

EXTRACTION OF SALTS FROM LAKE QUAROUN, EGYPT: ENVIRONMENTAL AND ECONOMIC IMPACTS

A.A. DARDIR¹
A.M.A. WALI^{2,*}

¹General Manager of the Egyptian Salts
and Minerals Co. (EMISAL)

²Dept. Geology-Fac. Sci.-Cairo University
and EMISAL Consultant

Received: 19/08/08

Accepted: 30/12/08

*to whom all correspondence should be addressed:

e-mail: amawali52@hotmail.com

ABSTRACT

Lake Quaroun is situated north Fayoum Province, 112 km southwest of Cairo. Its water depth ranges from 1m to 8m and covers 215 km² in surface area. The drainage water coming from the cultivated land of Fayoum Province feeds the lake. History of Lake Quaroun witnesses several drastic changes affecting its role as economic potential site for living natural resources. The main reasons came from salinity gradient continuous rise formulating the main issue to extract economic salts. Continuous evaporation and absence of any fresh water supply caused its deterioration, shrinkage in area and rarity of its fish population.

Chemical analyses of the lake waters proved the presence of considerable amounts of sodium sulfate in addition to sodium chloride. Magnesium and other salts also present in appreciable quantities.

The lake area was declared a protected one by the prime ministerial decree No. 943 of 1989.

For salt extraction an area of 5 km² was cut from the lake and divided into 4 evaporation ponds. The lake water total dissolved solids, which is approximately 34 g l⁻¹, was concentrated in these ponds to about 340 g l⁻¹ by solar energy. The percentage of salts concentrated in pond 4 brine is as follows: 1. Sodium Sulfate (12% of the TDS) 2. Sodium Chloride (68% of the TDS) 3. Magnesium Salts (16% of the TDS) and 4. Others (4% of the TDS).

The brine of pond 4 is pumped to the sodium sulfate plant, where it is cooled down to -1°C in stages. At this temperature sodium sulfate decahydrate (Glauber's salt) crystallizes out. It is then separated from mother liquor by a centrifuge. The other salts remain in solution. To economize energy consumption this cold liquor is used to cool the new incoming brine down to ambient temperature.

The design capacity of the sodium sulfate plant amounts to 100 thousand tons per year. By the end of year 2001 exceeded 700 000 t, consumed mainly in detergent industry. Liquor coming out of the sodium sulfate plant, is left to dry leaving behind residual liquid the bittern, rich in magnesium salts.

Harvested and accumulated dry raw salts reached more than 500000 t. This raw salt is the feed for the sodium chloride plant, where it is purified in the sodium chloride plant of 20 t h⁻¹ capacities. The bittern is mainly of magnesium salts. The most important and more feasible salt of which is magnesium sulfate. A feasibility study is prepared to produce 27000 t y⁻¹ of magnesium sulfate out of this bittern is envisaged.

This amount of extracted salts has a great effect in reducing the salinity of the Lake water, which shows a positive effect on the lake environment, yet the lake is still endangered and is subject to lose its function as a drainage reservoir as sand dunes and wind blown sands attack the lake from north and northwest, causing its continuous shallowness and shrink from both sides. Also the drainage water reaching the lake becoming more turbid and the turbidities usually settles nearest southern coast, causing shallowness of the lake in the vicinity and further inside. The increase of algae, organic matter and plankton is also noticed.

Efforts should be directed to keep the lake function as a drainage reservoir, a fishery and also as a touristic place.

KEYWORDS: salinity increase - water composition - EMISAL-sodium sulfate - sodium chloride - Mg salts

INTRODUCTION AND SCOPE

Lake Quaroun (Figure 1, A and B) represents efficient part of Egyptian history, where its potential economic resources were based on the fact of its fertile land for cultivation and fish resources. Last two centuries witnessed deterioration events raised by damming and bridges over the Nile course hindering excess floodwaters from reaching the depression through Yossef canal as described by Beadnell (1905). The main results appear in raising the salinity in Quaroun Lake water during the 18th century (Said, 1981). The raising rate witnesses few turns since then (10.5 g l⁻¹ in 1906 till 35.3 g l⁻¹ by 1976), but the outcome by the beginning of the 19th century focused first on the bio-diversity changes in the fish population. This result changing the aqua population into marine ones by 1928 to adapt the continuous rise in salinity till it matches the seawater salinity 33 ± 2 g l⁻¹ (Figure 2) and since then biodiversity in fish population and types had started (El-Shabrawy, 2002). The anticipated view summaries the pessimistic view (Figure 2), which urged scientist to interfere and to propose way outs taking into consideration the environmental balances between living and non-living natural resources. This fact was exaggerated due to the fact that Lake water level was 70 m a.s.l. (Above sea level) and dropped to -43.80 m b.s.l. (Below sea level) according to the study carried out by Fayioum water management project (FWMP, 1999; 2000). Consequently, stabilizing the lake water level at -43.8 m b.s.l. $\pm$ 0.6 m is another challenge to limit salinity rise. Ministry irrigation and water resources in collaboration with Ministry of agriculture approved adding agricultural wastewaters into the lake as to stabilize its level and to control its salinity gradient rise.

During the seventies, trials to estimate the economic beneficiation of salt extraction as a clue to re-balance and/or turn back the situation in the Quaroun Lake into norm was the target heading to re-directing thoughts for a better sustainable development of the area as a whole. Implementation to extract salt was a convincing concept by Ministry of Industry; hence studies were devoted to El Nasr Saline Co. (ENSCO) to carry out the project. ENSCO started in collaboration with the British White young and Partners-consulting Engineers (WYP) by 1976 and their final study reached its goal (1992), where DSS engineers INC Coopers and Lybrand CRS International final report was approved. The feasibility study indicates possible economic extraction of Na₂SO₄, NaCl and Mg salts from Lake Quaroun water. The three products proved to be of ultimate need to replace imports and to satisfy local domestic and industrial market.

SALT EXTRACTION AND REACHED GOALS

Since the execution of the approved feasibility study, the Egyptian Salts and Minerals Co. (EMISAL) was the founder of this step as industrial complex site (Figure 1C) with three main targets, these are:

1. Extraction of economic salts from Lake Quaroun water to control salinity rise.
2. Establishing industrial base in Fayioum region with expertise in salt industry.
3. Increasing economic income through replacing imported product and to satisfy local market with possibility for export.

The Egyptian Salts and Minerals Co. started production by October 1992 (Dardir, 2000; 2002a) with a designed capacity of 100000 tones per year of high quality anhydrous sodium sulfate (Table 1). Infrastructure of the site required 3 years of continuous work to cut-off the design area (Batnet Aboksa, Figure 1B) in order to subdivide part of the into four evaporation ponds with a dyke separating the battery limit from Lake Quaroun. Lake water are pumped to the evaporation ponds (ponds 1- 4, Figure 1C), where concentration reaches 340 g l⁻¹ in average as to suite the crystallization of glauber salt by cooling and then drying-up will led to anhydrous sodium sulfate product.

Table 1. Specifications of anhydrous sodium sulfate

A) Chemical Composition (On dry basis)

1. Na_2SO_4	99.00	% wt/wt min.
2. Chloride as Cl^-	0.50	% wt/wt max.
3. Other soluble salts	0.50	% wt/wt max.
4. Iron (as Fe)	0.003	% wt/wt max.
5. Moisture	0.20	% wt/wt max.
6. pH (1% solution)	7.0 ± 0.5	

B) Physical Properties:

1. Bulk density:	1.3 ± 0.1	g cm^{-3}
2. Degree of color:	80	% of MgO
3. Form:	white crystalline and free flowing	
4. Sieve analysis:		
Passing 9 mesh (2000 micron)	100	% wt
> 20 mesh (800 micron)	2	% wt max
> 60 mesh (250 micron)	70	% wt max
60-250 mesh (250 – 63 micron)	65	% wt max
< 250 mesh (63 micron)	20	% wt max

(Chemical Analysis according to ISO 3237 & 3241)

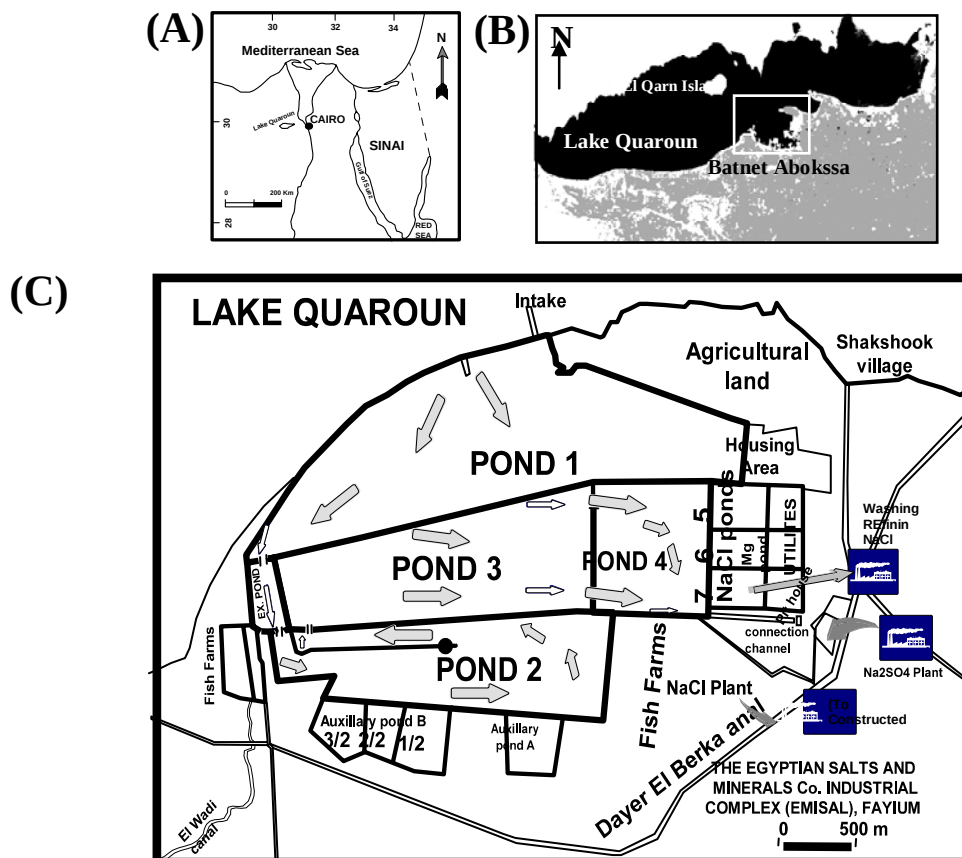


Figure 1. Location map of Lake Quaroun. A and B=location maps showing Lake Quaroun and EMISAL site. C=EMISAL site with concentration ponds

Modifications was a target by company expertise, which led to improving brine qualifications and production reached $108\,000\text{ t y}^{-1}$ by 1996. The effluent brine from Na_2SO_4 plant is pumped to storage auxiliary ponds till dryness formulating the raw material for refining and purification in the NaCl plant (Table 2). Till the present year (2002) accumulated raw salt reaches 500000 tones formulating feed stock consumption within 20 to 30 years. The

remaining residual brine after harvesting raw NaCl salt constitute the raw brine feed stock for the third $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ plant of a capacity of 27 500 t y^{-1} of magnesium sulfate with additional 5000 KCl (starting production by 2003-2004). Additional minor but valuable products including B and Br compounds represent the finalization step of industrial extraction of Lake Quaroun salts.

Since implementation of EMISAL as a project in 1984, effective goals were reached concerning Lake Quaroun salinity control. These are:

1. Pumping of 240 million m^3 from Lake Quaroun waters to be evaporated by solar energy in the concentration ponds.
2. About 7 million tones as salt were extracted including 3 million tones permanently stored in the evaporation ponds.
 - A. 700 000 t of sodium sulfate were extracted and marketed.
 - B. 500 000 t of raw NaCl dry salt for washing and refining NaCl plant.
 - C. 1.5 million tones of raw NaCl salt in various stages of dryness.
 - D. 100 000 t of pure NaCl for domestic and industrial grade were marketed.
 - E. 100 000 m^3 of residual brine accumulated as a raw for $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ plant.
 - F. Industrial base foundation with trainee and expertise in salt industry field.

Table 2. Mother Liquor Composition (Effluent of Na_2SO_4 Plant)

Items	Unit	Specifications
Sp.Gr.	g cm^{-3}	1.183
T.D.S.	g l^{-1}	277.470
CO_3^{--}	g l^{-1}	0.347
HCO_3^-	g l^{-1}	0.527
SO_4^{--}	g l^{-1}	22.404
Cl^-	g l^{-1}	148.797
Ca^{++}	g l^{-1}	0.228
Mg^{++}	g l^{-1}	13.508
Na^+	g l^{-1}	81.768
Others	g l^{-1}	9.892

The previously mentioned amounts formulate effective parameter as to control salinity increase of Lake Quaroun water. The salinity at the year 2010 was estimated to reach 40 g l^{-1} . The recorded measures indicate lowering of average salinity measures during the last 5 years to reach 34-35.5 g l^{-1} meaning a lowering of 4-5 g l^{-1} than the previously estimated measures (Figure 2). This result was reached through direct cooperation between the Ministry of Water Resources and Irrigation and the company (EMISAL).

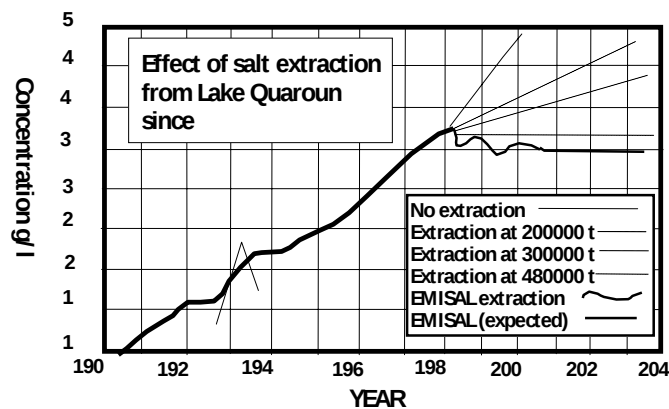


Figure 2. Salinity values with respect to time

ANTICIPATED HAZARDOUS

History of Lake Quaroun and its developing stages till today had caused certain parameters to develop and their developing directions imply proper understanding of these anticipated hazardous. The main active three parameters are:

1. Silting the lake bottom

Many plans were executed as to maintain Lake Quaroun level at -43.5 m (b.s.l.). The main success was considering Lake Quaroun as a receiver for the agricultural drainage waters in order to re-balance the evaporation rate. Moreover, the applied procedure aims to control the quantity of the drainage water reaching the lake. The obtained results during the last ten years witnesses the effectiveness of this procedure, except for the carried out amounts of silt and clay particles poured into the lake.

Figure 3 is a TM map showing the silting effect on raising the bottom of the lake, particularly in the eastern and northeastern sides, due to wind action effect on the poured out water containing silt and clay particles (Figure 3, white arrows). Lake Quaroun bathymetry in its deepest point reaches 12 m with an average depth of 7 m. The flanks are the shallowest parts; hence the importance of shallowing up the bottom appears to be critical one. This type of anticipated hazard could lead to indirectly increasing salinity of the lake water as evaporation rate will increase. The anticipated value of lake water salinity is the sum of the original water salinity, in addition to two other components as increasing rate of evaporation and added saline component within the agricultural wastewaters. The addition of silt and clay will continue due to these two reasons particularly the eastern and northeastern parts of the lake.

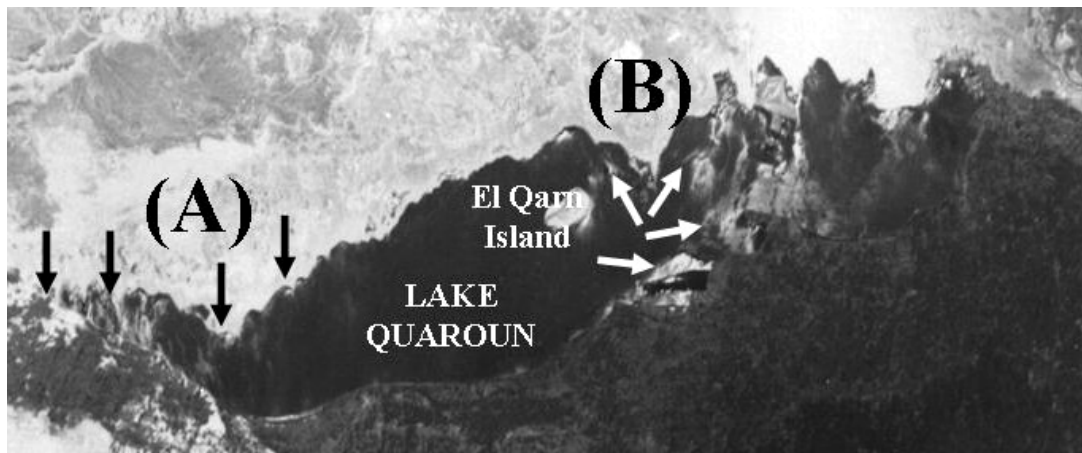


Figure 3. TM image map (Spot 1995) of Lake Quaroun. White arrows point to silt and clay accumulations leading to shallowing up of the bottom of the lake. Black arrows point to direction of the migrated sand dunes. (A) and (B) points to the proposed salt extraction sites

2. Dune movement

Historically the size and dimensions of Lake Quaroun was extremely larger than its size and dimensions today. A scientific link between increasing salinity and dune migration is a positive one, while its effect was a target of recent work of Wali (2002 and Wali *et al.* (2000), where anticipated hazards of dune migration can lead to lake desiccation and disappearance in the future. As salinity increases, the atmospheric pressure will increase, leading to predominance of different direction of wind stream (from N and NW) that enables wind-blown sand to move towards the shallow areas causing its shallowness, engulfing and sabkha formation). Sabkhas will cause recycling of the atmospheric pressure difference and consequent anticipation of repeated process will go on, but with more severe action. Figures 3 and 4 are TM images since 1995, where in Figure 3, migrating dunes directions are seen as black arrows, particularly in the western shallow parts, where dune advancement is fast. Figure 4 is another TM image showing the northern and northeastern parts of the lake, where white arrows point to dune advancement and the black arrows point to shallow sabkha sites.

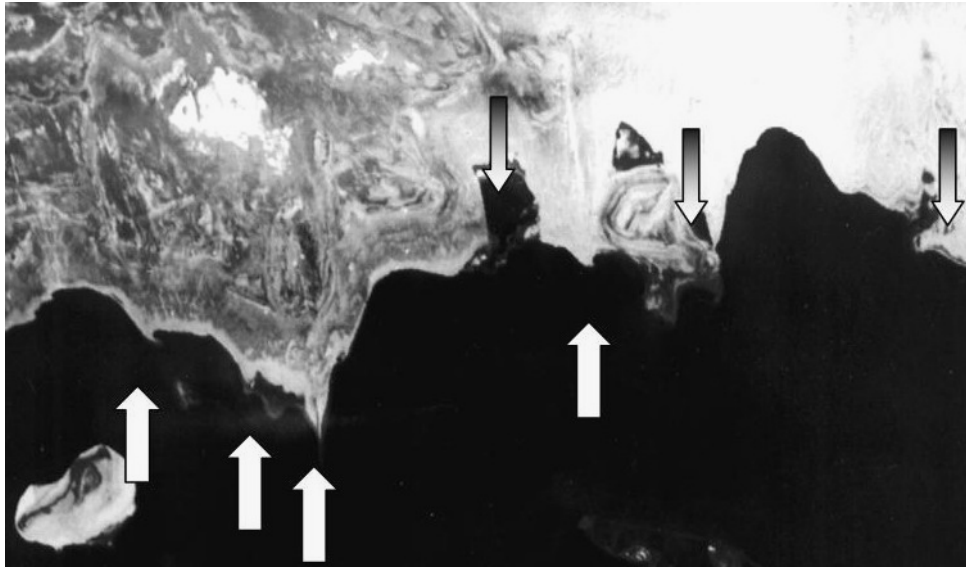


Figure 4. TM image (Spot 1995) showing the direction of migrated dunes (white arrows) and the formed sabkha sites (black arrows)

3. Lake water composition

Lake Quaroun waters witnessed drastic changes in total salt content in the last decades and the lake turns into saline one. In 1998 a survey of the water budget in the lake was estimated as 859 Million m^3 in comparison to 1.2 billion m^3 ten years ago. This volume comprises about 3.4 thousand kilotons of salts (as T.D.S.) equivalent to 0.36 g l^{-1} per year. The estimated leftover amounts of salts after EMISAL extracted amounts indicate a remaining salt budget exceeding 900 000 t of salts.

The executed programs of the Ministry of Water Resources and Irrigation aim to stabilize the lake level at -43.8 m . Addition of agricultural wastewaters should rebalance the evaporated waters. Consequently the added wastewaters had changed the chemistry of lake water composition as shown from Table 3, the documented water composition was that of White young and Partners-consulting Engineers (WYP) (1992) and the latest is based on the FWMP (2000). The obtained difference in water chemistry of the lake indicates the increase of certain elements as K, B, Br, which were not detected before. This means that the addition of agricultural drainage waters supply can change lake water chemistry even if the rate is too slow. Recent researches indicating an increase also in organic content of Lake Quaroun waters. This is evidenced in the concentration ponds (Figure 1C). The organics have different effects on the pH, solubility products and on biomineralization process, which urged for more attention to be paid for understanding and optimizing their effects.

Table 3. Average Analysis of Lake Quaroun Years 1992 and 2000

Item	Unit	1992	2000
Sp.Gr.	g cm^{-3}	1.023	1.026
T.D.S.	g l^{-1}	32.748	35.952
CO_3^{2-}	g l^{-1}	0.052	0.027
HCO_3^-	g l^{-1}	0.137	0.32
SO_4^{2-}	g l^{-1}	8.081	9.454
Cl^-	g l^{-1}	12.29	13.228
Ca^{++}	g l^{-1}	0.52	0.491
Mg^{++}	g l^{-1}	1.204	1.293
Na^+	g l^{-1}	8.894	10.049
K^+	g l^{-1}	0.26	0.3
Others	g l^{-1}	1.31	0.79

DEVELOPING LAKE QUAROUN AS A PROTECTED AREA

Protected areas are a demonstrative sign of modernized and civilized countries. The fact that it represents conservation of Egyptian heritage in different fields of culture, art, etc. Lake Quaroun witnesses civilized part of the Egyptian history because of its topographic position as a part of the Fayioum depression. The fertile loam coming with the flood waters causes its suitability for cultivation with the associated living natural resources formulates the area to act as center for dense population and consequently it is among historical heritage of Western Desert of Egypt. Since then, monuments and archeological sites indicate its importance, particularly during Roman times.

In order to develop Lake Quaroun as a protected area, the following parameters should be fulfilled:

1. Newer salt extraction sites

The accumulated salt budget reaching Lake Quaroun annually amounts to 700 000 t starting from the year 2002. The annual increase in salt budget will rise the same amount to reach in 2006 a total of 3500 000 t, taking into consideration The Egyptian salt and Minerals Co. will extract 300 000 t y^{-1} (Dardir, 2002a). Consequently, newer salt extractions sites are recommended as to balance the increasing rate of add salts to the lake waters through the incoming annual agricultural wastewaters. A proposed two newer sites in Figure 3 having the symbols "A" and "B" are proposed.

2. Dredging shallow areas

Accumulated silt and clay particles in front of the collective drainage terminals and the pumping stations reaching the lake of agricultural waters into Lake Quaroun are forming growing up small delta causing shallowing up of the northern, northeastern and western parts of the lake. In order to overcome this problem a continuous dredging of the accumulated sediments should be run. Continuous dredging will deepen the depth increasing the lake water depth, better dynamic flow and better aeration of water column.

3. Construction of green fences

The northern cliff should be fenced with green trees as to hinder the migrated rate of the sand dunes coming from the north and northwest directions. This process represents a preliminary step among successive green belts should occupy the high plateau of Qatrani mountain. The weathered bedrock of the area is a rich and fertile one, which encourages plantation of high and dense tree types.

EMISAL EFFORTS FOR SUSTAINABLE DEVELOPMENT

The Egyptian Salts and Minerals Co. (EMISAL) were founded as an environmental project with aim of extracting salts from the lake to minimize the annually added quantities. This aim will control events that would cause environmental hazardous (Dardir, 2002b). Raising rate of salinity will turn the lake into second example as the Dead Sea, but the effect will farther threaten the social and welfare of the long lasting jobs as fishermen (about 10 000 in number).

The Egyptian Salts and Minerals Co. (EMISAL) since starting production had added valuable scores to both environment and economic, these are:

1. Annual pumping of ~ 15 million m^3 from Lake Water since 1992 till now constituting a total of 150 million m^3 . This figure is of average salinity about 34 g l^{-1} will represent effective tool towards decreasing the rate of increasing salinity. Consequently, part of the policy adopted by Ministry of Water Resources and Irrigation in a direct cooperation with the company as to control raising rate of salinity.
2. The extracted salts value helped government to save 330 m. L.E. representing the value of the produced Na_2SO_4 instead of importing. Production of sodium chloride and magnesium sulfate will double the number in the future.
3. Improving the social well fare of the people in the area, where 600 workers of different technical degrees represent employees in the company and most of them belong to the area and the nearby ones. This concept did add another component of important value, which is improving the culture level of the area.

Lake Quaroun requires continuous monitoring as to predict and to control the migrating dune and adjust the lake water composition "organic content-type of added salts-bathymetry of the lake". These parameters will offer safe preservation and protection of one of the oldest lake all over the world since its historical heritage and natural resources should be under sustainable development programs in order to maintain its continuous development.

REFERENCES

- Beadnell H.J.L., (1905), Contribution to the geography of Egypt. Egypt. Survey Dept. pp. 308.
- Dardir A., (2000), Salt extraction from Lake Qaroun, Egypt as means to improve environment. 8th *Worlds Salt Symp.*, R. E. Geertman (ed.). Elsevier, 2: pp. 1297-1302.
- Dardir A., (2002a), Improving environment of Lake Quaroun from economic views. Seminar on "Developing Lake Quaroun by the beginning of the 3rd millennium". Organized by The National Institute of Fishery and EMISAL, March 2002. pp. 42-51. (in Arabic).
- Dardir A., (2002b), Salt production from Lake Quaroun as environmental project. Seminar on modern treatment of pollution resulted from mining and industry, Morocco, October 8th-10th 2002. Abstract (In Arabic).
- El-Shabrawy M., (2002), Biodiversity of (planktons-bottom dwellers-fish) in Lake Quaroun and its relation with fish production. Seminar on "Developing Lake Quaroun by the beginning of the 3rd millennium". Organized by The National Institute of Fishery and EMISAL, March 2002. pp. 16-26. (in Arabic).
- Fayioum Water Management Project (FWMP), 1999, Salinisation monitoring of Lake Qarun between 1901 and 1998. ARCADIS Euroconsult, Arnhem, The Netherlands and Darwish Consulting Engineers, Cairo. pp.16.
- Fayioum Water Management Project (FWMP), 2000, Water management in Fayioum. ARCADIS euroconsult, Arnhen, The Netherlands in co-operation with Darwish Consulting Engineers, Cairo. pp. 24.
- Said R., (1981), The geological evolution of the River Nile. Springer-Verlag. Berlin. pp 320.
- White Young Partners-consulting Engineers (1992), Exploitation of salts from Lake Quarun, 2 (reports and miscellaneous data, part 3 Of 3), DSS previous report to El Nasr Salines Co. final report (1979).81 pp.
- Wali A.M.A., (2002), The phenomenon of Lake disappearance: causes and effects. Seminar on "Developing Lake Quaroun by the beginning of the 3rd millennium". Organized by The National Institute of Fishery and EMISAL, March 2002. pp. 52-55. (In Arabic).
- Wali A.M.A., El-Asmar H. and Assal E.M., (2000), Interrelation between coastal sabkha belts and dune migration (rate and trend): bearing on developing N.Sinai, Egypt. 8th *Worlds Salt Sym.*, R. E. Geertman (ed.). Elsevier, 2: pp. 1237-1238.