ISSN: 2634 - 8845

Journal of Earth and Environmental Sciences Research

Research Article

Open Access

Inaccurate Application of Isotope Hydrology Techniques to Nubian Sandstones Aquifer System in Sinai and North-Western Sahara Aquifers Systems

Samir A Al-Gamal

Egyptian Atomic Energy Authority, 3Ahmed Al-ZOMOR St, Nasr city 11672, Cairo, Egypt

ABSTRACT

A comprehensive understanding of the groundwater dynamics of a transboundary aquifer system is highly needed for any successful transboundary cooperation policy. The present paper addresses the necessity of identifying specific cooperation problems which evolve out due to the improper handling and treatment of isotopic data of these hydro geological attributes and prevalent use patterns.

The main reasons that render the use of the treated isotopic data illegal, incomparable and have thus lost some of its power as an effective tool is the ignorance of both time and space variations in treating isotopic data of two major aquifer systems in Africa namely; Nubian Sandstones Aquifer System (NSAS) as well as North-Western Sahara Aquifer System (NWSAS).

For any quantitative application of the stable isotopes labeling of waters a geo-hydrological tool, it is necessary to establish how well the isotopic composition of a groundwater source is defined in a supposedly homogenous geographic setting. Both time and space variations were not considered in all isotopic data of both aquifer systems; NSAS and NWSAS, where some of the sample were taken in 1968,1971,1972 other in 1982,1995 and 2000,2006,2010 and were all in some cases combined together in one diagram regardless the significant difference in time or lag-time i.e. not one month lag ,but years. This situation would therefore be misleading and represents one of the most obvious inaccuracies as well. On the contrary, one might also argue this inaccuracy to be negligible or at least of little importance, due to spatial and temporal reasons. In either case it seems to be sensible to at least address the respective mismatches.

***Corresponding author**

Samir A Al-Gamal, Egyptian Atomic Energy Authority, 3Ahmed Al-ZOMOR St, Nasr city 11672, Cairo, Egypt. E-mail: samir.algamal@gmail.com

Received: March 24, 2020; **Accepted:** March 30, 2020; **Published:** May 18, 2020

Keywords: Isotope Hydrology, Inaccurate, Mismatch, Nubian Sandstones Aquifer (Nsas), North-Western Sahara Aquifer System (Nwsas), Environmental Isotopes

Introduction

The Nubian Sandstone Aquifer System (NSAS) is considered one of the most important groundwater basins in North Africa and the Arab Region. Its large areal extent across the borders of four African Countries; Egypt, Sudan, Libya, and Chad, along with the huge groundwater reserves contained in its various water bearing formations, imply serious consideration, towards optimizing the utilization of this most vital natural water resource. Whereas, The North-West Sahara Aquifer System(NWSAS) often referred to as the Système Aquifère du Sahara Septentrional (SASS) is one of major North African transboundary groundwater basins in Africa. The huge groundwater reservoir of the North-West Sahara Aquifer System (NWSAS) is being shared by three North African countries of Algeria, Tunisia and Libya. Both aquifers constitute the major groundwater resources in the forgoing countries.

Methodology and techniques

Palaeo climatic condition were assessed from the isotopic composition of groundwater samples taken from the foregoing water bearing formations using stable isotopes of O-18, H-2, and radioactive isotopes of H-3 and C-14. Altitude effect as well as effect of depth on isotopic composition of both aquifers were quantified. A statistical package "SSC-Stat v2. nn" developed by Statistical Center of Reading University as well as isotope hydrology program 'Diagram" were acknowledge ably used for the analysis of isotopic data.

Review of the present Case studies

Nubian Sandstone Aquifer System (NSAS) in Sinai Peninsula

The Nubian Sandstone Aquifer System (NSAS) in Sinai Peninsula; exposed at the foothills of the Precambrian basement outcrops in Sinai and in the Negev desert and underlies large segments of the central Sinai Peninsula and the southern part of the Negev desert (Figure.1) [1,2]. The NSAS is composed of thick (up to 3 km in basin center) sequences of unfossiliferous continental sandstone with intercalated shale of shallow marine and deltaic origin, unconformably overlying basement rocks [3-5]. The NSAS is composed of unfossiliferous continental sandstone of Lower Cretaceous age intercalated with shale of shallow marine and deltaic origin of the Malha Formation in central and southern Sinai and marine limestone of the Risan Aneiza Formation in northern Sinai [6,7]. The Malha and the Risan Aneiza Formations are part of the Nubian Sandstone group that rests unconformably on the basement rock units and is overlain by calcareous sequences of Cenomanian to Upper Eocene age (Figure 1) [1,4]. There is a general consensus that the There is a general consensus that the paleoclimatic regimes of the North African Sahara Desert alternated between dry and wet periods throughout the Pleistocene Epoch and that it was during these wet periods that the NSAS was recharged. However, the nature of these wet periods remains a subject of debate. Two main hypotheses have been advocated to address the origin of the fossil water of the NSAS: (1) intensification of paleo westerlies during glacial periods or (2) intensifi-cation of paleo monsoons during interglacial periods [8-23].

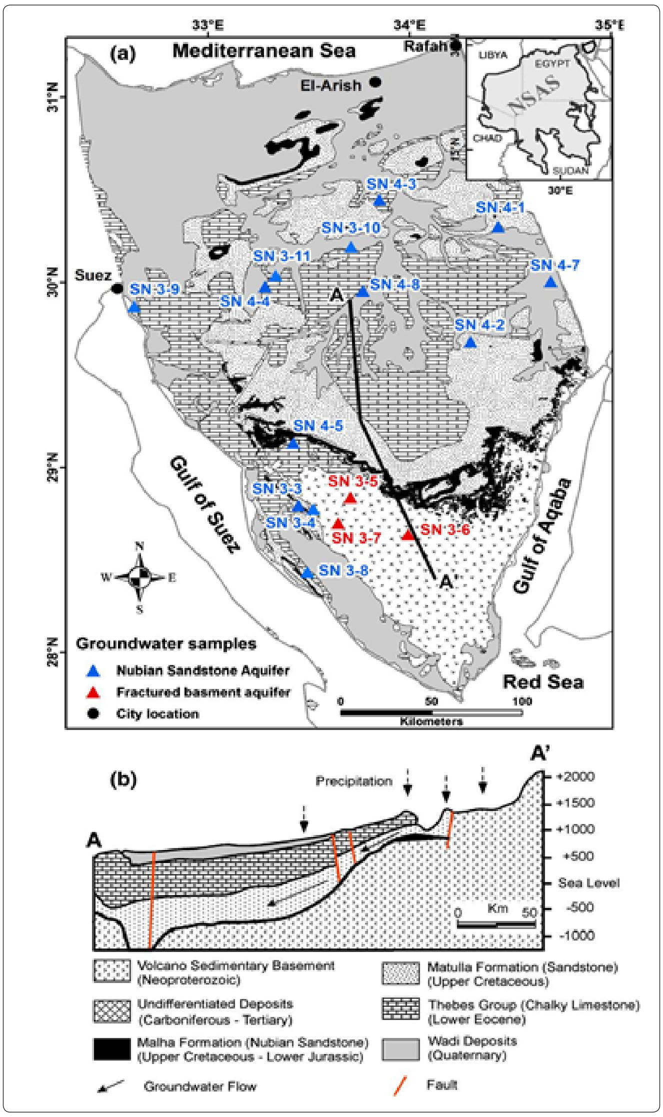


Figure 1: Location map for groundwater samples and south–North cross section [18]. Groundwater samples collected for isotopic analysis by A. Abouelmagd et al., were conducted in January and June of 2010 from 12 drilled wells and from the Ayun Musa spring, which taps the NSAS and from three open wells in the fractured base-ment as shown in Figure 2 .The inspection of Figures 1 and 2 reveals that samples are widely distributed and represent totally different elevation as far as altitude of recharge areas is concerned and totally different depth as far as groundwater depth is concerned (cross section A-A of Figure 1).

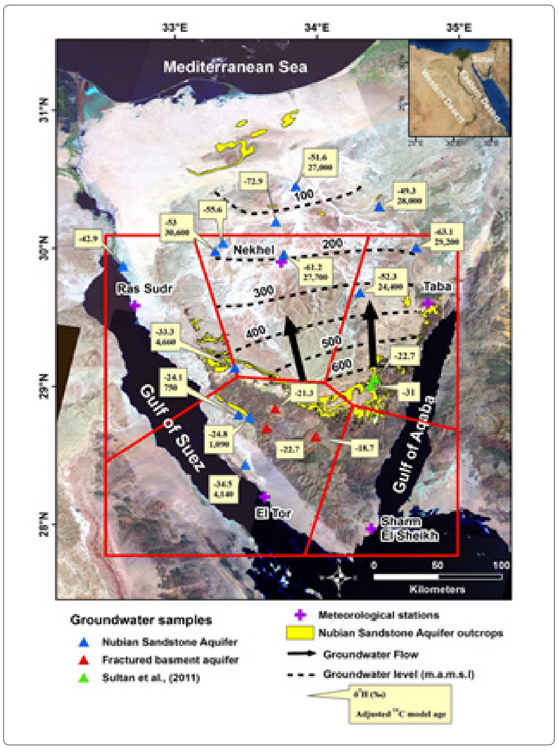


Figure 2: A base map false-color Landsat TM image showing (1) our groundwater sample locations from wells and a spring tapping the NSAS (blue triangles) and from wells tapping the fractured basement aquifer (red triangles); (2) groundwater sample locations for open wells tapping the NSAS in the recharge areas (green triangles); (3) groundwater levels (dashed lines) and flow directions (black arrows); and (4) δ2H value (yellow box: upper), adjusted 14C model age (yellow box: lower) [24,25]. Also shown is a graphical representation for polygons (outlined by red lines) defined by the Thiessen method that was applied to interpolate present-day mean weighted annual temperature from meteorological stations (purple cross) to the surrounding areas including the Nubian Sandstone Aquifer outcrops.

Table 1: Sample locations, well information, O and H isotopic compositions, and tritium activities for groundwater samples from wells tapping the NSAS and the fractured basement in Sinai [18].

ID	Name	Latitude N	Longitude E	Aquifer/ Well	TD[a] (m)	DWL[a] (m)	TDS[b] (mg/L)	δ^2H[c] (‰)	$\delta^{18}O$[c] (‰)	^3H[c] TU	Group
SN4-1	Arif El Naqa 2	30°18.21′	34°26.30′	NSS/D	870	271	3810	−49.3	−7.62	–	I
SN4-2	El Themed 2	29°40.80′	34°18.20′	NSS/D	747	376.8	1830	−52.3	−7.7	–	I
SN4-3	El Hasana 3	30°26.99′	33°51.06′	NSS/D	1200	200	3260	−51.6	−7.19	–	I
SN4-4	Sudr El Hetan 3	29°58.70′	33°16.95′	NSS/D	1040	270	1740	−53	−7.85	–	I
SN4-5	El Rueikna 3	29°08.06′	33°25.35′	NSS/D	–	55.6	480	−33.3	−5.89	–	II
SN4-7	El Kuntella 3	30°00.38′	34°42.04′	NSS/D	1121	353.4	1827	−63.1	−8.85	–	I
SN4-8	Nekhel 5	29°57.27′	33°46.08′	NSS/D	1200	200.6	1622	−61.2	−8.81	–	I
SN3-3	Mekatab 3	28°47.71′	33°26.89′	NSS/D	366	49.7	953	−24.1	−4.84	b1.0	II
SN3-4	Nadya El Soda	28°46.55′	33°31.35′	NSS/D	63	–	934	−24.8	−4.93	2.78 ± 0.29	II
SN3-5	Haroun	28°50.37′	33°42.41′	FB/O	31	29.7	827	−21.3	−4.13	2.42 ± 0.27	II
SN3-6	Halwagy	28°38.33′	33°59.62′	FB/O	–	30	868	−18.7	−3.36	2.55 ± 0.30	II
SN3-7	Dir El Banat	28°42.00′	33°38.80′	FB/O	–	–	675	−22.7	−4.54	3.04 ± 0.28	II
SN3-8	Regwa 12	28°26.05′	33°29.59′	NSS/D	–	18.4	622	−34.5	−5.72	b1.0	II
SN3-9	Ayun Musa	29°52.28′	32°38.03′	NSS/S	n/a	n/a	2778	−42.9	−6.53	b1.0	I
SN3-10	El Berouk 4	30°11.60′	33°42.58′	NSS/D	955	137	2682	−72.9	−9.59	b1.0	I
SN3-11	Erirah El Far 4	30°02.35′	33°20.15′	NSS/D	1250	–	2215	−55.6	−8	b1.0	I

Abbreviations: NSS: Nubian Sandstone; FB: fractured basement; D: drilled well; O: open well; S: spring; TU: tritium unit.

a Data collected from field work and from JICA (1999).

b Western Michigan University geochemical labs.

c Analyzed at Isotech Laboratories, Champaign, Illinois.

North-Western Sahara Aquifer System (NWSAS)

The North-Western Sahara Aquifer System (NWSAS) often referred to as the Système Aquifère du Sahara Septentrional (SASS) is one of major North African transboundary groundwater basins in Africa. The huge groundwater reservoir of the North-West Sahara Aquifer System (NWSAS) is being shared by three North African countries of Algeria, Tunisia and Libya (Figure 1).The NWSAS covers an approximately half the size of the Nubian Sandstone Aquifer System, shared by Egypt, Sudan, Libya and Chad and it is predicted to cover around 1 million km^2 and reaching a scale of 1,800 km from east to west and 900 km from north to south. The NWSAS can be categorized as a multi-layered system of aquifers which embodies a huge stock of non-renewable, fossil water. It displays a mostly porous and fissured / fractured structure. The geological structure determines the aquifer's recharge infiltration rate and the velocity of groundwater flows in time and space. Among its different layers, two have to be distinguished as being of major size and importance. The so called Continental Intercalaire (CI) is located on the lower level (Figure 2). It has a thickness of many hundreds of meters and is found in depths ranging from around 400 up to 2,000 meters below ground. According to Besbes et al. the CI contains a set of layers with very differing lithology, comprising mainly continental sandstone in alternation with marine limestones and clay formations (Figure 2). NWSAS being identified as type "F" according to Eckstein and Eckstein, and was thus considered as unrelated to any surface body of water, disconnected from the hydrological cycle, and devoid of any meaningful recharge. However the present study was designed to reveals the real situation of NWSAS and whether it is a renewable or non-renewable water resource

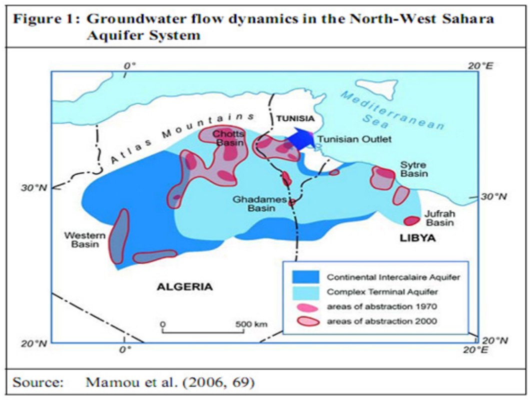


Figure 3: Location map and areal extent of North-Western Sahra Aquifer System (NWSAS)

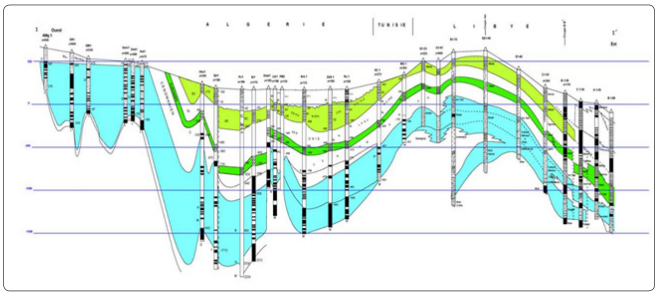


Figure 4: East-West lithostratigraphic cross section along the three countries (OSS internal report)

Table 2: Isotopic data of North Western Sahara Aquifer System (NWSAS)(OSS Int. Report)

Code	Name of water point	Date	Aquifer	^{18}O	^{2}H	^{14}C %	^{13}C%.
15.0.16	Hassi Maroket 66 L 8	27/11/69	ind (Sa)			1.0 ±0.7	-5.6
15.0.17	Hassi Maroket 66 L 9	01/12/70	ind (Sa)	-5.7		1.0±0.1	
14.14.16	Hassi Enfil P n°5	27/03/69	ind (Sa)	-6.0	-58	59.6 ±4.4	-5.1
13.0.0	Fogg. Amghaier (Timimoun)	26/03/69	ind (Sa)	-7.9	-64		
CF	Terr. Aviation (Timimoun)	01/12/70	ind (Sa)	-8.3		30.9 ±0.5	-6.5
8.0.0	Foggara Adrar	24/03/69	ind (Sa)	-7.0	6 60		
9.0.0	Ferme expale Adrar	25/03/69	ind (Sa)	-6.1	-52		
CF	Shell - Sonatrach-Adrar	27/04/69	ind (Sa)	-7.1	-54		
CF	Adrar	01/12/70	ind (Sa)	-6.5		24.4 ± 0.5	-8.7
CF	Adrar	04/04/68	ind (Sa)	-6.8			
CF	Adrar	28/04/68	ind (Sa)	-6.7			
CF	Adrar	23/04/68	ind (Sa)	-7.1	-61		
CF	Bou Ali	01/12/70	ind (Sa)	-8.7		22.3 ± 0.4	-8.8
CF	Bou Ali	28/04/68	ind (Sa)	-7.7			
CF	Bou Ali	28/04/68	ind (Sa)	-7.9			
CF	C.A.S (Reggane)	01/12/70	ind (Sa)			33.2 ±2.5	
CF	Reggane	14/04/68	ind (Sa)	-7.9			
CF	Reggane	01/11/71	ind (Sa)			33.5 ±2.5	
CF	OCI, Reggane	14/04/68	ind (Sa)	-7.4			
CF	Fogg. Beb Drao, Aoulef El Arab	14/04/68	ind (Sa)	-7.4	-58		
CF	Fogg. Beb Drao, Aoulef El Arab	01/12/70	ind (Sa)	-7.4			

51.0.0	Tit 101	01/14/71	ind (Sa)	-8.0	-60		
51.0.1	Tit 102	01/11/71	ind (Sa)			36.0 ±0.6	
CF	Hydraulique In Salah	01/12/70	ind (Sa)	-8.4		21.2 ±1.0	-10.2
CF	In Salah	14/04/68	ind (Sa)	-8.3	-64		
CF	Foggara Ez Zoua	13/04/68	ind (Sa)	-9.6			
CF	Foggara Gentour (Timimoun)	26/03/69	ind (Sa)+ CT (SC)	-6.6	-57		

Findings and discussion

Nubian Sandstones Aquifer System (NSAS)

The range of stable isotopes contents(Table 1) is interrupted with ^{2}H ranging from -18 (‰) to -72 (‰) and O-18 from -3 (‰) to -9.59 (‰) as a result of ignoring altitude effect defined by Gat, J.R. (1980) as " On the windward side of a mountain, the d^{18}O and dD values of precipitation decrease with increasing altitude". Typical gradients are -0.15 to -0.5 ‰ per 100m for 18O, and -1.5 to -4 ‰ per 100m for D was totally ignored in the foregoing study. Accordingly, the NSAS exhibits an altitude effect by which, mixing also occurred between waters precipitated at different altitudes, this could also account for the observed difference in stable isotopes and confirms that the aquifer receive a considerable fraction of modern water recharging the aquifer under consideration (Figure 5). A solid criterion indicating altitude effect was established using the same data of Table 1 as shown in Figure.5. A further scrutiny to Table 1 taking into consideration column of latitudes versus isotopic composition, it can be concluded that also "latitude effect (in which The d^{18}O and dD values decrease with increasing latitude because of the increasing degree of "rain-out") was not taken into consideration and represent mismatches. On the contrary, one might also argue this inaccuracy to be negligible or at least of little importance, due to spatial and temporal reasons. In either case it seems to be sensible to at least address the respective mismatches.

North-Western Sahara Aquifer System (NWSAS)

For any quantitative application of the stable isotopes labelling of waters a a geo-hydrological tool, it is necessary to establish how well the isotopic composition of a groundwater source is defined in a supposedly homogenous geographic setting. We have to consider both time and space variations [26].The inspection of Table 2 reveals that some of the sample were taken in 1968,1971,1972 other in 1982,1995 and were all in some cases combined together in one diagram regardless the significant difference in time or lag-time i.e. not one-month lag, but years.

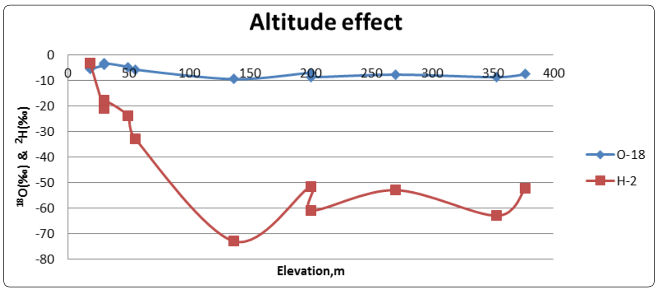
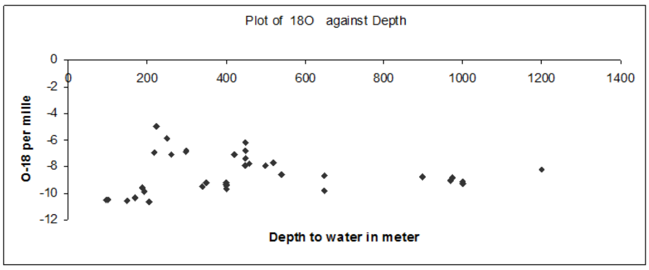


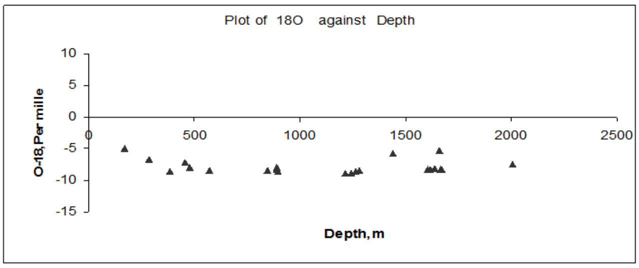
Figure 5: Altitude effect expressed as cross plot of O-18 versus elevation for NSAS in Sinai (Originated from the present author)

Furthermore, In a given region, the δ-values of precipitation at higher altitudes generally will be more negative in what is known as "Altitude effect". So combining data from Algeria and Tunisia with no differentian will lead to a total ignorance of one of the major effect on isotopic data ..the same fact remains true for variation in depth of water sample (Figure 6).The inspection of Figure 4 of litho-stratigraphic sequence indicates that a considerable portion of aquifer is confined with mean groundwater velocity of 6m/year,i.e.2cm/day which represents some sort of stagnancy as represented by slow velocity aided by elevated groundwater temperature will enforce water to have–rock–water interaction phenomenon which will change isotopic composition. This approach was not also considered.

Last but not least Spatial scatter within an aquifer is found in most cases to be more significant than variation in time. One must realize that no area is really uniform from topographical, morphological and ecological point of view. Accordingly, for transboundary aquifer shared by Algeria,Tunisia and Libyia, different recharge relation may apply at each point,(Figure 7) [26].



(a)



(b)

Figure 6: Cross plot of depth to water level, versus δ 18O‰ for C.I. aquifer in Libya (a) and in Tunisia (b)

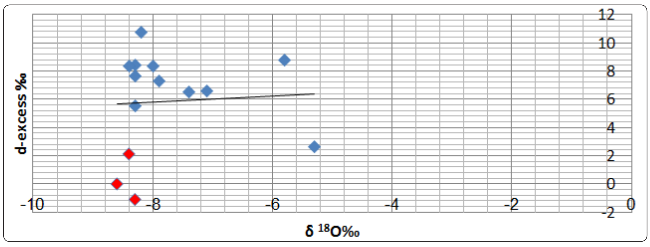


Figure 7: Relationship between δ18O and d-excess for Algerian C.I. with low d-excess values indicating the present-day recharge water (Filled Red squares). Originate from the present author

Conclusions

A comprehensive understanding is highly needed for any successful transboundary cooperation policy. Isotopic data interpreted in conjunction with conventional hydrologic data has confirmed the fact that NWSAS as well as NSAS are receiving a considerable fraction of modern water recharging both aquifers. This was clearly indicated by the frequent occurrences of significant amount 14C >2 % pmc, H-3 ≥5 T.U. and the abnormally low values of d-excess(-1‰).Isotopic data related to both aquifers ara not comparable as per the significant difference in time and space variation [27-76].

References

1. Said R (1962) The Geology of Egypt. Elsevier, Amsterdam 377.
2. Issar A, Bein A, Michaeli A (1972) On the ancient water of the Upper Nubian Sandstone aquifer in central Sinai and southern Israel. Journal of Hydrology 17: 353-374.
3. Himida H (1970) The Nubian artesian basin, its regional hydrogeological aspects and palaeohydrological reconstruction. Journal of Hydrology 9: 89-116.
4. Shata A (1982) Hydrogeology of the Great Nubian Sandstone basin, Egypt. Quarterly Jour-nal of Engineering Geology 15: 127-133.
5. Hesse KH, Hissese A, Kheir O, Schnacker E, Schneider M, (1987) Hydrogeological investigations in the Nubian Aquifer system, Eastern Sahara. In: Kilitzsch E, Schranck, E (Eds.), Research in Egypt and Sudan. Dietrich Reimer, Berlin pp397-464.
6. Abdallah, AM, Adindani A, Fahmy N (1963) Stratigraphy of Upper Paleozoic Rocks, Western Side of the Gulf of Suez, Egypt. Egyptian Geological Survey 1-18.
7. Said R (1971) Explanatory Notes to Accompany the Geological Map of Egypt. Geological Survey of Egypt, Cairo 123.
8. Sonntag C, Klitzsch E, Lohnert EP, El Shazly, EM Munnich, et al. (1978) Paleoclimatic Information from Deuterium and Oxygen-18 in Carbon-14-dated North Saharian groundwaters. Iso-tope Hydrology International Atomic Energy Agency (IAEA), Vienna 569-581.
9. Sultan M, Sturchio N, Hassan FA, Hamdan MAR, Mahmood AM, et al. (1997) Precipitation source inferred from stable isotopic composition of Pleistocene groundwater and carbonate deposits in the Western Desert of Egypt. Quaternary Re-search 48: 29-37.
10. Frumkin A, Ford DC, Schwarcz HP (2000) Paleoclimate and vegetation of the last glacial cycles in Jerusalem from a speleothem record. Global Biogeochemical Cycles 1: 1-9.
11. Bartov Y, Stein M, Enzel Y, Agnon A, Reches Z (2002) Lake levels and sequence stra-tigraphy of Lake Lisan, the late Pleistocene precursor of the Dead Sea. Quaternary Re-search 57: 9-21.
12. Brookes IA (2003) Geomorphic indicators of Holocene winds in Egypt's Western Desert. Geomorphology 56: 155-166.
13. Issar A (2003) Climate Changes During the Holocene and their Impact on Hydrological Systems. Cambridge University Press, Cambridge, United Kingdom 144.
14. Issar A, Zohar M (2004) Climate Change-Environment and Civilization in the Middle East. Springer, Berlin 252.
15. Stuiver M, Polach HA (1977) Reporting of 14C data. Radiocarbon 19: 355-363.
16. Sturchio NC, X Du, R Purtschert, R Purtschert, M Sultan et al., (2004) One million year old groundwater in the Sahara revealed by krypton-81 and chlorine-36. Geophysical Research Letters 31, L05503.
17. Vaks A, Bar-Matthews M, Ayalon A, Matthews A, Frumkin A, et al. 2006. Paleoclimate and location of the border between Mediterranean climate region and the Saharo–Arabian Desert as revealed by speleothems from the northern Negev Desert, Israel. Earth and Planetary Science Let-ters 249: 384-399.
18. Issar A (2010) Climate change as a draw bridge between Africa and the Middle East. Glob-al and Planetary Change 72: 451-454.
19. Abouelmagd A, Sultan M, Milewski A, Kehew AE, Sturchio NC, et al. (2012) Toward a better understanding of palaeoclimatic regimes that recharged the fossil aquifers in North Africa: inferences from stable isotope and remote sensing data. Palaeogeography, Palaeoclimatology, Palaeoecology 329-330: 137-149.
20. Weiss RF (1968) Piggyback samplers for dissolved gas studies on sealed water samples.Deep-Sea Research 15: 695-699.
21. Bar-Yosef O, Meadow R (1995) The origins of agriculture in the Near East. In: Price TD, Gebauer AB (Eds.), The Last Hunters—First Farmers: Perspectives on the Prehistoric Transition to Agriculture. School of American Research Press, Santa Fe, New Mexico pp 39-94.
22. Bar-Matthews M, Ayalon A, Gilmour M, Matthews A, Hawkesworth CJ (2003) Sea -land oxygen isotopic relationships from planktonic foraminifera and speleothems in the Eastern Mediterranean region and their implication for paleorainfall during in-terglacial intervals. Geochimica et Cosmochimica Acta 67 : 3181-3199.
23. Almogi-Labin A, Bar-Matthews M, Ayalon A (2004) Climate variability in the Levant and northeast Africa during the Late Quaternary based on marine and land records. In: Goren-Inbar N, Speth JD (Eds.), Human Paleoecology in the Levantine Corridor. Oxbow Press, Oxford, pp 117-134.
24. Osmond JK, Dabous AA (2004) Timing and intensity of groundwater movement during Egyptian Sahara pluvial periods by U-series analysis of secondary U in ores and car-bonates. Quaternary Research 61: 85-94.
25. United States Geological Survey (2003) USGS Global Visualization Viewer (GLOVIS). URL: http://glovis.usgs.gov.
26. Sultan M, Metwally S, Milewski A, Becker D, Ahmed M, et al. (2011) Modern re-charge to fossil aquifers: geochemical, geophysical, and modeling constraints. Journal of Hydrology 403: 14-24.
27. Gat JR, Mazor E, Tzur Y (1969) The stable isotope composition of mineral waters in the Jordan Rift Valley, Israel. Journal of Hydrology 7: 334-352.
28. Aeschbach-Hertig W (2006) Environmental tracer study of groundwater recharge near the Nile Delta, Egypt. DPG-Tagung, Heidelberg, unpublished report.
29. Aeschbach-Hertig W, El-Gamal H, Dahab K, Kipfer R, Bonani G (2006a) Environmental tracer study of groundwater recharge near the Nile Delta, Egypt. Determining paleotemperature and other variables by using an error-weighted, nonlinear inver-sion of noble gas concentrations in water. Geochimica et Cosmochimica Acta 63: 2315-2336.
30. Aeschbach-Hertig W, El-Gamal H, Dahab K, Kipfer R, Hajdas I, Bonani G (2006b) Using environmental tracers to assess groundwater resources in reclamation areas of Egypt. Geophysical Research Abstracts 8, A-05515.
31. Aeschbach-Hertig W, El-Gamal H, Dahab K, Friedrich R, Kipfer R, et al. (2007) Identifying and dating the origin of groundwater resources in reclamation areas of Egypt. Advances in Isotope Hydrology and its Role in Sustainable Water Resources Management. International Atomic Energy Agency (IAEA), Vienna pp 395-403.
32. Alsharhan AS, Salah MG (1996) Geologic setting and hydrocarbon potential of North Sinai, Egypt. Bulletin of Canadian Petroleum Geology 44: 615-631.
33. Bartov Y, Goldstein SL, Stein M, Enzel Y (2003) Catastrophic

arid episodes in the east Mediterranean linked with the Atlantic Heinrich events. Geology 31: 439-442.

34. Blasband B, White S, Brooijmans P, De Boorder H, Visser W (2000) Late Proterozoic extensional collapse in the Arabian–Nubian Shield. Journal of the Geological Society of London 157: 615-628.
35. Broecker W, Johnson S, McManus J, Labeyrie L, Jouzel J, et al. (1993) Correlation between climate records from North Atlantic sediments and Greenland ice. Nature 365: 507-508.
36. Cherkinsky AE, Culp RA, Dvoracek DK, Noakes JE (2010) Status of the AMS facility at the University of Georgia. Nuclear Instruments and Methods in Physics Research 268: 867-870.
37. Clark PU, Dyke AS, Sakun JD, Carlson AE, Clark J, et al. (2009) The last glacial maximum. Science 325: 710-714.
38. Coplen TB (1996) New guidelines for reporting stable hydrogen, carbon, and oxygen isotope-ratio data. Geochimica et Cosmochimica Acta 60 3359-3360.
39. Craig H (1961) Isotopic variations in meteoric waters. Science 133: 1702-1703.
40. Edmunds WM, Fellman E, Goni IB (1999) Lakes, groundwater and paleohydrology in the Sahel of NE Nigerai: evidence from hydro geochemistry. Journal of the Geological Society of London 156: 45-355.
41. Egyptian Meteorological Authority (1996) Climatic Atlas of Egypt. Egyptian Meteo-rological Authority, Ministry of Transport and Communications, Cairo, Egypt.
42. Fairbanks RG, Mortlock RA, Chiu T-C, Cao L, Kaplan A, et al. (2005) Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired 230Th/234U/238U and 14C dates on pris-tine corals. Quaternary Science Reviews 24: 1781-1796.
43. Fontes J-C, Garnier J-M (1979) Determination of the initial 14C activity of the total dis-solved carbon: a review of the existing models and a new approach. Water Resources Research 15: 399-413.
44. Geb M (2000) Factors favoring precipitation in North Africa: seen from the viewpoint of present-day meteorology. Global and Planetary Change 26: 85-96.
45. Gheith H, Sultan M (2002) Construction of a hydrologic model for estimating wadi runoff and groundwater recharge in the Eastern Desert, Egypt. Journal of Hydrology 263: 36-55.
46. Guendouz A, Moulla AS, Edmunds WM, Shand P, Poole J, (1998) Palaeoclimatic information contained in groundwater of the Grand ERG Orien-tal, North Africa. Isotope Techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and Atmosphere. IAEA, Vienna pp 555-571.
47. Hesse KH, Hissese A, Kheir O, Schnacker E, Schneider M, et al. (1987) Hydrogeological investigations in the Nubian Aquifer system, Eastern Sahara. In: Kilitzsch E, Schranck E (Eds.), Research in Egypt and Sudan. Dietrich Reimer, Berlin pp 397-464.
48. International Atomic Energy Agency (IAEA), Water Isotope System for Data Analysis, Visualization, Electronic Retrieval (2010) Water Isotope System for Data Analysis, Visualization, and Electronic Retrieval 7th ed.
49. Japan International Cooperation Agency (1999) South Sinai Groundwater Resources Study in the Arab Republic of Egypt, Tokyo, Japan. 220.
50. Kipfer R, Aeschbach-Hertig W, Peeters F, Stute M (2002) Noble gases in lakes and ground waters. In: Porcelli D, Ballentine C, Wieler R (Eds.), Reviews in Mineralogy and Geochemistry, Noble gases in Geochemistry and Cosmochemistry. Mineralogical Society of America and Geochemical Society, Washington, DC pp 615-700.
51. Klump S, Tomonaga Y, Kienzler P, Kinzelbach W, Baumann T, et al. (2007) Field experiments yield new insights into gas exchange and excess air for-mation in natural porous media. Geochimica et Cosmochimica Acta 71: 1385-1397.
52. Lehmann KK, Berden G, Engeln R (2009) An Introduction to Cavity Ring-Down Spec-trometry. In: Berden, G., Engeln, R. (Eds.), Cavity Ring-Down Spectrometry Tech-niques and Applications. John Wiley & Sons Ltd., United Kingdom pp 1-26.
53. Lisker S, Vaks A, Bar-Matthews M, Porat R, Frumkin A (2009) Stromatolites in caves of the Dead Sea Fault Escarpment: implications to latest Pleistocene lake levels and tec-tonic subsidence. Quaternary Science Reviews 28: 80-92.
54. Manning AH, Solomon DK (2003) Using noble gases to investigate mountain-front re-charge. Journal of Hydrology 275: 194-207.
55. Mazor E (1972) Paleotemperatures and other hydrological parameters deduced from noble gases dissolved in groundwaters; Jordan Rift Valley, Israel. Geochimica et Cosmochimica Acta 36: 1321-1336.
56. National Climate Data Center (2012) Surface Data, Global Summary of the Day and Hourly Global. URL: http://www7.ncdc.noaa.gov/CDO/cdo.
57. Parkhurst DL, Charlton SR (2008) NetpathXL-An Excel® Interface to the Program NETPATH: U.S. Geological Survey Techniques and Methods 11: 6-A26.
58. Patterson LJ (2003) Chlorine-36 and stable chlorine isotopes in the Nubian Aquifer, Western Desert, Egypt. Earth and Environmental Sciences.University of Illinois Chicago 81.
59. Pinti DL, Van Drom E (1988) PALEOTEMP: a Mathematica® program for evaluating paleotemperatures from the concentration of atmosphere-derived noble gases in groundwater. Computers & Geosciences 24 33-41.
60. Plummer LN, Sprinkle CL (2001) Radiocarbon dating of dissolved inorganic carbon in groundwater from confined parts of the Upper Floridan aquifer, Florida, USA. Hydro-geology Journal 9: 127-150.
61. Plummer LN, Michel RL, Thurman EM, Glynn PD (1993) Environmental tracers for age dating young ground water. Regional ground-water quality. An Nostrand Reinhold, New York 255-294.
62. Plummer LN, Prestemon EC, Parkhurst DL (1994) An interactive code (NETPATH) for modeling net geochemical reactions along a flow path Version 2.0. U.S. Geological Survey Water-Resources Investigations Report 94–4169.
63. Prell WL, Kutzbach JE (1987) Monsoon variability over the past 150,000 years. Journal of Geophysical Research 92: 8411-8425.
64. Rossignol-Strick M (1983) African monsoons, an immediate climate response to orbital insolation. Nature 304; 46-49.
65. Sanford WE (1997) Correcting for diffusion in carbon-14 dating of groundwater. Ground-water 35: 357-361.
66. Solomon DK, Cook PG, Sanford WE (1998) Dissolved gases in subsurface hydrology. In: Kendall C, McDonnell JJ (Eds.), Isotope Tracers in Catchment Hydrology. Elsevier, Amsterdam pp 291-318.
67. Stern RJ, Kroner A (1993) Late Precambrian crustal evolution in NE Sudan: isotopic and geochronologic constraints. Journal of Geology 101 555-574.
68. Stute M, Schlosser P (1993) Principles and applications of the noble gas paleo-thermometer. In: Swart PK, Lohmann KC, Savin S (Eds.), Climatic Change in Continental Isotopic Records. Geophysical Monograph Series. American Geophysical Union pp 89-100.
69. Stute M, Clark JF, Schlosser P, Broecker WS (1995) A 30,000 yr continental paleotemperature record derived from noble

gases dissolved in groundwater from the San Juan Basin, New Mexico. Quaternary Research 43: 209-220.
70. M Arvidson R., Duncan IJ, Stern RJ, El Kaliouby B (1988) Extension of the Najd shear system from Saudi Arabia to the central Eastern Desert of Egypt based on integrated field and Landsat observations. Tectonics 7: 1291-1306.
71. Tamers MA (1975) Validity of radiocarbon dates on groundwater. Geophysical Surveys 2 : 217-239.
72. Thorweihe U (1990) Nubian aquifer system. In: Said, R. (Ed.), Geology of Egypt. Balkema, Rotterdam, pp 601-611.
73. Torfstein A, Goldstein SL, Stein M, Enzel Y (2013) Impacts of abrupt climate changes in the Levant from last glacial Dead Sea levels. Quaternary Science Reviews 69: 1-7.
74. Vaks A, Bar-Matthews M, Ayalon A, Schilman B, Gilmour M, et al. (2003) Paleoclimate reconstruction based on the timing of speleothem growth and oxygen and carbon isotope composition in a cave located in the rain shadow in Israel. Quaternary Research 59: 139-284.
75. Vogel JC (1967) Investigation of groundwater flow with radiocarbon. Isotopes in Hydrol-ogy. International Atomic Energy Agency, Vienna pp 255-368.
76. Vogel JS, Southon JR, Nelson DE, Brown TA (1984) Performance of catalytically con-densed carbon for use in accelerator mass spectrometry. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 5: 289-293.