Harrison, 1987).

Results and Discussion

Isotopic Composition of Groundwater

The isotopic composition ($\delta^{18}O$ and $\delta^{2}H$) of the studied groundwater is relatively wide (Figs. 2 and 7). Table I gives their linear fitness. Descriptive statistics* of the isotope contents of subgroups are given in Table II. Groundwater of the two desertic areas (Tahrir and Khatatbah) is characterized by the most depleted isotopic composition (Fig 4) compared to that of Behira, Western Strip and main irrigation canals. Mle water in the studied area is in the range +3.39% o to +4.18‰ (mean= +3.86 ‰) for 18o, and in the range +27.6 ‰ to +33.0 % o (mean= +30.6 ‰) for 2H, both with respect to SMOW. Stable isotope composition of groundwater in the Western Strip and Behira is close to that of Nile water in some wells whereas it is depleted in others indicating recent changes of the Nile isotopic composition.

Frequency distribution of Tritium content is plotted (Fig. 3) after enhancement by other data (Awad, et al, 1993) for the same sectors of the aquifer as ours. It shows that Khatatbah has the lowest Tritium content, some sites in Behira have higher contents than the present-day Nile water and Tritium in Tahrir is much more dispersed than the other areas. Nile water has moderate Tritium contents (mean= 25 TU) compared to 50% of the samples whereas 50% sampled wells (at the south eastern sector of Behira and north Tahrir) have higher Tritium contents than Nile water. Tritium data coupled with stable isotope data suggests a mixing process. So, the interpretation of Tritium data in terms of residence time corresponding to unique groundwater source (i.e. without mixing) could be misleading. The high Tritium content in some Behira wells (~ 80 TU) could be the remnant radioactive signature of the 60^{ies} peak. Normally, lower Tritium content indicate greater period of decay (older groundwater), but since we are now on the decreasing side of the Tritium peak of meteoric water, some older groundwater (in stagnation zones) could have higher Tritium than some younger groundwater (in active recharge zones).

Isotopic Mixing of Groundwater

Fourteen groundwater samples have < 5 meq.l^{-1} aqueous solutes (Fig. 5). Eight of them have salinity below the lowest level (3.7 meq.l^{-1}) of the present-day Nile water in the studied region. The most dilute groundwater samples in a given basin could have an important geochemical and isotopic importance since they could indicate conditions close to those of recharge water (on the contrary to samples with higher dissolved solutes which could have gained higher salinity by leaching). The low TDS of many of the isotopically depleted (in ^{18}O and ^{2}H) samples in each subgroup (Fig 5) along with the observation of isotopically- enriched/ moderately-saline samples of different compositions could be interpreted by four-poles mixing model as discussed below (Table III and Fig 8 and 9). This new data supports the hypothesis previously developed by Hussein (1990) - based on groundwater isotopic composition of Wadi Natron (some 20 km further to the west of the area of the present study) - for the contribution of a depleted palaeo-groundwater which mixes with the relatively enriched sub-recent fluvial water outflowing from the delta. Nile irrigation water has the highest content of the heavy stable isotopes (Fig. 4 and 5). Three (no. 25, 41 and 39) of the most dilute eight groundwater samples

(TDS lower than the present-day Nile water) are in the north and middle sectors of the Western Strip, two (no. 45 and 46) from the south eastern Behira and in both cases these wells are at somewhat short distance (< 15 km) either form Rosetta Nile or from great irrigation canals (El-Khandek and El-Hager canals) and three (no. 21, 23 and 24) from Tahrir at moderate to far distance (10-50 km) form closest river or irrigation channel.

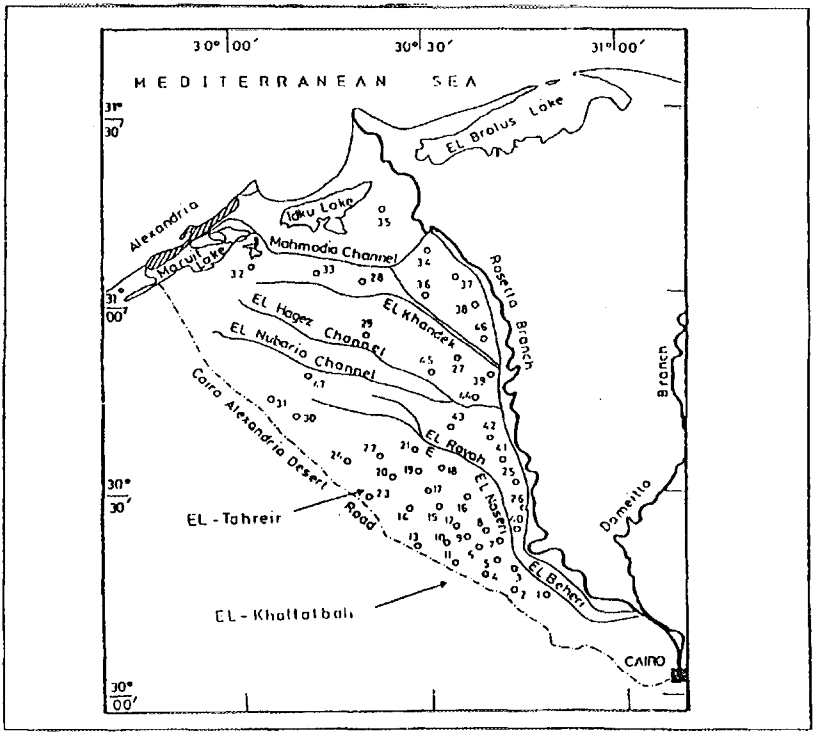


Fig 1

Table I: $\delta^{18}O$ - δ^2H Relationships in Groundwater

$y = \delta^2H,\ x = \delta^{18}O$

[1] Nile
$y = 5.96x + 7.66,\ r^2 = .68$

[2] Western Strip
$y = 4.96x + 7.05,\ r^2 = .87$

[3] Nile + Western Strip
$y = 6.65x + 4.22,\ r^2 = .93$

[4] Behira + Western Strip
$y = 6.63x + 4.00,\ r^2 = .91$

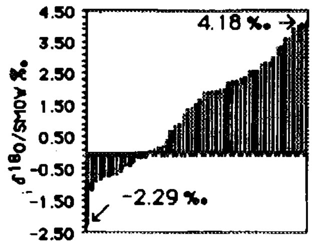
[5] Behira
$y = 7.39x + 2.92,\ r^2 = .95$

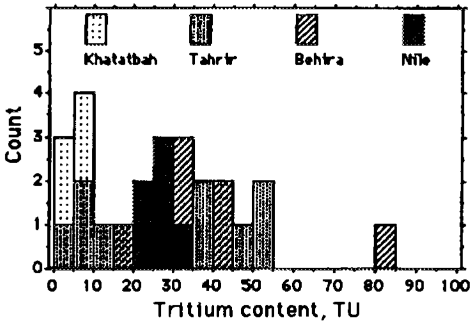
[6] Tahrir
$y = 7.71x + 2.03,\ r^2 = .94$

[7] Tahrir + Khatatbah
$y = 8.06x + 0.49,\ r^2 = .93$

[8] Khatatbah
$y = 6.45x - 2.00,\ r^2 = .92$

Meteoric Water
$y = 8.17x + 10.52$





On the left: Fig. 2 Sorted $\delta^{18}O$/SMOW ‰ values of the Desert-Delta interface.

On the right: Fig. 3 Frequency distribution of the environmental radioactive isotope ^3H

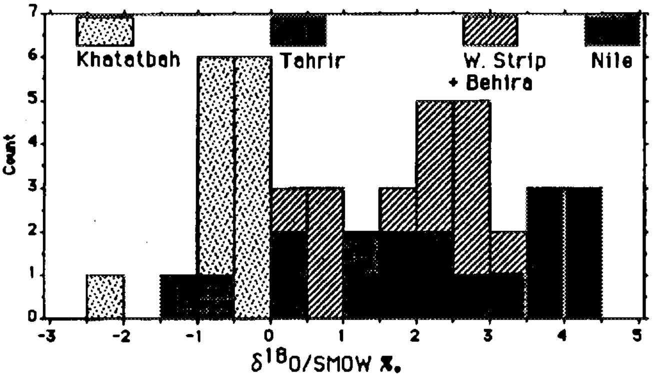


Fig. 4 Frequency distribution of the stable isotope ^{18}O in three areas, west of the Nile Delta

Table II Descriptive statistics of isotopic data, $\delta^{18}O/SMOW$.*

Statistic on $\delta^{18}O/SMOW$ ‰	Khatatbah	Tahrir	Behira	Behira & W. Strip	Western Strip	Nile, north west of Cairo
Mean	-0.66	1.04	1.74	1.86	2.19	3.86
Std. Deviation	0.54	1.32	0.95	0.96	1.01	0.30
Std. Error	0.15	0.40	0.24	0.21	0.41	0.11
Variance	0.29	1.74	0.90	0.93	1.01	0.09
Coff. of Variance	-82.28	126.33	54.54	51.66	45.85	7.67
Count	13	11	16	22	6	7
Maximum	-0.19	2.60	3.30	3.30	2.86	4.18
Minimum	-2.29	-1.20	0.20	0.19	0.19	3.39
Range	2.10	3.80	3.10	3.11	2.67	0.79
Kurtosis	4.58	-1.09	-1.08	-1.07	0.87	-1.25
Skewness	-2.19	-0.57	-0.02	-0.41	-1.60	-0.45z

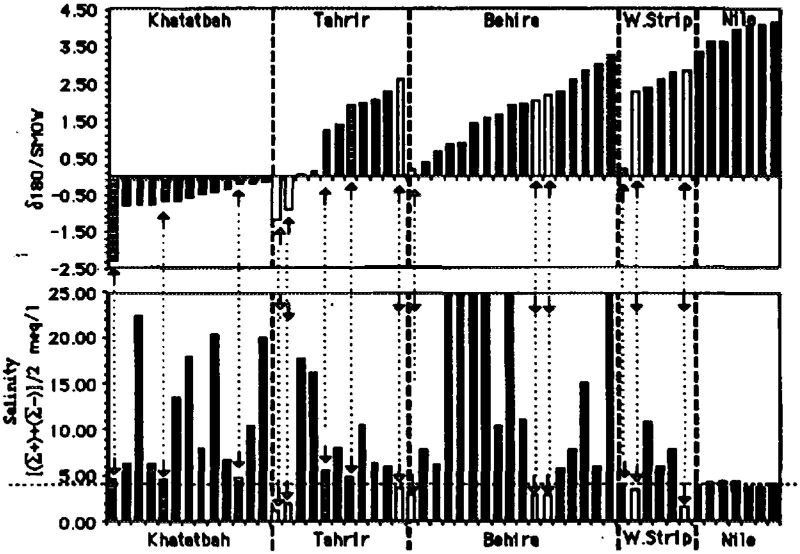


Fig. 5 $\delta^{18}O/SMOW$ ‰ and solutes (meq.l^{-1}) of sub-groups. Samples are sorted in each sub-group according to isotopic content. Any upper column representing isotope content corresponds to sample's salinity column in the lower diagram. Dilute samples are indicated by fleshes.

The outstanding presence of groundwater more dilute than the present-day Nile water (coupled with the observation of other groundwater samples with TDS content less than 5 meq.l^{-1} in nearby sites) could be viewed by the following interpretations:

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* Data of the fourth and sixth columns is included also in the fifth column.

Less Active Recharge from Nilotic Water

The sites of the most dilute water could have low recent recharge from Nilotic water. So, recent changes in the river chemistry and isotope geochemistry in Egypt during the last 30 years have not yet been introduced in the aquifer at these sites due to the lateral heterogeneity and darnped horizontal flow. obviously, groundwater samples with higher TDS levels (comparable to that of the present-day river water) could not be directly read as an indication of active recent recharge form the river, since hydrochemical data must be supported by isotopic data, the last is only capable of approving or negating water origin. Recent changes of Nile water is due to several facts but evaporation in Lake Nasser is one of the most important factors. Evaporation estimation using isotope data (Hussein, 1990) was as high as 15% between the south and north of this lake, leading to a corresponding TDS increase by a factor of 1.18. Higher estimation of evaporative water loss (19%) from this lake is obtained by Aly et al, (1993). Additional evaporation takes place in conveyance canals (about 4% based on data by Abu Zeid, 1992). Comparing a group of two upstream (southern) wells (no. 40 and 26) with a group of four downstream (northern) wells (no. 25, 41, 39 and 46) along 75 km on the Western Strip but all at same distance (<15 km) form the river, it is obvious that upstream wells have higher TDS and $\delta^{18}O$ (+2.81 to +2.86‰) than the downstream wells ($\delta^{18}O$ = +2.40 to +0.90‰). The lower TDS and the relative isotopic depletion in downstream wells indicate that groundwater in this sector reflects the hydrochemical and isotopic characteristics of an "older or sub-recent" Nile water. This could mean less recharge in the downstream than in the upstream sector of Rosetta Nile due to hydrodynamic and sedimentoiogic aspects (lower river discharge northward, change of river bed, change of reservoir sediments and lower hydraulic gradient). This natural pattern is not yet disturbed by pumping-induced water flow. It is worthy, however, to note that probable "artificial stagnation" could have affected some of our data for the Western Strip since, due to lack of production wells, its groundwater samples are collected from observation piezometers. It is noteworthy to retain that a strip of ~10 km width on the bank of a river would be the limit of flood effect beyond which no effect on the groundwater body could be detected (IAEA, 1981) but only the successive annual flood tides could be effective, under favorable hydraulic gradient, in "displacing" (and mixing with) the groundwater body far from the river bank. Khatatbah (which is laying more upstream not far from the river than Tahrir) would have higher underground water outflow from the main delta than Tahrir due to higher river discharge upstream, higher groundwater piezometric gradient and relatively higher hydrostatic surface water pressure of the pool in front of the delta barrage some 3O km further to the southeast from Khatatbah). on the other hand, in Tahrir, Western Strip and Behira, the presence of an intensive irrigation surface water conveyance network could be responsible for somewhat higher contribution of direct Nile water recharge to the aquifer in the localities adjacent to main irrigation canals. In Khatatbah, Nilotic groundwater replenishment takes display of the changes that would take place in river water (like the increase of salinity, pollution risks and increase of ^{18}O and ^{2}H contents) in contrast to other areas of the region which receive both groundwater outflow form the main delta and surface water from irrigation water ways and excessively irrigated fields by vertical seepage from the upper shallow phreatic water-table downward to the aquifer. So, any major pollution risk in Mle water could have higher influence in Tahrir than in Khatatbah. Being closer to the main delta, Khatatbah could be wrongly considered as already affected by recent changes in river chemistry. This impression could be popularized when paying attention only to the hydrochemical aspects (e.g. slightly higher salinity in Khatatbah groundwater compared to Tahrir groundwater) without an isotopic criteria and the wrong interpretation of this higher salinity as if it is the resultant of recent changes in the river chemistry during the last 30 years. However, the matter is not such simple, since groundwater is more depleted in the stable heavy isotopes (^{18}O and ^{2}H) in Khatatbah than Tahrir. This discrepancy leads to the introduction of the following interpretation which elucidates the extent of the contribution of assumed palaeo-pole and its mixing ratio with recent to sub-recent Nilotic water. In Behira, the relative isotopic depletion is accompanied by moderate to high marine type salinity indicating underground seawater intrusion.

Mixing with Palaeowater

We suggest the contribution of dilute palaeo-groundwater body(s) (which would be either an external water flowing from the desert in a northeast direction towards the south western boundary of the Holocene Delta or water flowing upward by leakage form a deep aquifer) which mixes with groundwater flowing from the main Delta aquifer westward to the desert. This could give rise to the observed dilute to very dilute samples in some wells in Tahrir and Khatatbah (with more dilute mixture in Tahrir than Khatatbah, Fig. 9). Presumed upward leakage could be enhanced at present by local intensive water extraction which could shift groundwater regime from steady state to transient flow in a manner comparable to what has been suggested (Hussein, 1990) to take place in Wadi Natron desertic depression (20 km further to the west of the region of the present work) using ^{18}O, ^{2}H and ^{3}H, ^{13}C, ^{14}C and ^{34}S. Theoretical groundwater isotopic mixing of two-end members follows the relation:

$$\frac{\delta^{18}O}{\text{mixture}} = \left[\begin{matrix}\text{Fraction}\\ \text{contribution} * \\ \text{of pole 1}\end{matrix} \begin{pmatrix}\delta^{18}O & {}_{-}\delta^{18}O \\ \text{of pole 1} & \text{pole 2}\end{pmatrix}\right] \frac{+\,\delta^{18}O}{\text{pole 2}}$$

Table III* and Fig. 8 and 9 illustrate the mixing approach using four poles, the probable mixing ratios which correspond to the observed groundwater composition and their frequency distribution. The prediction is in conformity with the analytical TDS and isotopic data and provides an explanation of the most dilute groundwater in Tahrir and Khatatbah. The presence of more isotopically depleted water on the western borders of the Khatatbah-Tahrir area stands for the presence of an external palaeo-water pole flowing in a eastward or southwest-northeast direction, whereas the presence of water sink in Natron depression to the west stands against this probability. Moreover, it is not clear if the suggested palaeo-pole is an ancient recharge from intensive local palaeo-meteoric water or palaeo-Nile water recharged by older powerful river discharge (which would have an isotopic composition strongly different from the present-day Nile water) and stored in the aquifer of the deserts surrounding the Holocene delta. These questions need close spatial and temporal isotopic monitoring to follow the decrease of the non-renewable fraction by exhaustion and the extent to which it would be readily replaced by an equivalent fraction from the

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* An EXCEL^{TM}~ Two-input Table is put by the first author to permits examination of unlimited number of guessing of WHAT IF?- operations on the hydrochemical and isotopic components of groundwater mixtures.

main Nile delta aquifer system. This isotope monitoring is so vital for the sustainance of water resources development in the region. Mixing with underground seawater is detected in four samples in the north of Behira on chemical and isotopic basis. However, use of other isotopes and greater number of sampling points seems unavoidable in order to delineate inland intrusion of marine water.

Precipitation

Partial contribution of precipitation in recharge could be responsible for the isotopic depletion and dilute groundwater. However, this contribution is probable only in few sectors like north of Tahrir where the precipitation rate (~ 60 $mm.y^{-1}$) and soil textural and structural conditions of sandy soil permit relatively high infiltration rate and percolation to the unconfined aquifer. A probable higher contribution of rain water in aquifer recharge in Tahrir compared to Khatatbah is due to decrease of annual rainfall inland southward from the Mediterranean (~ 30 $mm.y^{-1}$ in Khatatbah). Despite the fact that total annual precipitation is relatively low, partial recharge from rainfall could be admitted during few heavy shower events or by downward water movement by diffusion.

Summary and Conclusions

Some groundwater extraction points to the west of Rosetta Nile were isotopically and hydrochemically studied to elucidate their relationship with the delta system, the possible development and expansion further to the west within the framework of water resources sustainance and environmental protection. An isotopic mixing model is developed and successfully used in the explanation of observations. Groundwater on the west of the delta has an important contribution of an ill-defined palaeo-water. This fact should be taken into consideration in any global development planing. Khatatbah aquifer has only an underground contact with the delta system whereas Tahrir area has an additional contact with surface water through the irrigated fields and conveyance canals, so any serious pollution risk would have more rapid effect on groundwater in Tahrir, Behira and Western Strip. Some low Nile water recharge zones are detected downstream in Behira and Western Strip. Close isotopic monitoring for groundwater in the desertic areas surrounding the Nile Delta is needed for obtaining information about the palaeowater / recent water interaction which is very important for the sustainance of water resources for the newly introduced agricultural expansion.

Table III Results of the groundwater mixing model for two areas.

no.	((Σ+)+(Σ-))/2	d180/SMOW	Contribution	
		analytical	depleted	enriched
	Khatatbah		pole	pole
12	**4.66**	**-0.71**	**0.53**	0.47
11	**4.75**	**-2.29**	**0.76**	0.24
4	**4.95**	-0.20	0.40	0.60
9	6.37	-0.76	0.54	0.46
13	6.41	-0.85	0.55	0.45
3	6.73	-0.37	0.48	0.52
6	8.04	-0.48	0.50	0.50
5	10.78	-0.20	0.46	0.54
1	14.12	-0.70	0.53	0.47
2	18.02	-0.59	0.51	0.49
10	20.41	-0.19	0.46	0.54
7	20.52	-0.46	0.49	0.51
8	22.56	-0.76	0.54	0.46
Poles enriched	7.00	3.00		
Poles depleted	4.00	-4.00		

no.	((Σ+)+(Σ-))/2	d180/SMOW	Contribution	
		analytical	depleted	enriched
	Tahrir		pole	pole
23	**1.31**	**-1.20**	**0.84**	0.16
24	**2.10**	**-0.93**	**0.79**	0.21
21	**3.72**	2.60	0.08	0.92
22	4.93	1.90	0.22	0.78
15	5.74	1.23	0.35	0.65
20	5.99	2.29	0.14	0.86
14	6.42	2.03	0.19	0.81
18	8.09	1.38	0.32	0.68
17	10.62	1.97	0.21	0.79
19	16.22	0.14	0.57	0.43
16	18.35	0.07	0.59	0.41
Poles enriched	1.50	3.00		
Poles depleted	1.00	-2.00		

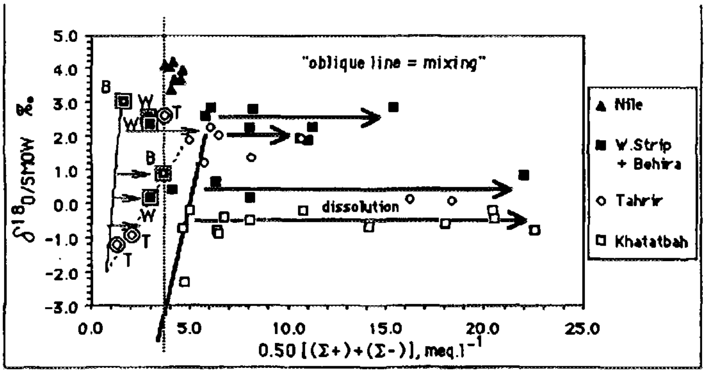


Fig.6 $\delta^{18}O/SMOW$‰ versus salinity. Mixing of groundwater with different isotopic contents and different hydrochemical compositions results in mixtures with intermediate isotopic and solute contents. The resulting mixture could have undergone further mineralization by leaching

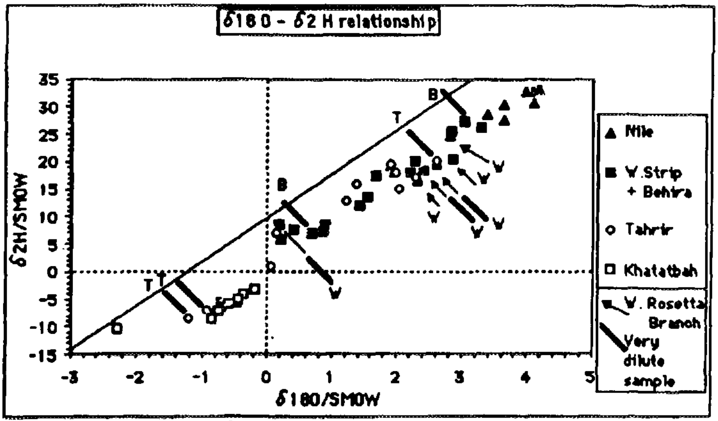
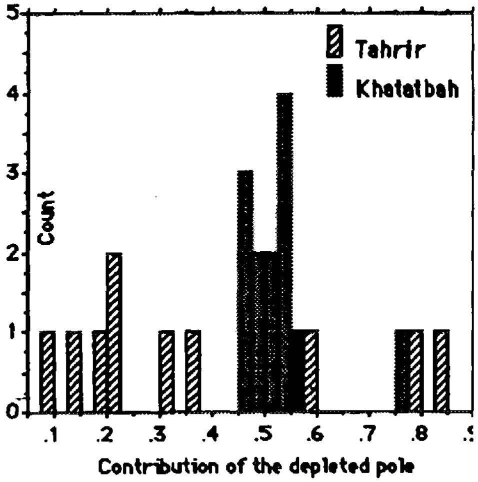


Fig.7 $\delta^{18}O$/SMOW‰ versus $\delta^{2}H$/SMOW‰ plot. The depleted pole could have a palaeo-origin (linear fit with slope 8 and intercept zero could be admitted). The extrapolation of this "palaeo" line to more enriched values covers the groundwater samples and supports a mixing interpretation. This line could be further extended to the Nile water. However, an evaporation line with slope < 8 could be fitted to present-day Nile water.



Pole 1 A	slightly depleted paleo-pole	Pole 2 A	main delta G.W. low salinity
TDS = 1 meq / l $\delta^{18}O$ = -2 ‰		TDS = 1.5 meq / l $\delta^{18}O$ = +3 ‰	
in Tahrir	if X = 0.5 mixture composition will be TDS = 1.25 meq / l $\delta^{18}O$ = +0.5 %		
	if X = 0.7 mixture composition will be TDS = 1.15 meq / l $\delta^{18}O$ = -0.5 ‰		
Pole 1 B	moderately depleted paleo-pole	Pole 2 B	main delta G.W. higher salinity
TDS = 4 meq / l $\delta^{18}O$ = -4 ‰		TDS = 7 meq / l $\delta^{18}O$ = +3 ‰	
in Khatatbah	if X = 0.5 mixture composition will be TDS = 5.5 meq / l $\delta^{18}O$ = -0.5 ‰		
	if X = 0.7 mixture composition will be TDS = 4.9 meq / l $\delta^{18}O$ = -1.9 ‰		

On the left: Fig. 8. Frequency distribution of the mixing ratios in desert groundwater
On the right : Fig. 9. Mixing in desert groundwater. X is the fraction of the depleted pole.
$\delta^{18}O$ values are given with respect to SMOW.

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