Origin, Anthropogenic and Climate Influences on the Occurrences of Saline Groundwater at the City of Cairo, Egypt Deduced by Chemical Parameters of the Water Composition

Werner Balderer, Fanny Leuenberger and Hussein Idris

Abstract Three old springs in the southeastern part at the border of Cairo City, named Ain Al Sira, Khayalat Al Shorta and Abo El Soud, used to be the origin of three natural ponds. Since the removal of one of these natural ponds (Abo El Soud) about three decades ago, by filling it with stones and recycled building material, an ongoing rise of the water level of the two remaining lakes or ponds has been observed. The water surface rise of the two ponds is still continuing and is actually even flooding nearby roads and cemeteries. The origin of the groundwater is from outflows of the outcropping Tertiary rocks according to the main chemical composition of Pond Nr. 1 Khayalat Al Shorta, as also outflows of the water of the Eocene formation outcrop along the Eastern bank of the Nile valley according to the main chemical composition of Pond Nr. 2 Ain Al Sira. A remediation of the present situation would most probably only be possible by restoring the pools to their original extent and maintaining the water level by controlled drainage of the groundwater overflow, by installing a drainage system for lowering the groundwater level with small pumping stations scattered throughout the area of high groundwater levels along the main streets in the direction of the Nile (which would possibly replace the disappeared historical channel system).

Keywords Water logging · Cairo ponds · Remediation of groundwater level · Origin and chemical composition of waters of Cairo ponds

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H. Idris is deceased

W. Balderer (✉) · F. Leuenberger
ETH Zurich, Zurich, Switzerland
e-mail: werner.balderer@erdw.ethz.ch

W. Balderer et al. (eds.), *Thermal and Mineral Waters*, Environmental Earth Sciences,
DOI: 10.1007/978-3-642-28824-1_2,

1 Introduction

Three old springs in the southeastern part at the border of Cairo City, named Ain Al Sira, Khayalat Al Shorta and Abo El Soud, used to be the origin of three lakes (see: Werwer et al. this volume).

Since the removal of one spring (Abo El Soud) about three decades ago by filling it with stones and recycled building material, an ongoing rise of the water level of the two remaining lakes or ponds has been observed. As indicated in Werwer et al. (this volume), the area of the two main ponds (Ain Al Sira and Khayalat Al Shorta) today occupies more than 100,000 m^2. The water surface rise of the two ponds is still continuing and actually even flooding nearby roads and cemeteries.

Before a remediation of this very ugly situation of overflowing lakes can be planned and carried out, the origin of this water inflow to these lakes by the springs involved (fed by groundwater) has to be identified. The aim of this study was to elucidate the origin of the water of these two remaining lakes/ponds, named Khayalat Al Shorta (Pond Nr. 1) and Ain Al Sira (Pond Nr. 2). Along with the observed increase in water level, the marked increase in salinity of these highly saline ponds must still be monitored.

Within this context the following possibilities of origin of the spring/lake water (according to the hydrogeological situation as described in Attia (1999) and Tahani (1979) will be further discussed based on the chemical composition of these waters.

By seepage from irrigation channels (water origin from Nile).

From the karstified carbonate aquifer system, assigned to the Eocene and to the Upper Cretaceous, which outcrops along the Nile system:

1. By upcoming of saline deep water of Nubian Sandstone, outcropping in the Western Desert;
2. By outflow of water from the outcropping fissured and weathered hard rock aquifer system, assigned to the Pre-Cambrian, outcrops in the Eastern Desert and the Sinai Peninsula;
3. By local groundwater aquifer in gravel to sandy sediments with a thickness of up to 60 m confined or semi-confined at the top by a thin layer of clay;
4. By uncontrolled sewage release from growing new settlements within this area of Cairo, which are infiltrating into the local groundwater;
5. A mixing of these possibilities of water origin.

2 Hydrogeological Situation

According to the geological map of Cairo by Tahani (1979) (Fig. 1), a connection of this local aquifer to the limestones, which are outcropping in the eastern part of Cairo, seems to be most probable. It may even be that local outflows to these two existing ponds occur in connection with the observed faults of East–West direction

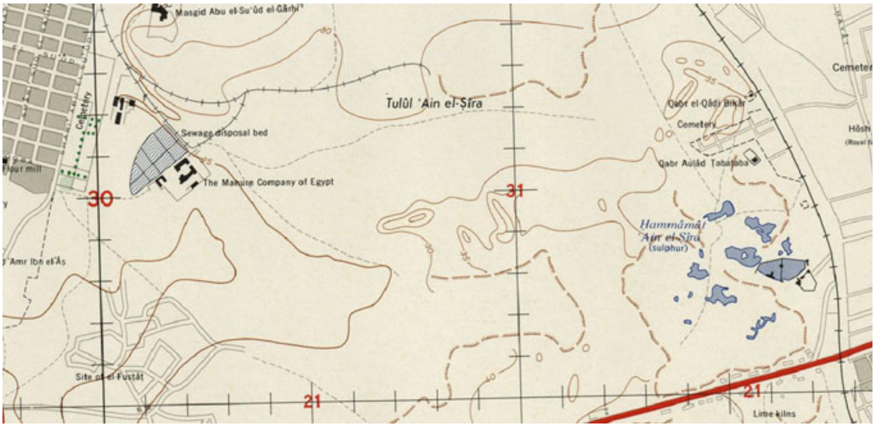

Fig. 1 Pond area in Cairo according to the Map 1:10,000 of the U.S. Army Map Service (1958): Cairo—South Cairo No. 1, Edition 4-AMS, Series P971

(Tahani 1979). However, this hydrogeological hypothesis must also be in agreement with the result of the chemical investigations to be accepted as a valid explanation.

3 History of the Ponds as Part of the Evolution of Cairo City

In the 16th to 18th centuries, canals and ponds outgoing from the Nile were systematically built, for irrigation purposes and as transport for ships. However, these networks of canals and related ponds fulfilled also twofold hydrological, mainly unknown, tasks: (i) first, as a tampering system in the Nile flood events; the network of canals and ponds were able to store temporarily the incoming flood water and in this way prevent the general flooding of Cairo City; (ii) secondly, during lower Nile water levels, it functioned as a drainage system by uptake of the outflow of groundwater and thus maintaining a sustainable groundwater level below the City of Cairo. After the construction of the Aswan High Dam in the 20th century (1970), these canals were no longer needed for irrigation and as storage capacity of the flood water. As a consequence of increased population growth, traffic development and intensified settlements, most of the canals and connected ponds were successively filled and used for road network extensions along former canals and for construction of new buildings above the filled ponds. If these canals, as man-made constructions, were situated above the groundwater level, their filling had no further consequences; the remaining water dried up by evaporation and by downward seepage to deeper soil horizons, as it was no longer fed by flooding Nile water.

However, some parts of the canals, and the ponds of Ain Al Sira, Khayalat Al Shorta and Abo El Soud which were now no longer connected to a canal system showed another contradictory behavior: As these ponds were filled up with dumping materials and one of them removed even completely from the landscape (Abo El Soud), the water was invading the basements of the constructed buildings as well as outflowing in other places.

4 Hydrogeological Explanation

The explanation of these observed phenomena is that these two remaining ponds are related to natural groundwater outflow, regulating its level like an overpressure valve.

4.1 The Hydrogeological Situation can be Traced Back in the Shorter History as Follows

- A view of the lakes in 1958, before the construction of the Aswan High Dam is shown on the topographical map 1:10,000 of the U.S. Army Map Service, 1958: Cairo—South Cairo No. 1, Edition 4-AMS, Series P971 (Fig. 1) where several open water bodies are documented in the area of the remaining ponds of Ain Al Sira and Khayalat Al Shorta.

  This map, also documents a sewage disposal bed (of the Manure Company of Egypt) situated only about 1 km west of the Ain el Sira pond area.

- In an initial study after the construction of the Aswan High Dam (finished in 1970) the effect of the rise of the groundwater level in the area of the city of Cairo was already observed and described by Youssef Tahani in 1979.
- The geological setting of the area of Cairo is presented in detail in Werwer et al. (this volume) as also in Tahani (1979) and Attia (1999).
- The main rock units, which according to Tahani (1979) (Fig. 2) outcrop in the closer area of Cairo, are: (i) the limestone unit assigned to Eocene and Upper Cretaceous (containing a karstified carbonate aquifer); (ii) covered by old sand dunes; these deposits are in their turn overlain near the eastern shore of the Nile river by; (iii) old gravel terraces; the central and lower areas of Cairo and the whole area towards the north are completely covered by; (iv) alluvium deposits, which are partly covered by; (v) the most recent flood sediments consisting of sand and gravel.

  These alluvium deposits underlying the whole area of Cairo City contain an aquifer in gravel to sandy sediments with a thickness of up to 60 m. As this aquifer is covered by a thin layer of clay it is characterized as a confined to semi-confined aquifer.

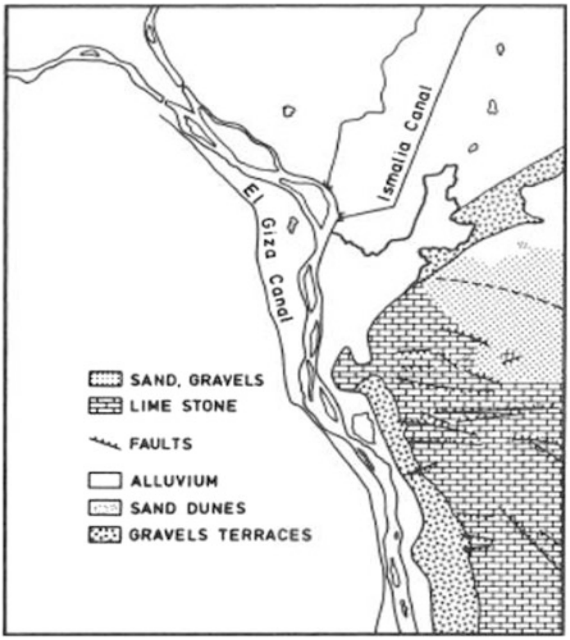

Fig. 2 Geological map of greater Cairo Region (Tahani 1979)

- According to the map of Tahani for the year 1979 (Fig. 3), the groundwater levels within the City of Cairo (situated on the Eastern bank of the river Nile) are in large parts (especially more distant from the River Nile) higher than the regulated Nile level of about 16.5–17 m a.s.l. (Fig. 4), if not situated in the areas of artificially lowered levels and influenced by nearby groundwater pumping stations.
- Therefore, the Nile can be considered as acting as a drainage level for the groundwater below Cairo City according to the map of groundwater levels in 1979 presented in Fig. 3.

5 Results and Interpretation of the Chemical Investigation of the Involved Water Sources

To test all the hypotheses of the origin of the water in the pond Nr. 1 and Nr. 2 in Cairo and to test possibilities of mixing to explain the present-day composition of the lake water the following water samples were analyzed:

- Low mineralized Nile water (origin also of water supply of Cairo municipality)
- Water of spring 1 and 2 in Helwan
- Original high saline groundwater (Sudr well and Hamam El Farun spring in Sinai), as potential end-member of the inferred mixing process
- Water of Alexander well in Baharia (from Nubian Sandstone, Western Dessert)

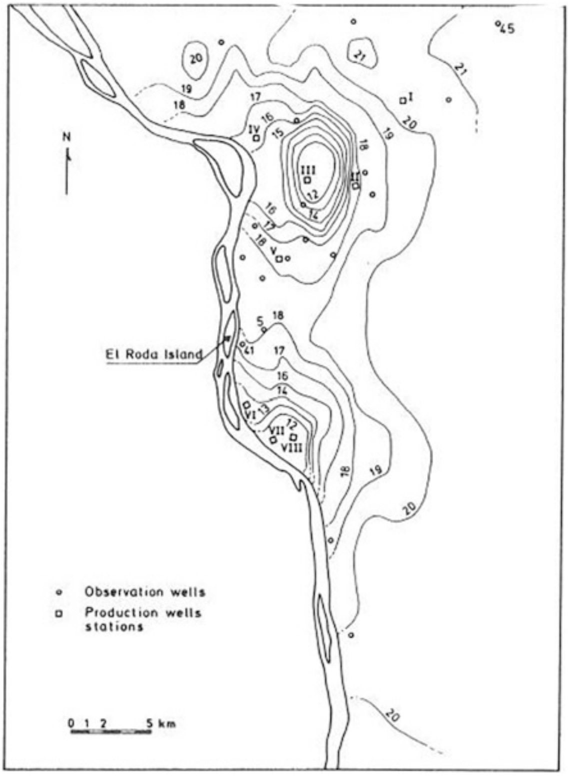

Fig. 3 Map of groundwater levels (water table) for the year 1979 according to Tahani (1979)

The results of anion and cation composition of the analyzed water samples (by Ion chromatography) are presented in Table 1.

6 Discussion of Origin of the Pond Waters 1 and 2 Based on the Chemical Composition of the Analyzed Water Samples by Means of Specific Diagrams

The resulting diagrams of main ionic composition are presented in Figs. 5 and 6 as Schoeller Diagrams (concentrations in meq/l). In addition to the analyzed water samples, the single available analyses of sewage water composition originating from Giza and Alexandria, as reported in Abdel-Ghaffar (1988) as well as a one water analyses from a well named M Nebwi NE 3, which is situated between Sudr and Hamam el Farun, as reported in Issar et al. (1971), were also introduced in the diagrams of the chemical composition for comparison.

Considering the individual groundwater composition curves in the Schoeller type diagram of Fig. 5, the following systematics can be derived:

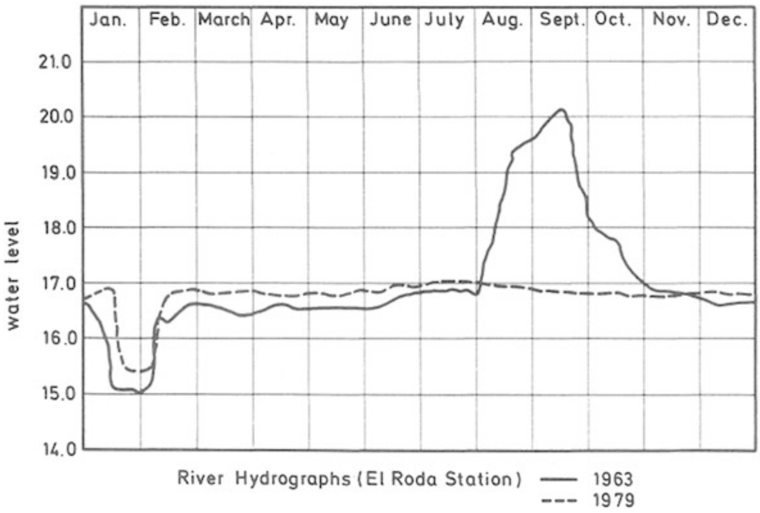

Fig. 4 Water level of Nile River (hydrograph) before 1963 and after operation of Aswan High Dam measured at El Roda Nile Island in 1979

- The waters of the Nile and the groundwater of the Alexander well of Baharia Oasis are much less mineralized than all other investigated waters.
- Considering individual ion concentrations and shape of the curves in Fig. 5, the water of Pond Nr. 2 matches quite closely the curves of Sudr well Nr. 20 of samples taken 28.5.2009 as well as 13.10.2009. A bit less concentrated, but nearly the same shape show the curves of the springs Helwan 1 and Helwan 2.
- Considering the two curves of Pond Nr. 1, which are almost similar, except some difference in the bicarbonate (alkalinity) concentration, they almost coincide with the curve of the historical water analyses of one sample of the M Nebwi NE 3 mentioned in Issar et al. (1971).
- The curves for the two samples of Hamam el Farun are situated in the Schoeller diagram in Fig. 5 between the curves of Pond Nr. 1 and Pond Nr. 2 and may therefore be considered as potential mixing components.

In the Schoeller type diagram of Fig. 6, a selection of analyzed water samples, as well as the uniquely available analytical results of sewage water composition originating from Giza and Alexandria, as reported in Abdel-Ghaffar (1988) are represented. According to this diagram the following relations are now appearing:

- The curve of the water of Pond Nr. 2 quite closely matches the curves of Sudr well Nr. 20 of samples of 13.10.2009 as already mentioned, and those of the sewage type water of Alexandria, as reported in Abdel-Ghaffar (1988).
- The two nearly identical curves of the two samples of Pond Nr. 1 pretty nearly coincide with the historical sample of the M Nebwi NE 3 well of 1971, which is characterized in Isaar et al. (1971) as Miocene formation water.

Table 1 Results of measurements and analyses of the investigated groundwater samples

Sampling date	Location	W. temp.	El. cond. (µS/cm)	pH	Cl (ppm)	NO_2 (ppm)	Br (ppm)	NO_3 (ppm)	SO_4 (ppm)	Na (ppm)	NH_4 (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Sr (ppm)
03.06.2009	P1, 1		74700	6.55	26956.00	37.00	33.00		5757.00	15893.89		635.00	1297.00	1425.00	53.03
15.1 0.2009	P1, 2	36	82700	6.36	31177.98		42.02		6920.42	19277.57		754.84	1560.62	1678.90	57.67
03.06.2009	P 2		11190	7.51	2446.00		0.00		3162.00	1570.00		487.00	240.00	790.00	16.12
03.06.2009	Nile		896	8.10	162.00		0.00		53.00	110.00		9.00	17.00	38.00	0.00
15.1 0.2009	Hel1	37	6260	7.29	1599.74		0.00	6.15	725.31	890.97		15.52	144.55	258.84	17.74
15.1 0.2009	Hel2	38	8270	7.06	1950.61		4.99		1441.95	1225.08	3.32	23.01	168.00	405.50	19.30
16.10.2009	Alex Baha	38	454	7.66	53.82		0.00		8.89	35.75	0.36	27.72	16.97	13.30	0.00
28.05.2009	Sudrl		11340	6.55	3404.00		27.00		624.00	1438.00		56.00	136.00	1009.00	13.82
28.05.2009	Far 1		24100	6.44	7676.00	19.00	50.00		714.00	3672.00		113.00	282.00	1127.00	18.79
13.10.2009	Sudr 2	87	11350	6.35	3526.72		26.92		658.67	1510.76		60.76	143.00	715.20	12.94
13.10.2009	Far 2	76	24900	6.20	8674.60		52.63		767.06	3990.63		120.68	304.39	1206.08	19.45

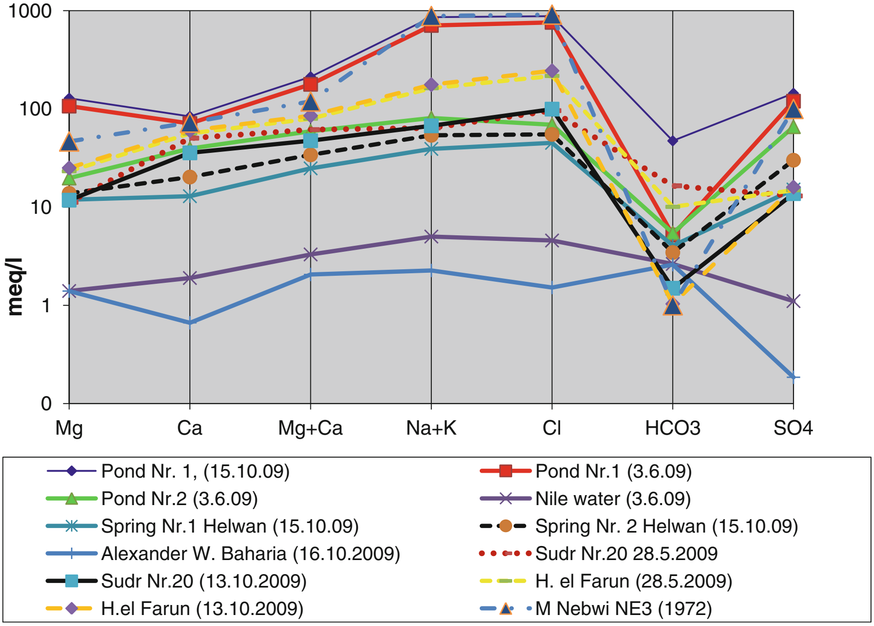

Fig. 5 Schoeller diagram of the investigated waters of Cairo and of the enlarged area for interpretation of origin of Cairo Ponds water

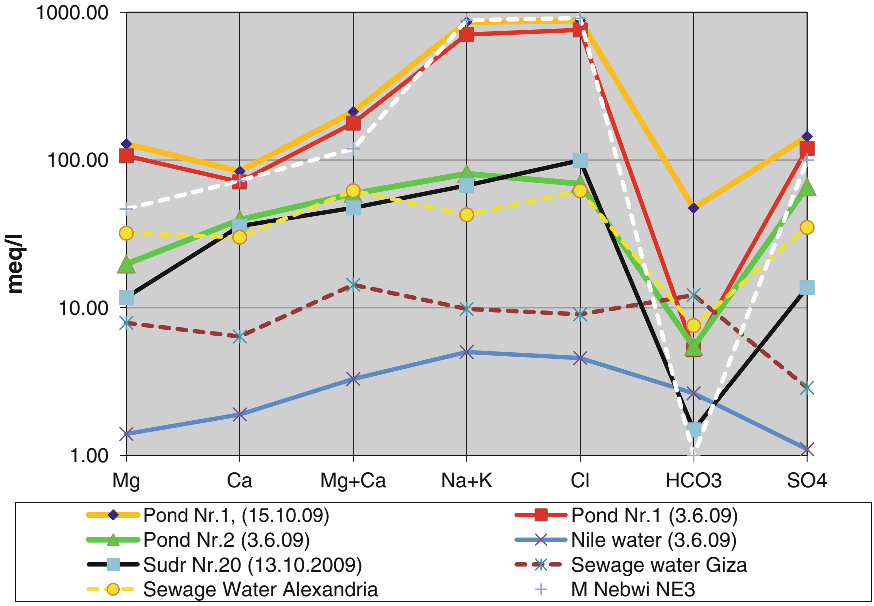

Fig. 6 Schoeller diagram of the investigated waters of Cairo and of enlarged area for interpretation of origin of Cairo Ponds water including analyses of sewage water from Giza and Alexandria (Abdel-Ghaffar 1988) and of the M Nebwi NE 3 well (Issar et al. 1971)

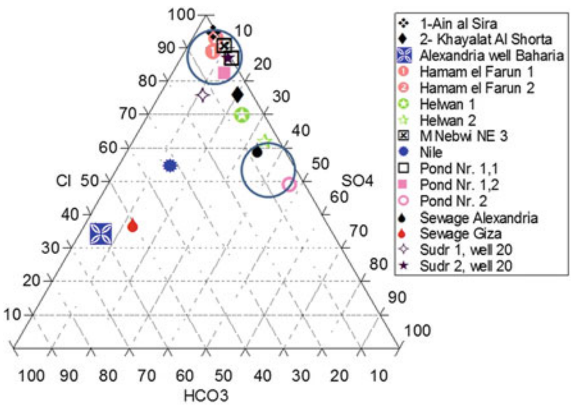

Fig. 7 Main anion composition of the investigated waters represented in a modified Piper diagram

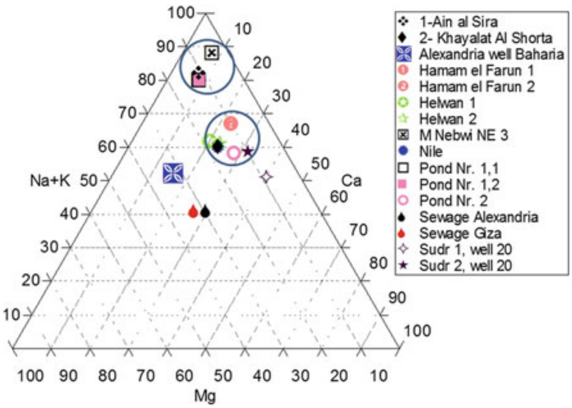

Fig. 8 Main cation composition of the investigated waters represented in a modified Piper diagram

In Figs. 7 and 8, the main ionic composition is represented in piper diagrams (with concentrations in meq % (of total sums of anions and cations). These diagrams of anions and cations include also the ionic compositions of the pond waters of Ain Al Sira (Pond Nr. 1) and Khayalat Al Shorta (Pond Nr. 2) as reported in Werwer et al. (this volume).

In these Piper diagrams of Figs. 7 and 8, the main anion and cation composition is reflected by their ion-equivalent rations (as meq %), where the sum of the main cations (Mg, Ca and Na + K), or anions are each equal to 100 %.

Based on these diagrams the following relationships with respect of the possible origin of the waters of the pond waters of Khayalat Al Shorta (Pond Nr. 1) and Ain Al Sira (Pond Nr. 2) can be stated:

- As in the process of evaporation, no change of the ion ratios occur (as long as no precipitation of dissolved species occurs); the respective position in the Piper diagrams of cations and anions will not change. If this aspect is considered, only points of waters situated at the same place (or very close to each other in the piper diagrams may be considered as potential starting waters for an evolution by evaporation only as would be the case for the higher concentrated waters of pond Nr. 1 and Pond Nr. 2.

- If also the concentrations of the main ions of water samples are very similar, which means that their respective lines nearly coincide in the Schoeller diagram, an almost identical evolution or even the same origin (within flow path) may be considered.
- Therefore, if the data of the investigated waters in the piper diagrams are considered, it results that none of the analyzed waters represent the original starting water for an evolution by only invoking a process of evaporation from the pond itself.

According to the piper diagram of the anions (Fig. 7) the following two clusters (in the circles) can be distinguished:

- One cluster contains the water samples of pond Nr. 1 (Khayalat Al Shorta) as also the water of Hamam El Farun (both samples) and water sample of October 2009 of Sudr well Nr. 20. Additionally, a water analysis from a well named M Nebwi NE 3, which is situated between Sudr and Hamam el Farun as reported in Issar et al. (1971), also fits well within this first cluster.
- The second cluster contains the water sample of October 2009 of Ain Al Sira (Pond Nr. 2), as also the water of Helwan spring 2 (near University) and sewage water of Alexandria.
- Between these two groups on nearly straight line the waters of Sudr well Nr. 20 (sample of May 2009), Helwan spring 1 (in Park Garden) as well as the anion ratios of Ain Al Sira (Pond Nr. 2, as reported in Werwer et al. this volume) are situated. Especially for the Pond Nr. 2 water composition, a mixing process between waters of cluster 1 and 2 may be considered.
- Outside of both clusters, and not grouped are situated the sewage water of Giza, the Nile water and the fresh groundwater of Nubian sandstone of Alexander spring at Baharia Oasis.

According to the piper diagram of cation concentrations (Fig. 8) also two clusters (in the circles) in the domain of sodium-rich waters can be distinguished:

- The main cluster contains the waters of Ain Al Sira (Pond Nr. 2, all analyses), Nile Water, Helwan spring 1 and 2, as well as Sudr well Nr. 20, sample of October 2009, as well as both samples of Haman El Farun.
- The sample of Sudr well Nr. 20 of May 2009 has the same ratio for magnesium as the abovementioned waters, but lower ratios of alkaline and calcium concentrations. It may be considered as diluted by nearby shallow groundwater.
- The groundwater of the Alexander well of Baharia oasis yields higher concentration ratios of magnesium but lower concentrations of calcium and magnesium.
- The two sewage waters yield nearly the same composition of cation concentration ratio of magnesium as the Baharia Oasis water, but lower concentrations

in alkaline and higher calcium concentrations. These sewage waters may therefore be considered as originating from local drinking water supply (of fresh water composition like the Alexander well water) with a contribution of calcium by washing agents.

- A second cluster contains the waters of pond Nr. 1 (Khayalat Al Shorta, all analyses) and one water analyses from a well named M Nebwi NE 3, which is situated between Sudr and Hamam el Farun as reported in Issar et al. (1971).
- This last observation is now very important, as for all three analyses of the water of pond Nr. 1 (Khayalat Al Shorta) and one water from a well named M Nebwi NE 3, a nearly perfect fit of their position in both Piper diagrams of Figs. 7 and 8, for anions and cations results. As the absolute concentrations are quite similar, the water of Pond Nr. 1 may therefore be considered as direct outflow (and originating) of the water of the type of M Nebwi NE 3, which was described by Issar et al. (1971) as Miocene formation waters.

7 Discussion of Origin of the Pond Waters 1 and 2 Based on the Chemical Composition of the Analyzed Water Samples Especially Based on the Resulting Chloride and Bromide Concentrations

According to Table 1 and Fig. 9 the Bromide concentration shows a dependency with the chloride concentration (logarithmic regression coefficient $R^2 = 0.5637$).

The resulting line of logarithmic regression shows a trend from the Nile water as lowest mineralized water on one end and the highest mineralized water of Pond Nr. 1 (sample of October 2009) on the other end. It may, therefore, be interpreted as the dilution line between two end-members. This means that the outflowing mineralized water of Pond Nr. 1 represents an outflow of deep-seated brine water along existing faults which is mixed with the water of the local gravel aquifer, and which, in turn, is influenced by Nile water and dispersed water of seepage losses of the local water supply.

Similar dilution relations are also revealed by the strontium versus chloride and strontium versus sulphate diagrams in Figs. 10 and 11. The corresponding linear regressions are even more confirmed by coefficients of $R^2 = 0.8697$ and of $R^2 = 0.8697$. In its relationship with respect to Bromide as well as to Strontium, the water of Pond Nr. 1 is confirmed as being the concentrated end-member, which is diluted, compared to all other considered waters.

That may invoke now also the hydraulic process of equilibrium between the water bodies/aquifers of different densities: if the level of the Nile River as the regional discharge system is lowered (decreased) but the hydraulic potential of the dense formation water is constant, the outflow of this deep water in the area of Pond Nr. 1 will increase. The loss of sewage water of the new unregulated settlements will further increase the groundwater level in the local gravel aquifer in

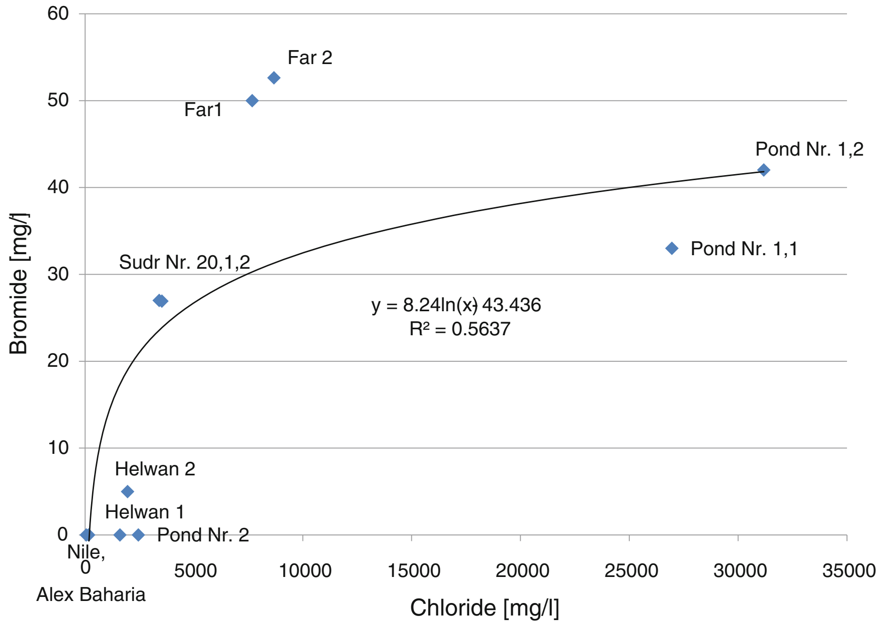

Fig. 9 Bromide versus chloride concentration (mg/l) of the investigated waters

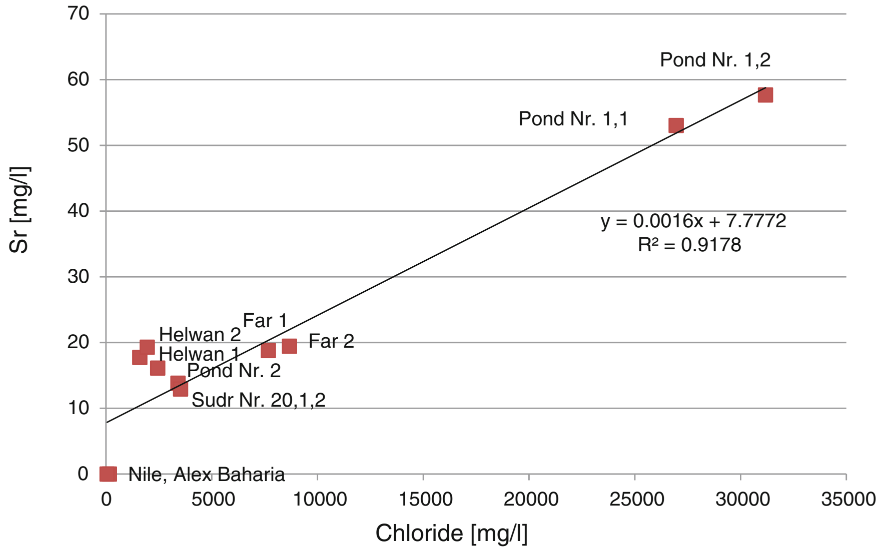

Fig. 10 Strontium versus chloride concentration (mg/l) of the investigated waters

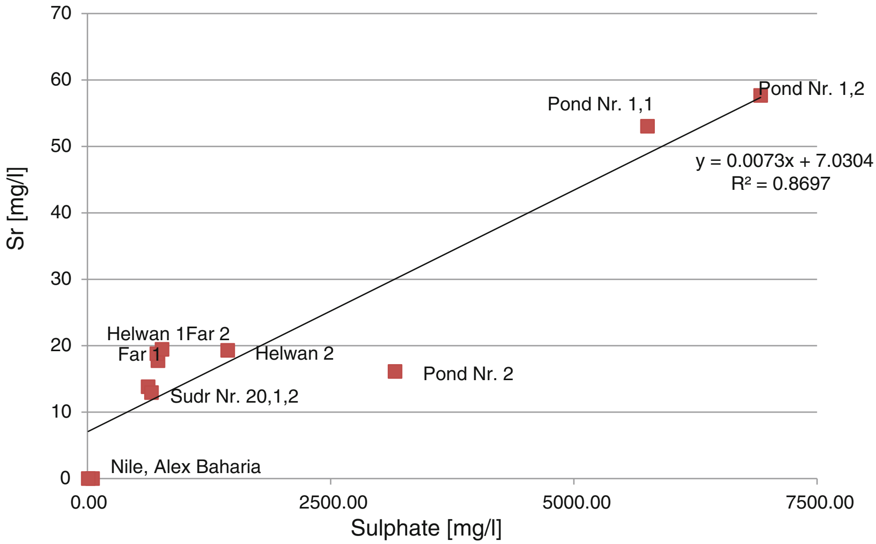

Fig. 11 Strontium versus sulphate concentration (mg/l) of the investigated waters

areas that are not drained anymore by canals connected to the Nile River as they are presently nonexistent.

8 Conclusions with Respect of the Hydrogeological Situation of the Pond Waters of Khayalat Al Shorta (Pond Nr. 1) and Ain Al Sira (Pond Nr. 2)

According to its chemical composition, the highly mineralized water of Pond Nr. 1 Khayalat Al Shorta can reasonably only be derived from outflowing water of the outcropping Tertiary rocks which probably would have a similar chemical composition as the water documented by the water well named M Nebwi NE 3, originating from Miocene formations.

- Concerning the water composition of Pond Nr. 2 Ain Al Sira, an anthropogenic influence of sewage water inflow cannot be ruled out; but the main contribution seems to be natural outflowing groundwater with a composition close to that of the Sudr well Nr. 20 water. This would also imply an outflow from the outcropping Eocene formation near the Nile valley. For both Ponds a flow direction from east to west seems to be most probable, which is also in agreement with the water level map of 1979 as presented by Youssef Tahani.
- The increase of the water level in and around Cairo city, especially on the eastern bank of the Nile already observed in 1979, is most probably due to the infilling of some channels (formerly connected to the Nile River) after the

established High Dam regime. The main effect was that the drainage by the open channels was diminished by their filling up with soils and other materials. This argument is in agreement with the modelled situation by Yossef Tahani. He expressed his findings by the following conclusions:

- To lower the groundwater table, four pumping stations were suggested, each having a steady pumping rate of 40,000 m^3/day.
- This suggested solution for lowering the groundwater table by adding some pumping stations to those already existing was proved by the simulated model to be unsuccessful in lowering the water table.
- The other suggestion of scattering small pumping stations in order to get a uniform sinking of the water table is only a theoretical idea of the author.

If the main problem is the general rise of the water table (groundwater level) in large parts of the city of Cairo, a remediation would only be possible by:

1. Restoring the pools in their original extent, maintaining the water level by controlled drainage of the groundwater overflow,
2. Installing a drainage system for lowering the groundwater table along the main streets in the direction to the Nile (which would possibly replace the disappeared channel system).

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http://www.springer.com/978-3-642-28823-4

Thermal and Mineral Waters
Origin, Properties and Applications
Balderer, W.; Porowski, A.; Idris, H.; LaMoreaux, J.W.
(Eds.)
2014, XV, 135 p. 85 illus., 49 illus. in color., Hardcover
ISBN: 978-3-642-28823-4