Preventing An Ecological Disaster- The Saving Of Lake Qarun

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Introduction

Lake Qarun, situated in Egypt, is presently a salt water lake situated about 90 km south west of Cairo in Egypt. Fig 1. Soliman(1989) describes it as confined to latitudes 29^o 24'39" N and 29^o 32' 38" N and longitude 30^o 27' E to 30^o 44' 38" E. The maximum depth of lake is 8.5 meters to the west of El-Qarn Island and the eastern part is shallower with depth of about 3 meters. Fig 1. It has played an important role in the history of Egypt will be evident from the following.

Fig 1 . Location of lake Qarun

Lake Qarun, the present day remnant of the ancient Lake Moeris and the Al-Fayoum depression continues to draw attention, as it has done over thousands of years indicating its importance to Egypt.

In the history of dams and the story of civilisations, the first dams were built in Egypt and Iraq around 3000 BC where they controlled canals and irrigation works. The history of dams followed closely the rise and fall of civilisations, especially where these depended on the development of the water resources.

For centuries, the prosperity of Egypt relied on the annual flood of the Nile River from July to September and the irrigation systems. One of the most enormous efforts of the Egyptian Kings was the creation of the Lake Moeris in the Al-Fayoum depression and the construction of a 16 km long canal connecting the Lake to the Nile. The Lake was used to regulate the Nile river and as a water reservoir for irrigation purposes. There are suggestions that there were in fact two lakes, Schnitter (1994) In any case, Willcocks (1919) and Hathaway (1958) provided a lot of evidence supporting the existence of Lake Moeris.

The connection between the river and the depression was a natural cut in the mountains. It was in existence at the time of the King Menes, founder of the 1st Egyptian dynasty (2900 BC). At that time, the Al-Fayoum depression contained only a natural lake filled from the Nile during large floods.

BC 2300 King Amenembat (12th dynasty) widened and deepened the canal between the Nile and the Fayum depression. He converted the existing lake into an artificial reservoir that controlled the highest flood of the Nile.

BC 230 Abandonment of Lake Moeris - primarily due to the fact that the Lahoun branch of the Nile dwindled in size and reduced the use of the reservoir, the area inundated by Lake Moeris became the Governorate of Fayoum as it is today.

Lake Qarun as it is known now has shrunk in size and is presently nearly – 44 meters below sea level. It plays an important part in the agriculture and ecology of Fayoum region as it receives the drainage water from the irrigation canals. It is land locked and does not have any outlet. It was noticed in the studies done as early as 1930's that the Lake was turning into a salt water lake from a fresh water lake. As result of more intensive cultivation and irrigation the situation has been aggravated and it was predicted that if action is not taken it will become a dead lake.

When a fresh water lake starts turning gradually saline most of the fresh water flora and fauna die some adapt and survive for some time until the salinity increases beyond their ability to adapt and these also disappear. The surrounding flora also starts disappearing until the whole area is dead. Thus an ecological disaster happens and entire area becomes inhabitable for nature as well as men. The salinity of Lake Qarun rose from 3.5 gms/liter in 1890's to 26 gms/liter in 1950, and was predicted that it would reach almost 50 gms/liter by 2005-2010.

Nile water irrigation is the life blood of Al-Fayoum region and over the years it has intensified with the reuse of drainage water. One of the reasons for increasing salinity is the increase in the total dissolved solids of the drain water over many years.

A salt and water balance can be established by knowing the rate of addition of salts and water, the total evaporation, and the changes in levels with the surplus or deficit volume and the analysis of TDS.

Water and salt addition

Most of the drainage water reaches the lake through two main drains, El-Wadi drain near the mid-point of southern shore and El-Bats drain at the north-eastern end. The remaining drainage water reaches by number of small drains. In the 1980's the annual drainage was 350 x10^6 $M^{3.}$ Abd Ellah (1999) has indicated water flow of 381x10^6 M^3.

Egyptian National Committee on Irrigation and Drainage (ENCID) mentions sources from Ministry of Public Works and Water Resources (MPWWR) that 650x10^6 M^3/year water is drained from the irrigated land in the Al-Fayoum region. In a report to the Ministry of Environment, Prof. M. El Raey indicates a drainage flow rate of approx 450 x10^6 M^3/year into Lake Qarun. Table1 shows the total quantity of drainage water reaching the lake and its total dissolved solids.

Year	Average TDS mg/liter	Total flow x 10^6 M3/year
1990	1890	495
1995	1890	380
1997	2200	488
1998	2260	453

Table 1. Drainage water reaching Lake Qarun and total dissolved salts period 1990 - 1998.

It will be seen that it shows a surplus of approx. 200x 10^6 M^3/year. Abd Ellah (1999) has indicated a drainage of 221.4 x 10^6 M^3/year is diverted from the El-Wadi drain to Wadi El-Rayan another man made lake. Thus it could be said that the surplus is diverted to Wadi El-Rayan.

Area and Volume of Lake

The area of lake was measured from satellite photo, August 2003, Fig.2 and it gave area of 241.3 Sq. km. and a length of 41 km.

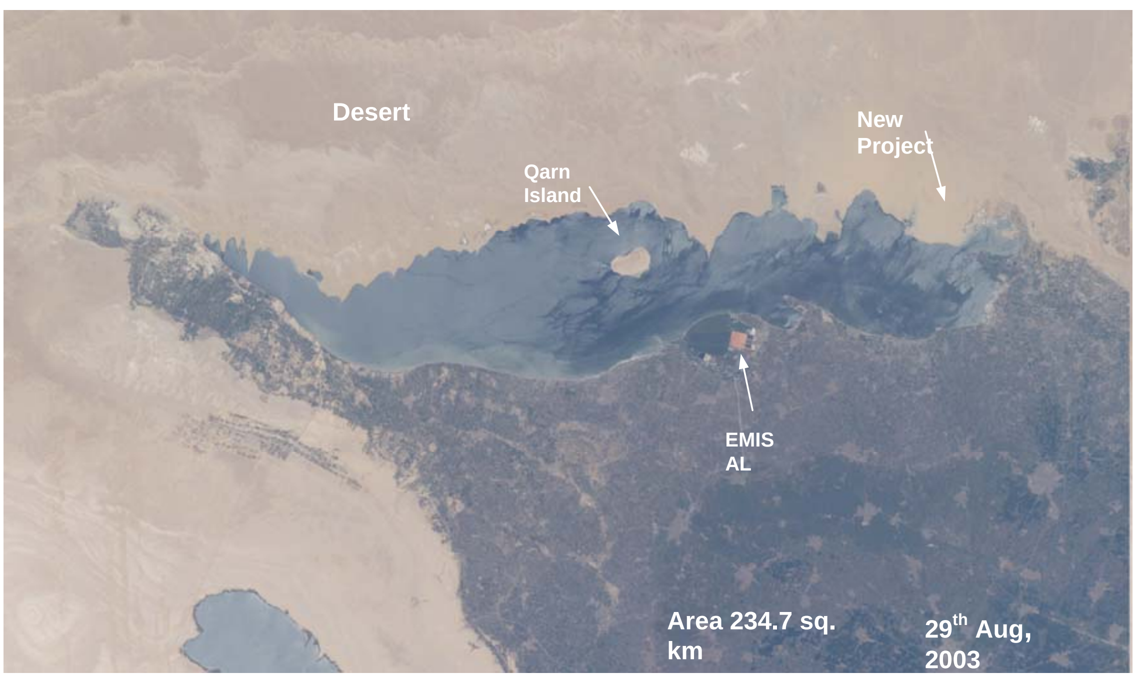

Fig 2 Lake Qarun indicating EMISAL site and location of new project

Ball (1939) established to empirical formulae for the calculation of area of the lake and its volume,

$A=166 + 24(47-L)$

$V=422 + 166(47-L) + 12(47- L)^2$

Where A is area in sq. km and V is volume in 10^6 M^3

If the volume was to go to zero then per the formula L= -53.92 meters, indicating depth of 9.92 meters at a datum of -44. The max. depth mentioned by Abdel-Malek and Fouda (1990) is 8.7 meters. Soliman mentions depth of 8.4 meters.

Use of this formula for level of -42.95 gives area value of 263.2 sq. km. an error of +8.1% and the volume is 1291.1 x 10^6 M^3 an error of +39.7%. As per the recent study the average depth at -42.95 is 3.8 meters whereas the data of Ball indicates an average depth at the same level as 4.905 meters.

The above empirical formulae have been reworked based on present observations and are given below

$A=194.5 + 26.557(45.07-L)$

$V=695 + 194.5(45.07-L) + 13.6(45.07- L)^2$

In these equations the volume and area will be nil for a depth of 8.394 meters.

It should be noted that the lake area fluctuates year round due to changes in evaporation rates with the weather conditions and the drainage input to the lake. M.Khalil (1990) indicated that for the years 1969-89 the mean level of the lake was -43.64 meters and the level fluctuated by + or – 0.39 meters. The volume of lake calculated as per the modified formula is 1000.9 x 10^6 M^3.

For the purposes of this report a lake volume of 1000 x10^6 M^3 is taken.

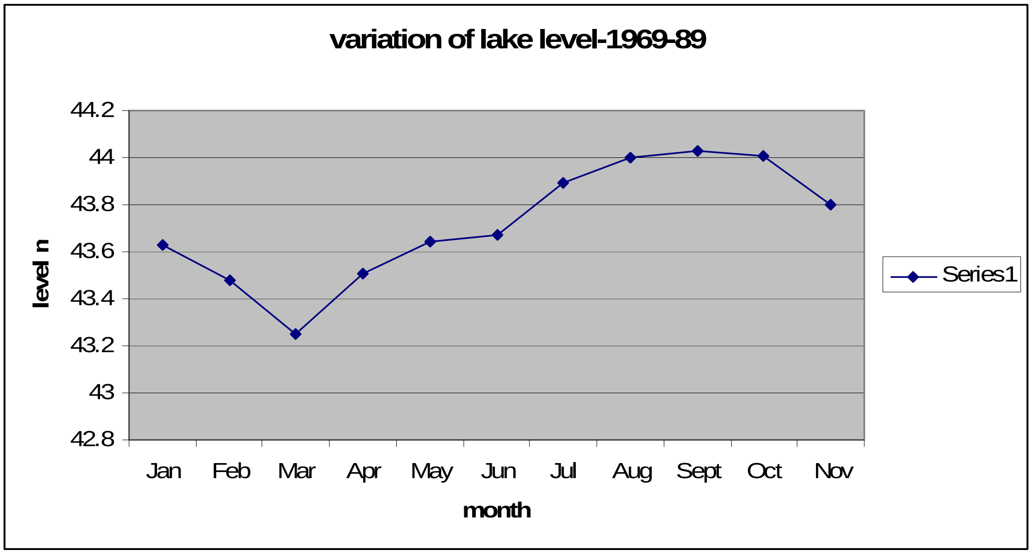

Fig 3. Annual variation of lake level (after Soliman)

Rate of evaporation

Evaporation is the one the main factor affecting the level of the lake and the salinity. A number studies have bee done on the water budget of the lake, Ball(1939), Gorgy(1959), Meshal(1973), Boshai and Kirollous(1980), Meshall and Morcos(1981), Soliman (1989), Abd Ellah(1999). Ball (1939) used an evaporimeters of 1 and 2 sq. meters and concluded that the rate of evaporation could be taken as 0.8 of that of the evaporimeter. Gorgy(1959) used energy equations and Meshal and Morcos(1981) aerodynamic method.

The three methods yielded varying results Ball – 177.4 cms/yr, Gorgy – 183.83 cms/year and Meshal – 190.08 cms/yr.

It is well known that the following factors affect rate of evaporation. 1. Temperature 2. Wind velocity 3. Humidity 4 Vapour pressure of the water, 5 Solar radiation, 6. length of the water surface in the direction of the wind.

Recent (1997) measurements indicate a rate of 284 mm/month in Aug. and 41 mm/month in Dec. The inflow is 450 x 10^6 M^3/year the pumping by EMISAL is approx. 15 x10^6 M^3/year. The net evaporation has to be about 436 x10^6 M^3/year, if the average level is to be maintained.

If the area of the lake is taken as 243.4 sq.km the yearly rate of evaporation rate has to be 178.9 cms/year to maintain the lake level. This is with in the estimates made earlier. Further it indicates an evaporation rate of 149.1 mm/month a rate that is about 10% lower than the yearly average of 163 mm, recent measurements Anon (1997).

Abd Ellah (1999) gives an evaporation rate of 415.3 x10^6 M^3 /year. Allam (2000) states that the annual inflow of drainage water is 430 x10^6 M^3 /year. The annual evaporation rate is 420 x10^6 M^3 /year.

From the above it can be concluded with in a reasonable degree of error that the rate of evaporation can be assumed to be about 450 x 10^6 M^3 /year.

Salt Balance

Year	Average TDS mg/liter	Total quantity flow x 10^6 M3/year	Total salt 106 tons
1990	1890	495	0.9356
1995	1890	380	0.7182
1997	2200	488	1.0736
1998	2260	453	1.0238

Table 2 gives the total quantum salts that are added to the lake every year from the drainage water.

This indicates that close to say 900,000 tons of salts are added to the lake. The lake would become saltier every year the salt concentration increasing every year by 0.86 gms per liter.

Many studies have been done, Soliman (1989) and Gorgy (1959) on these aspects and it was predicted that by the year 2025 the lake would reach a TDS of 50 gms/liter. At this salt content, fishes and most other organisms cannot survive.

The salt content of the lake was analysed and details of 8 samples are given in Table .

Species	1 E	2 W	1.1	2.1	3.1	4.1	5.1	Average
Na	10.854	10.081	10.132	10.040	10.849	10.366	10.408	10.390
Mg	0.996	1.149	0.996	0.945	1.200	1.098	1.098	1.069
Ca	0.707	0.648	0.618	0.559	0.559	0.530	0.530	0.593
Cl	13.099	12.453	12.735	12.343	13.088	13.093	13.457	12.895
SO4	10.546	10.270	9.321	9.315	11.005	9.515	9.109	9.869
Total	36.201	34.601	33.802	33.202	36.701	34.602	34.602	34.816

Table 3. Analysis of lake water samples at various places in Lake Qarun.

It will be noticed that there are wide variations as shown in Table 3 and the extent of deviation from the average is indicated in Table 4.

species	dev +ve	dev -ve
Na	4.46	-3.37
Mg	12.28	-11.6
Ca	19.15	-10.68
Cl	4.36	-4.28
SO4	11.51	-7.69
Total	5.41	-4.63

Table 4. Deviations of salt content from average

The wide variation in Magnesium and Calcium values is intriguing. The above samples were taken along the lengthy of the lake up to about half the length starting from eastern end. Further sampling to take a detailed look at the spatial variations could not be done as the funding was with held.

It will be worthwhile investigating variations in analysis at various places on lake surface as well as variation at various depths.

Analysis of a combined sample also indicated the following metals, Potassium – 0.232 gms/liter, Copper- 0.643 ppm, Iron-0.221 ppm, Zinc- 0.179 ppm, Cobalt-4.71 ppm.

The Birth of EMISAL

The Egyptian authorities became aware of these facts in 1980’s and decided upon a course of action. They decided that the best course of action was to extract the salts from the lake. That is put up solar evaporation ponds and manufacturing plants to produce salts from the lake water and thus control the salinity. Thus the present

Government of Egypt started the EMISAL project. (Egyptian Salts and Minerals Company)

The company has been in operation for 14 years and has probably pumped out Lake Waters containing about a 10 million tons of salt out of which it would have extracted approx. 3.5 million tons of salts as sodium sulphate and refined sodium chloride, and the remaining is stocked as raw or dry sodium chloride and in bitterns. This would mean that nearly 2.6 million tons of salts have been added to the lake.

The current situation is that since EMISAl is not able to maintain the salt balance the salts content of the lake is increasing. The capacity of EMISAL plants is fixed and its site is now overflowing with excess salts. If it has to maintain the stock level and operate to capacity then the total intake from lake has to be reduced, this will in turn further increase the salt level. This would lead to increasing salt content of the lake with lapse of time. There are not many choices the only way is to put up another project to extract salts. The capacity has to be sufficiently large to once for all mitigate the problem.

Average pumping rate of EMISAL – year 2004 – 12 x 10^6 M^3. Average salt content 35.05 gms/liter. Salt removed from lake 421,000 tons.

Incoming salts at drainage flow

Min. 430 x 10^6 M^3 –	946,000 tons
Max.480 x 10^6 M^3 –	1,056,000 tons
At 450 x 10^6 M^3 -	990,000 tons
Salt removed by EMISAL	421,000 tons
Salts remaining –	569,000 tons

The ionic species as shown in Table 5 may be interpreted as follows,

Species	Gms/liter	Total salt tons/year
Density	2.7-2.8 Be’	
NaCl	16.12	273,000
Na_2SO_4	12.50	212,500
$MgCl_2$	4.19	71.200
KCl	0.44	7.500
$CaSO_4$	2.01	34,100
Total	35.048	598,400

Table 5. Extractable quantities of salts from lake water by the New Project

In addition to these there could be possibility of recovering of bromine approx. 700 tons per year.

Plants to process and recover the above mentioned salts is required to be put up, except for calcium sulphate which would mostly precipitate out in solar ponds. The recovery of salts is important to the survival of Lake Qarun, however the value of the products is low as per current international prices. The project can be made sustainable without the crutches of subsidy if down stream added value products are produced. To do this in the most economical way and have a globally competitive project is a subject matter best dealt with in another paper.

Additional Cropping Area

The quantity of lake water required is indicated below,
Water pumping rate 16.1 x 10^6 M^3/year
Peak pumping rate 2500 M^3/hr – during summer
Pumping capacity - 21 x 10^6 M^3/year

The total water that would be pumped out by both the projects would be approx. 28 x 10^6 M^3/year. The irrigation system could pump in this additional quantity to maintain the Lake level. The salt content would then fall slightly by about 2.5%.

The above quantity of water is the irrigation drainage water. The amount of water that returns to drains from irrigated lands is relatively high (about 25 to 30%). This drainage flow comes from three sources; tail end and seepage losses from canals; surface runoff from irrigated fields; and deep percolation from irrigated fields (partially required for leaching salt). None of these sources is independent of the Nile River.

To add this quantity of water to the lake the water released from the river Nile would be approx. 100 x 10^6 M^3/year. Thus an additional acreage could be brought under cropping. It is estimated by ENCID and MPWWR that 1 feddan (1.04 acres) uses 5100 M^3 of water per year thus approx. 20,000 acres of additional land could be brought under cropping. The area would vary somewhat depending upon choice of crop and how water intensive it is.

This will hardly have any effect on EMISAL or the New Project to extract additional quantity of salt. Some additional benefits from the project could be the development of saltwater fishery and also the production of Betacarotene.

Implementing the project

Fig 4 indicates a possible scenario that integrates ecology with energy economy. Production of “fresh” water using RO could be integrated with power production and increased evaporation rates, that is lower land requirements. The reject from RO plant would also be concentrated enough to be added to the second solar pond rather than pond 1, thus saving additional land. If solar evaporation alone was used the land requirements would be 1720 acres / 6.96 million sq. meters. This could be reduced by 196 acres. Not only there is reduction in land area but also in the related infrastructure costs.

Water could go straight to solar ponds for evaporation or it could go, through a fish farm, and then to the solar ponds after it is treated for reduction of BOD and COD.

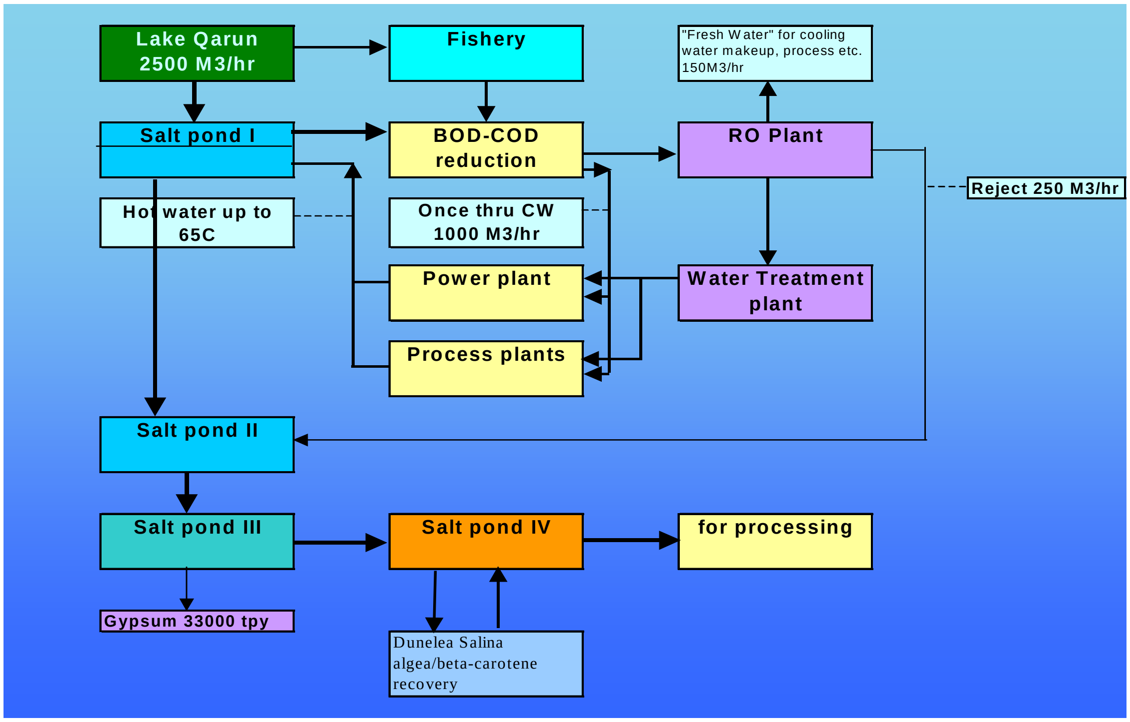

Fig 4- Processing of lake water

Cost of project

The cost of the project for water pumping, solar evaporation, RO plant and recovery of salts is estimated at approx. $82 million. The cost of cogen plant would vary considerably depending on the total energy to be generated and the ratio of power to heat. The total energy generation could be realistically estimated only when the product mix of down stream products is known. Down stream products such as caustic soda, etc. would be energy intensive. Suffice it to say that the costs of cogen power and steam would be lower than that obtained from grid and or normal power plants.

Location

Fig 2 indicates that the southern side of Lake Qarun is populated and has large amount agricultural activities. Any new project requiring large area of land would displace persons and existing economic activities if it was situated on the easily accessible southern side. A possible choice is indicated in same figure on the north eastern shores of the Lake, the area has little or no human habitation, it is gently slopping so that the earthwork for solar ponds will be minimized. The winds mostly from northwesterly direction will be dry and this would improve evaporation from solar ponds.

Ecological benefits

The fish that are being presently being stocked in the lake are Tilapia, Mullet, Egyptian Sole (*Solea aegyptiaca)*, and prawns. The fish farm could be used for rearing not only the presently available fish varieties but others also. M. Ahmed (2000) mentions that Barramundi, also known as Sea Bass (*Lates calcarifer*), Black Bream (*Acanthopagrus butcheri*), Red Snapper (*Pagrus auratus*), Milk Fish (*Chanos chanos*), have been successfully grown in saline waters in Australia. More saline waters could be used for growing brine shrimps (*Artemia salina*), that are feed for finned fishes. Sea bass(*Lates calcarifer*) and milk fish(*Chanos chanos*) are successfully grown in brackish waters in India.

Another product that can be produced is Beta carotene. In later stages of evaporation at a salt sp.gr 1.16 and higher an algae proliferates. *Dunaliella Salina* is a unicellular algae characteristic of the salt production cycle in almost every salt field in the world, it only lives under high levels of salt concentration. It is a natural culture for the salt field ponds as it naturally forms part of the salt production process. It colours the brine waters to the familiar orange-reddish aspect that any salt field in the world have and in addition it gives a light citric smell. The reddish tinge of pond 4 of EMISAL, shown in satellite image Fig 5. is due to heavy proliferation of this algae.

Fig 5. EMISAL site showing Dunelliela Salina formation in pond 4

The algae can be harvested and processed using biotechnology processes to produce beta carotene an important nutraceutical. It can also be dried and used in fish feed. There are existing projects in India, Australia and in Spain.

Lake Qarun has been declared a protected nature conservation area in 1989.

A total of 205 birds species have been identified mostly migratory. As many as 80-90 types of water birds are found in the area of the lake, Sorensen(1994). These would increase because of larger water spread and greater feed availability.

The location will help in reducing the desertification of the northern shores. The green belt can be extended with minimum water usage. Plantation using arid zone trees such as neem (*Azadirachta indica*), varieties of acacia, juniper, etc. could be grown. There are more than 75 varieties of arid zone trees, out of which nearly 80% have economic value other than fuel wood. Many of the varieties act as wind breaks, and dune and soil stabilizers. Arid zone crops such as aloe vera, senna, guar, etc. that need very little water can be grown. Intercropping is an option. The products from the trees and crops have economic value and can be source of income and employment.

Conclusions

1. The salinity of Lake Qarun has been increasing over period of time.
2. The EMISAL project has been beneficial in reducing the rate of increase of salinity but not completely controlling it.
3. Another project of higher capacity to extract all the salts can stop the increase in salinity and perhaps reduce it slightly.
4. The project should have a capacity of 600,000 tons of salts per year.
5. An integrated system of fresh water production using RO process, cogeneration of power, and once through cooling can reduce the infrastructure and processing costs.
6. The project could be made sustainable by producing added value down stream products.
7. 20,000 acres of cropping area could be additionally developed.
8. Yield of fish can be increased by the use solar ponds as fish farms
9. It would be possible to obtain betacarotene or fish feed supplement from the algal growth in solar ponds.
10. The advance of desert can be stopped on the certain parts of northern shores of the lake.
11. Arid zone economic forestry and agriculture can be practiced around the project site.

Lessons for India

Is there any lesson for India? The answer appears to be yes. Vast areas of land in Haryana, Punjab, eastern UP are irrigated by canals, the agricultural run off and seepages from canals etc. has caused large areas to turn saline and unfit for cultivation. The Central Soil Salinity Research Institute (CSSRI), a part of the Indian Council of Agricultural Research (ICAR) system, estimates that about 8.6 million hectares of India’s land area is afflicted with the twin problems of alkalinity and salinity coupled with water logging, which seriously reduce agricultural productivity and has grave implications for our food security system. Use of tube wells in canal fed areas leads to reuse of water and increase in dissolved solids. Perhaps large scale drainage works could be under taken to collect these in to geographical depressions converting them to lakes and if required extract salts. If geographical depressions are not available then artificial lakes can be created. Similar projects are underway in Australia.

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