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Estimation of seasonal salt balance in soil water of Siwa Oasis closed basin, Western Desert, Egypt

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ABSTRACT: Salinity of soil water problem in closed basins is so vital to water and soil. Siwa Oasis suffers from serious soil-water salinization and water logging problems. During the last four decades, more trials were carried out for improving soil water salinity via different authorities. Nowadays, some random reclamation projects are carried out in Siwa Oasis causing soil deterioration especially in the old cultivated land around Siwa lake (3000 Fed.). The present paper throws light on the changes in soil-water salinity as a result of the present agricultural activities. To achieve this goal, the salt balance of the soil-water of these cultivated lands is estimated. The estimation of the input and output components was carried out in the present work based on the field measurements during 1999.The estimated mean daily salt influx, input component to the soil water via 620 flowing wells and springs, reaches 215.4 ton and 465.1 ton during winter and summer season respectively. The high value of salt influx in summer season may attribute to the intensive irrigation activity in this season. The Output component includes the salt efflux through different drains from subsurface flow and the salinity losses due to plant uptake. The estimated daily mean value of salt efflux reaches 118.9 ton during winter season, while during summer season it reaches 378 ton. The average storage component, which equals to the difference between the salt influx and the salt efflux, is 7 ton /day and 88 ton /day during winter and summer season respectively. The estimation of salt balance shows that the soil water receives an excess of salt content ranges from 32 and 29 kg /day / Fed during winter and summer season respectively. While the salt load due to leaching of the root zone reaches more than 100 ton /day.
Recommendations concerning salt reduction in the soil zone through improvement of irrigation and drainage techniques are focused in this paper.
Additional Keywords: Hydrogeology, soil salinization, salt balance, Siwa oasis, Egypt.

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I. INTRODUCTION

The Siwa depression is located in the northern part of the Western Desert of Egypt, about 65 kilometers east of the Libyan border and 300 kilometers south of the Mediterranean Sea as shown in Figure (1). The Siwa Oasis is usually considered to include that area lying below the zero contour of elevation. The ground surface elevation within the Siwa depression varies between zero and 18 below the mean sea level. The Oasis is an elongated area running about 100 kilometers in an easterly direction and varying in width from five to 25 kilometers. Historically, Siwa was known as the Oasis of Amun because of its famed temple. Alexander the Great visited Siwa to consult with the Siwa Oracle and was deeply impressed by this

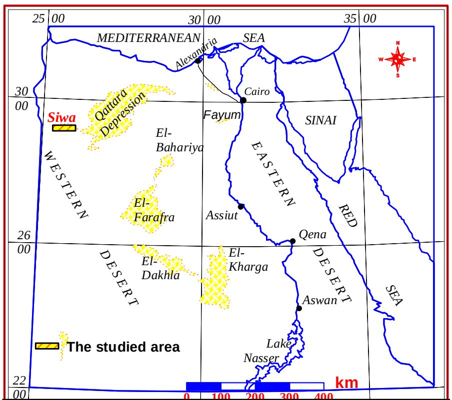

Fig.1: Location map of Siwa Oasis

remarkable Oasis. The people of Siwa are a mixture of Bedouin, Berber and Sudanese races. They have their own language, which is a Berber dialect, unrelated to Arabic.

Ancient writers reported that Siwa once contained thousands of flowing springs. In 1962 there were less than 200 developed springs of any importance (Parsons 1963). Today, approximately 20,000 people live in the Oasis and practice farming on nearly 12,000 acres compared to 5000 people and 2000 acres in 1962. The main crops grown in this area are dates, olives and alpha-alpha. The high level of salinity and the shallow water table in the low topography areas characterize the soil conditions. The climate of Siwa Oasis follows the Western Desert conditions with very hot summers and mild winters. The monthly mean maximum temperature ranges from 20^{o}C in January to 38^{o}C in July, while the monthly mean minimum temperature ranges from 4^{o}C in January to 21^{o}C in July. The mean monthly relative humidity ranges from 30% to 58% and finally the daily evaporation rate ranges from 17 millimeters in June to 5 millimeters in December. Rainfall is almost negligible in Siwa, with an average annual rainfall of 10 millimeters (Gad, 1999).

In 1962, the Egyptian General Development Organization conducted an extensive study on the potential of ground water and agricultural development in the Siwa Oasis to offer more opportunities for qualified farmers to move out of the crowded Nile Valley and start new lives on freshly-reclaimed, productive farm lands (Parsons 1963). According to Parsons (1963), careful consideration was given to crop diversification, irrigation requirements, drainage and soil salinization. The proposed agricultural development of Siwa as suggested by the early study was based upon the assumption that only the best and most efficient agricultural practices will be employed. Yet, this assumption was not valid since the farmers are not ready for advanced irrigation practices that are mostly expensive and unaffordable at that time. Some other recommendations were implemented to minimize the water losses from the flowing springs and to improve the drainage system in the oasis.

Starting from the 1980, the authors learned by consultation with the Siwian farmers that more than 1000 naturally uncontrolled flowing wells were drilled in the shallow carbonate aquifer system producing an excess groundwater more than the agricultural demands (Sakr et al., 2002). The authors are not aware of any published reports that describe the status of the hydrogeologic conditions as a result of these drilled wells in the early 1980s. In 1996, the farmers in Siwa complained of loosing their cultivated lands because of the waterlogging and soil salinization especially in the low lands near to the drainage lakes. In response to this vital socio-economic problem, the government of Egypt through the Ministry of Water Resources and Irrigation financed a research project to investigate and identify the problems and to propose short and long-term mitigation options.

In this paper, highlights of the findings of this research will be addressed. This includes the assessment of the ground water conditions as depicted from the well inventory and the water losses to the lakes as measured in the drainage network. Based on this information a proposed work plan will be addressed for water conservation in the Siwa Oasis. The results of the implementation of this plan are monitored continuously using two performance indicators. These indicators are the depth to the soil water level and the reduction of the water losses rate from the uncontrolled wells to the lakes.

Geographically, Siwa Oasis lies between longitudes 25˚ 16´ and 26˚ 12´ E and latitudes 29˚ 06´ and 29˚ 24´ N. The area that lying below the zero contour level elevation is usually considered as Siwa depression. It lies at 330 km southwest of the Mediterranean shoreline and at 65 km east of the Libyan borders (Fig.1). It attains about 75 km length and a variable width of range 5 to 25 km. The ground surface elevation ranges from 10 to 20m below mean sea level. The total surface area inside the zero contour line reaches 1088 km^2. Siwa Oasis is characterized by desert climate. The average temperature ranges between 5.8 ºC in January and 37.8 ºC in July. The precipitation is scarce and does not exceed 10 mm/year (Egyptian Meteorological Authority,1993).

Geomorphologically, Siwa oasis occupies a large depression opening from the border of the Tamir and Libyan plateaux to the large desert area of the Great Sand Sea in correspondence of which its altitude Fig.1. Location map of Siwa Oasis sinks by some meters below sea level. Proceeding from north, the plateau is fragmented into numerous small isolated relieves (outlier hills), representative of erosion remnants of the depression escarpment. These relieves with more or less steep concave slopes reach the bottom of the basin occupied by large water stretches and by emerged zones, gradually moving towards south to the vast extensions of the dunes of the desert.

Within the oasis some geomorphological features may be identified and grouped as follows (Fig.2):

- The rock outcrops microreliefs (limestones and calcareous sandstones, 100 to 150 m.a.s.l).
- The alluvial fan and the colluvial deposits.

- The water sheets (lakes with surface area 61.748 km^2).
- The cultivated areas (old and new with area 10000 Fed.).
- The areas of sabkha (wet and covered with karshif of total area 355.68 km^2).
- The sand sheet and the dunes (zero to 30 m.a.s.l).
- The isolated hills (158 hills ,from 30 to 120 m.a.s.l).

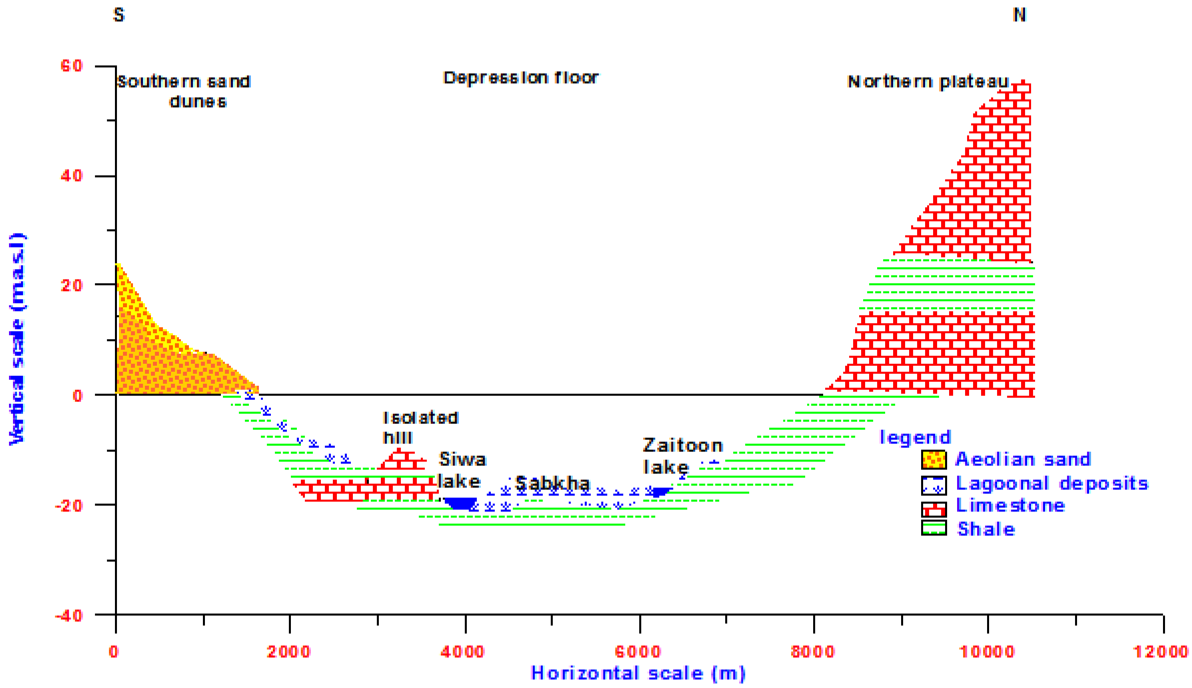

Fig. 2: Geomorphologic cross-section in N-S direction in Siwa Oasis.

Geologically, sedimentary rocks belonging to Middle Miocene and Quaternary occupy the surface in Siwa Oasis. The Middle Miocene section is composed of chalky limestone, marl, shale and dolomite having a thickness of about 94m. The Quaternary section is differentiated into aeolian sand, alluvial and lagoonal deposits of variable thickness. In the subsurface, the stratigraphic section attains a thickness of about 3527 m and rests directly on the basement. This section belongs, from top to base, to Miocene (250m), Eocene (350 - 400m) Cretaceous (600m), Carboniferous (765m), Devonian (1038m), Silurian (470m) and Carbo-Ordovician (320m). Hydrogeologically ,the groundwater system that underlies Siwa Oasis consists of two productive aquifers; the Lower Cretaceous Nubia sandstone and the Middle Miocene fractured limestone besides the Quaternary sand and clay water bearing. The former represents the only sustainable fresh groundwater source in the whole Western Desert. Its thickness decreases generally from south to north till it reaches about 200m at Siwa Oasis (Regwa, 1997). The groundwater flow is from SW to NE direction. The hydraulic pressure differs from 5.5 to 11 atm (RIGW, 1996). And increases towards south and east. The permeability coefficient of the saturated zone ranges between 0.93 and 24.6 m/day. The extracted water from this aquifer for irrigation purposes reaches 15x 10^6 m^3/year). (Gad, 1999)

In Siwa Oasis, the salinity of this aquifer increases downward from less than 400 ppm to more than 55000 ppm (GPC 1991). Its groundwater occurs under artesian condition. On the other hand, high fractured zones acting as water conduits characterize the Middle Miocene limestone aquifer. Its thickness ranges between 400 m and 700 m. Two salinity zones were distinguished in this aquifer, one to a depth of about 200 m with salinity ranging between 1500 ppm to 7000 ppm and the second separated from the upper one by a thin clay layer with salinity of the order 12000 ppm.

Worthmentioning that the more deteriorated area, with respect to salinization problem, is the soil zone of the old cultivated land between Siwa and Aghormi lakes. The coping with the problem of this locality requires an estimation of soil water salt balance. The total porosity of this locality ranges between 39.68 to 69.21% with mean value

50% and the effective porosity ranges between 8 to 21 % with an average 14.5% . The average hydraulic conductivity value reaches 3 m/day. The gravimeteric soil water content of the root zone varies between 0.21% and 53%.The saturation capacity of the unsaturated soil zone ranges between 35% and 57% with total mean value of 41% while the field capacity ranges between 15% and 30% with total mean value of 24%. The wilting point of the unsaturated soil zone ranges between 5% and 15% with total mean value of 11.5% while the available water holding capacity has an average value of magnitude 12%. The old cultivated land (3000 Fed.), which has a variable thickness increasing from north to south and southeast, is underlain by an impervious stratum allowing no leakage. The old cultivated land possesses excess groundwater discharge from 620 flowing wells and springs (Fig.3).

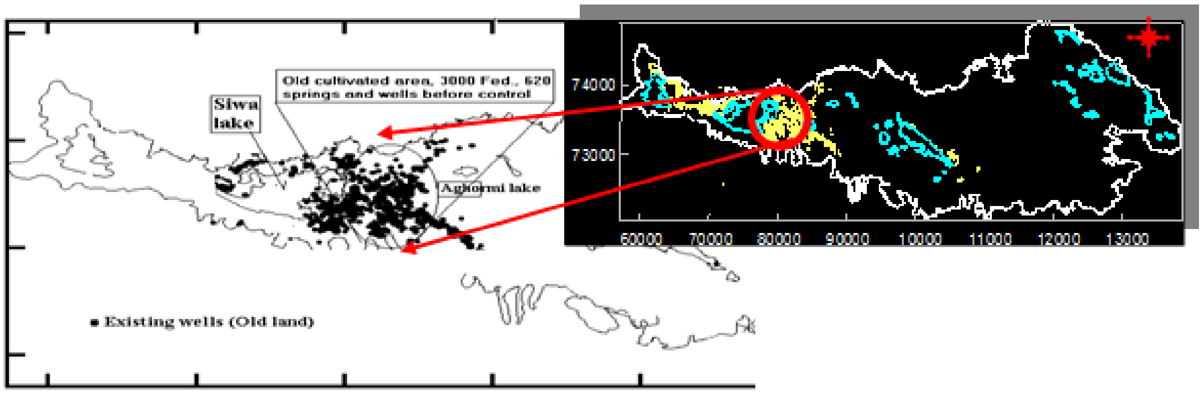

Fig. 3: Location map of the different flowing wells and springs in the old cultivated land

II. MATERIAL and METHODS

Hydrogeological measurements as well as hydro-geochemical techniques provide valuable information on the sources, movement and quality of soil water in different environments, including rivers and lakes. Also, these records are particularly effective in investigation soil water and provide insights into water's behavior. They help to build the foundations for rational utilization of this precious soil water resource. These hydrogeologic measurements include depth to water, absolute ground elevation, pumping tests, groundwater salinity and all parameters needed for constructing of the resultant soil water table and salinity maps.

In the present work, a combined approach of hydrogeological and geochemical studies has been used. Eighty water samples were collected during March 1996 and February 1999 from the periodic monitoring of the soil water fluctuations and salinity through the constructed network of **60** piezometers. The mean increase in soil water storage and chemical species were estimated using standard methods (Clesceri et al., 1989). Twenty six productive wells as well as sixty surface water samples were analyzed. These samples were analyzed for major cations and anions. In addition, the salt balance of the soil zone in any irrigated lands depends on the assumption that, all salts are soluble and not precipitate. The general equation for salt balance estimation can be written as;

Soil water salt influx = Soil water salt efflux + Change in soil water salinity ……………..(1)

All components that comprising salt influx and efflux depend on the quantities of water entering and flowing out from the soil zone multiplied by its salinity. Accordingly,the equation for the estimation of salt balance in an irrigated area can be expressed as (ILRI, 1994);

$$\mathbf{I.C_i + E.C_i + R.C_r + G.C_g = ET_c . C_i + D.C_d + P.C_p + \Delta S} \quad \text{……………(2)}$$

Where; water (ppm) and the suffix $_{\mathbf{i,\ r,\ g,\ d}}$ and $_{\mathbf{p}}$ refer to salinity of irrigation water, rain water, groundwater, drainage water and deep percolation water respectively. $\mathbf{I.C_i}$ and $\mathbf{E.C_i}$ represent the salt influx due to irrigation and evaporation from the shallow water table or surface water bodies. $\mathbf{R.C_r}$ and $\mathbf{G.C_g}$ are the salt influx resulted from rainfall and upward flow of groundwater. Due to the scarcity of rainfall and presence of impermeable beds beneath the soil zone in Siwa Oasis, both elements can be neglected.

$\mathbf{ET_c\,.\,C_i}$ and $\mathbf{D.C_d}$ are the salt efflux due to plant evapotranspiration and subsurface flow to the drains. $\mathbf{P.C_p}$ is the salt efflux due to deep percolation from the soil zone. For the studied area, this element is excluded. **Δ S** is the change in the soil salt storage.

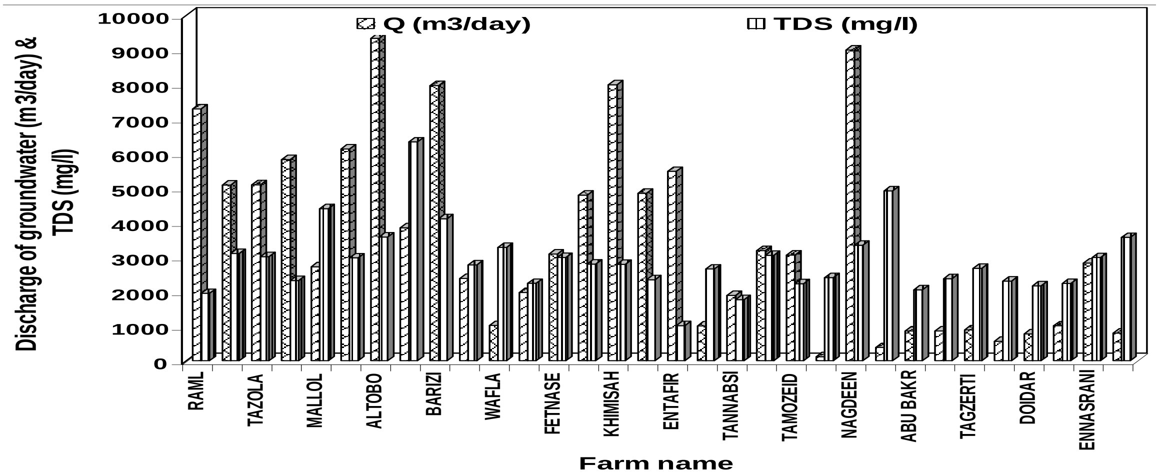

Fig. 4: The discharge and salinity of the groundwater of different farms in the study area (1999).

III-RESULTS and DISCUSSIONS

Salt balance estimation

Viewing ILRI's equation and neglecting the non-represented components, the salt balance equation for the soil zone of Siwa Oasis can be written as follows:

$\mathbf{(I.\ C_i\ ) - (\ D.C_d + ET_c\,.\ C_i\ )\ = \Delta\ S}$ ……………3

Estimation of mean salt influx (I. C_i)

Referring to Table 1 and Fig.4, the old cultivated land of Siwa Oasis comprises the presence of 32 farms having an area of 3000 Feddan and containing 620 flowing springs and wells with a total discharge of 182998 m^3/day. A part of this amount infiltrates to the soil zone, from which the subsurface inflow component takes place. The other part seeps directly to the lakes through drainage network. Thus:

The seepage to the soil zone (**I**) = Total discharge – (drainage water discharge - subsurface inflow).

Considering the recorded amount of drainage water during winter and summer of 1999 as 110786 and 27633 m^3/day respectively (Fig. 5&6 and Table 2), thus the subsurface inflow can be estimated by applying Darcy's law. Assuming that the total length of the drainage network is 51 km, the average saturated thickness of the soil zone reaches 2 m in winter and 2.5m in summer seasons (Gad et al 2000), the average hydraulic gradient reaches 2.4 $x10^{-3}$ and the infiltration rate approaches 3.25 m/day (Abdel-Mogheeth 1996), then the subsurface inflow equals:

2 x 51x 2 x 2.4 $x10^{-3}$ x 3.25 = 1591.2 m^3/day in winter and

2 x 51x 2.5 x 2.4 $x10^{-3}$ x 3.25 = 3978 m^3/day in summer,

The mean seepage to the soil zone I =182998 – (110786 - 1591.2) = 73803.2 m^3/day in winter and in summer it equals,

= 182998 – (27633 – 3978) = 159343 m^3/day,

Concerning the average salinity of irrigation water C_i equals (96.33 / 33 =2.919) g/l (Table,1); so

The mean salt influx (I. C_i) = 73803.2 x 2.919 $x10^{3}$ g /day = 215.432 ton/day in winter, while in summer ; the mean salt influx (I. C_i) = 159343 x 2.919 $x10^{3}$ g /day = 465.12 ton/day

It is noticed that the mean salt influx in summer season is more than twice in winter season. This may attribute to the intensive irrigation activity in summer season with high consumption water use in leaching requirements of the soil zone.

Table 1 : The discharge (m^3/day) and the salinity (ppm) of the different wells and springs in the farms of the old cultivated area in Siwa Oasis (1999)

S.N	Farm name*	Area* (Fed.)	Discharge I (m^3/day)	Salinity C_i TDS (ppm)
1	RAML	300	7292	1.951
2	ZAGAWA	220	5091	3.105
3	TAZOLA	200	5094	3.01325
4	SHAHAIM	200	5825	2.324
5	MALLOL	180	2724	4.405
6	SHATTORI	150	6132	2.980
7	ALTOBO	140	9336	3.583
8	MESHINDID	140	3850	6.337
9	BARIZI	120	7968	4.115
10	ELLEHRIK	115	2388	2.779
11	WAFLA	105	1021	3.281
12	TATRAPENT	90	1980	2.243
13	FETNASE	85	3094	2.9894
14	AZMORI	80	4795	2.802
15	KHIMISAH	70	7992	2.792
16	TELHRAM	70	4848	2.347
17	ENTAFIR	60	5484	1.016
18	QUTA	60	1008.5	2.657
19	TANNABSI	60	1894	1.768
20	UMELSUS	60	3194.4	3.0505
21	TAMOZEID	55	3062	2.230
22	ABOELLIF	55	122	2.409
23	NAGDEEN	50	9000	3.346
24	UMELSIR	50	384	4.921
25	ABU BAKR	40	864	2.0565
26	ABOSLIMAN	40	864	2.376
27	TAGZERTI	40	896.5	2.679
28	KORDI	35	564	2.307
29	DOIDAR	35	780.5	2.170
30	KONGAL	35	1014	2.239
31	ENNASRANI	30	2832	2.988
32	TRABEEA	30	804	3.572
33	Natural springs (66 springs)		70800	3.500
TOTALL		3000	182998	96.33

* Agricultural Authority of Matrouh,1996

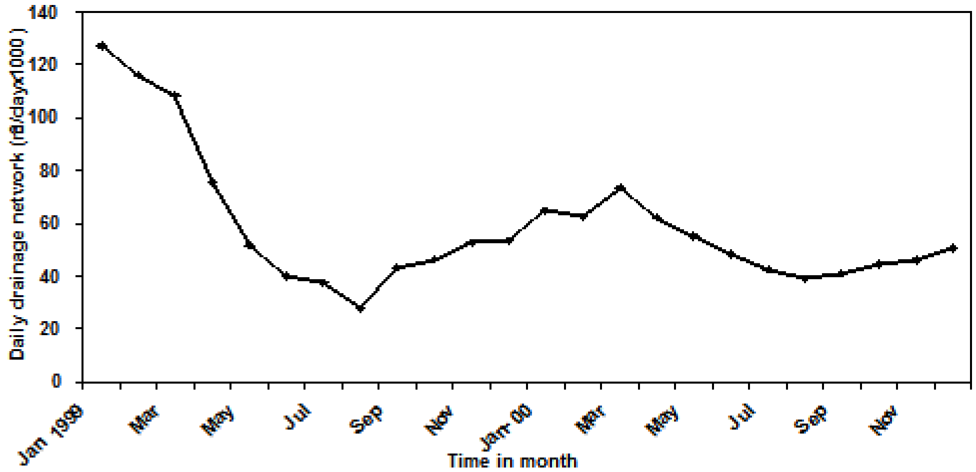

Fig.5: The total discharge (thousands m^3/day) of the drainage network in the study area (1999-2000).

Table 2: The discharge (m^3/day) and the salinity (ppm) of the drainage network in the old cultivated lands (1999)

S.N.	Drain name	Winter season of 1999		Summer season of 1999		Groundwater salinity in the drainage area ppm
		Mean discharge m^3/day	Mean drain salinity (ppm)	Mean discharge m^3/day	Mean drain salinity (ppm)	
1	El-Qibli	23040	5.88	10100	6.89	2.98
2	Shakren	14237	6.899	1223	8.10	2.79
3	El-Gary	4800	6.36	1550	7.61	5.74
4	Tizawah	7015	8.67	1110	10.32	3.34
5	Dehiba	5461	6.15	2190	9.40	2.75
6	Tomrabit	4111	6.30	460	8.91	3.39
7	Altobo	12320	6.08	dry	9.49	3.58
8	Siwa	39802	6.36	11000	7.63	2.73
Total discharge		110786		27633		

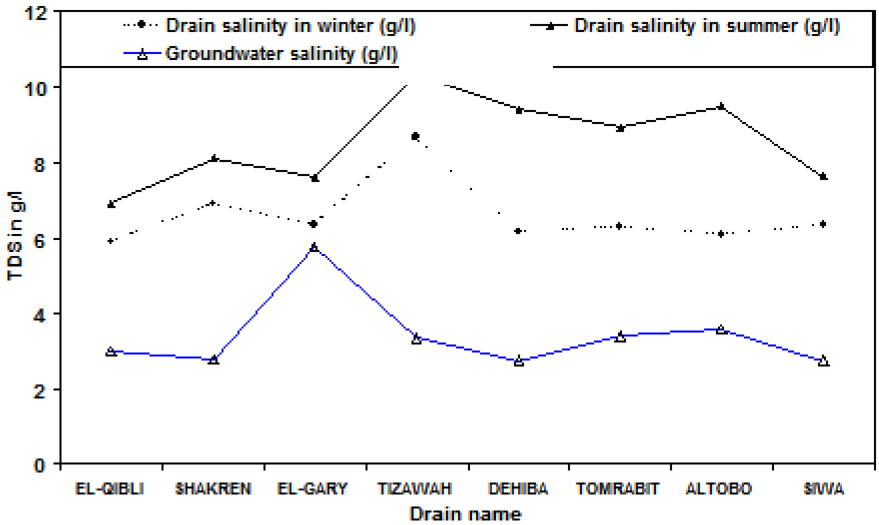

Fig.6: The comparison between the groundwater and drainage water salinity in ppm in the study area (1999)

Estimation of mean salt efflux ($D.C_d + ET_c . C_i$):
The subsurface salt efflux to the drains ($D.C_d$) is calculated by multiplying the subsurface flow (D) by the average salinity of soil water (C_d). The subsurface flow equals, as estimated before, 1591.2 m^3/day in winter and 3978 m^3/day in summer. While the average salinity of soil water can be considered 16 g/l in winter and 22 g/l in summer (as detected from the chemical analysis of the soil water samples from the sixty piezometers drilled in the soil zone until 1999). Therefore,

The mean $D.C_d$ component in winter = 1591.2m^3x16g/l = 25.459 ton/day and in summe = 3978 m^3 x 22 g/l = 87.516 ton/day.

The second component concerning the salt efflux is the evapotranspiration ($ET_c . C_i$). The mean evapotranspiration of the crop unit in Siwa Oasis was estimated depending on class A pan (FAO 1977) to be 9.118 m^3/day/Fed during winter and 28.299 m^3/day/Fed during summer (Gad, 2002, Fig.7).It follows;
The daily mean salt efflux by plant uptake = mean ET_c per Fed.x area in Fed. x average TDS of irrigation water C_i = 9.118 x 3000 x 3.41648 = 93.454 ton in winter =290.059 ton in summer.
The total mean salt efflux during winter = 25.459 + 93.454 = 118.913 ton /day, and during summer = 87.516 + 290.059 = 377.575 ton /day.

It is obvious that the mean salt efflux due to ET_c component (78.5% in winter and 76.8% in summer) is three times that due to subsurface flow component (21.5% in winter and 23 % in summer) which reflects the bad drainage network.

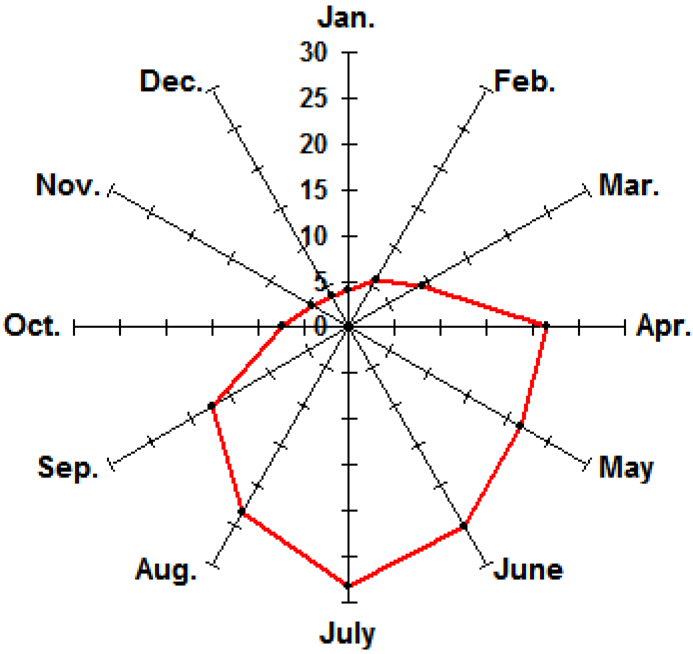

Fig.7: The daily evapotranspiration of the crop unit in the old cultivated land (m^3/day/Fed.).

Estimation of storage parameter (Δ S)

The difference between salt influx and efflux equals the storage factor. The estimated net result of the salt influx and the salt efflux of the old cultivated lands during hydrologic year 1999-2000 refers to (Table 3);

Mean daily salt storage = Mean daily salt influx - Mean daily salt efflux
= 215.432 - 118.913 = <u>96.519 ton</u> (winter season)
= 465.12 - 377.575 = <u>87.545 ton</u> (summer season)

Table 3: The estimated mean daily salt balance of the old cultivated land in Siwa Oasis (during winter and summer of 1999)

Season	Mean salt influx ($I.C_i$) in tons	Mean salt efflux ($D.C_d + ET_c . C_i$) in tons	Mean storage (Δ S) in tons
Winter	215.432	118.913	96.519
Summer	465.12	377.575	87.545
Annual mean	340.276	248.244	92.032

The estimated salt balance of the soil water in the old cultivated land shows that the annual mean of the salt influx reaches 340 ton/day while the annual mean of the salt efflux reaches 248 ton/day with an annual average storage of magnitude 92.032 ton/day (Table 3). These figures mean that every Fed. in the studied area receives about 32 and 29 kg of salts every day during winter and summer season respectively (mainly sodium chloride). This causes the sharp deterioration problem for these cultivated areas. The increase of salt load per Feddan in winter than that in summer may attribute to the intensive agriculture activities in summer more than in winter. So, the change in crop unit may use in decreasing the deterioration problem.

Worth mention that the periodic monitoring of the soil water fluctuation through the constructed network of 60 piezometers show that the mean increase in soil water storage during winter of 1999 approaches 3.25 cm (0.1 cm daily) which reflects total daily increase of 12600 m^3.

This means that the daily salt storage depending on the field measurements reaches 202 ton. The difference between the recorded and estimated daily salt storage may attribute to the salt load through leaching process of the root zone.

It is obvious that the system is unbalanced concerning salt loads where the input exceeds the outputs with more or less than twice. This unbalance might be due to the salt loads resulting from leaching.

III. CONCLUSION and ECOMMENDATION

The estimation of the salt balance in the soil water of the old cultivated land in Siwa Oasis (3000 Fed. with total discharge **182998 m^3/day**) during the hydrologic year 1999 exhibits the following;

The average quantity of water entering the soil zone during winter season reaches **73803 m^3/day,** with average daily salt influx of magnitude **215 ton .**While in summer season it reaches **159343 m^3/day** with average daily salt influx of magnitude **465 ton .**

The mean daily salt efflux from the soil water reaches **119 ton** during winter season and **378 ton** during summer season.

The average daily of salt storage approaches **97** and **88 ton** during winter and summer season respectively. While the recorded value from field measurements for winter season reaches **43 ton**. The estimated figure means that every Fed. in the concerned area receives about **32** and **29 kg** of salts every day during winter and summer season respectively (mainly sodium chloride).

Accordingly, the following is recommended:

1. The flood irrigation must be changed to modern irrigation techniques to minimize the losses and consequently, decrease the salt influx.
2. The crop unit must be changed into highly consumed plants to increase the salt efflux required for salt balance, since the mean salt efflux due to the evapotranspiration represents three times the mean salt efflux due to the subsurface flow.
3. Since the Aghormi lake and its great Sabkha affect the salt balance, so it is recommended to make it a collector drainage network for all excess water in the Oasis by building a fence around it. Also to prevent more deterioration for the adjacent low-land cultivated areas.

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