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Irrigation and Agricultural Development

Based on an International Expert Consultation, Baghdad, Iraq,
24 February - 1 March 1979

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1980

Published for the
UNITED NATIONS
by
PERGAMON PRESS
OXFORD · NEW YORK · TORONTO · SYDNEY · PARIS · FRANKFURT

Studies on Nile Water Quality Before and After the High Dam and its Effects on Soil Fertility

B. S. Zikri and M. S. El-Sawaby

INTRODUCTION

The Aswan High Dam has been built to store water for expanding the cultivated area by about 1.3 million acres, besides converting about one million acres of land from basin to perennial irrigation. The change in irrigation system and natural balance of the water regime has affected the water quality and, consequently, the fertility of the soils. Also the storage of water in Lake Nasser and sedimentation could affect the water characteristics. Opinions differ on the quality of Nile water downstream from the High Dam. Some argue that no distinct change is likely to occur. Others believe that most of the Nile water suspension will be sedimented in Lake Nasser, thus depriving the Nile alluvial soils from this important element of soil fertility. They also predict variation in the quality of water itself.

This study examines some important changes occurring in the Nile water components due to the construction of the High Dam which can affect alluvial soils of Egypt. Waters were sampled before the High Dam was built and after the basin lands of Upper Egypt were put under permanent irrigation.

WATER QUALITY

The Nile water quality has long been the subject of interest to the investigators of Egyptian soils and of the Nile river. Many studies on the Nile water along the river course were undertaken by scientists such as Lucas (1908), Aladjem (1930), Williamson (1936), Ball (1939), Kaddah (1954), Hamdi (1959), Moustafa and others (1959) and Hafez (1962). Scientists continued such studies right up to the construction of High Dam when persons in charge of the project also started sharing interest. These investigations and additional series of records for recent years yielded good data for evaluation of the effects of the High Dam on water quality. Table 1 presents a comparison between the average concentration of dissolved salts at Cairo before and after the construction of the High Dam. The data show that there exist yearly and seasonal variations in the amounts of soluble constituents of the Nile water. These variations are mainly due to the seasonal rainfall on the Ethiopian plateau and different waters supplementing the main Nile from different sources during different parts of the year.

TABLE 1. Dissolved Salt Concentrations of the Nile Water at Cairo before and after the Construction of High Dam

(ppm)

Month	Before construction of High Dam				After construction of High Dam	
	Ministry of Public Health 1919-1927	Williamson 1932-1936	Ministry of Agriculture 1957-1958	Ministry of Irrigation 1963	Mitkees 1968	High Dam Authority 1972
January	197	151	183	182	137	211
February	189	160	183	190	173	198
March	217	174	197	192	186	190
April	232	200	215	178	173	207
May	229	204	157	182	n.d	207
June	207	194	160	176	n.d	181
July	199	212	169	204	166	188
August	138	174	177	163	192	177
September	128	137	115	162	179	181
October	133	130	133	162	192	237
November	136	135	183	172	224	207
December	154	138	193	178	166	221
Mean	179	167	172	178	182	199

Note: 1968 is the first year of full-flood water retention.
1972 is the eighth year after water impoundment in the High Dam lake.

Prior to the construction of the High Dam, the values revealed a distinct variation in salt concentration over the year. During flood months, from July to November and, especially during September, the water had the lowest concentration of total soluble salts. In the remaining months, the salt content increased and reached its maximum during April and May. At Cairo, the variation was between 115 ppm during September and 232 ppm during April.

After the construction of the High Dam, the salt contents did not decrease significantly during flood months, but there was a gradual increase during the summer months, as a result of high temperature which accelerated the evaporation. At Cairo, the minimum concentration of soluble salts was 162 ppm in 1963 (prior to the construction of the High Dam) and it increased slowly to 177 in 1972. The corresponding maximum values were 204 and 237 in 1963 and 1972, respectively. Table 2 shows that, as a general trend, the concentration of all ions increased but at different rates. A distinct increase was noticed in the contents of K^+, $SO_4^=$ and HCO_3^-. For example, the soluble K^+ content doubled before the construction of the High Dam. The water did not contain $CO_3^=$, because the dissolved CO_2 in water converted all $CO_3^=$ to HCO_3^-.

TABLE 2. The State of the Nile Water Components at Cairo as Affected by the High Dam Construction

	T.S.S. (ppm)	Constituents in meq per litre						
		$CO_3^=$ and HCO_3^-	Cl^-	$SO_4^=$	Ca^{++}	Mg^{++}	Na^+	K^+
Before: flood season 1/	131	1.78	0.14	0.20	1.13	0.60	0.41	0.07
low season 1/	187	2.36	0.48	0.24	1.24	0.75	1.28	0.14
After (1974)	227	2.94	0.62	0.45	1.28	0.89	1.39	0.18

1/ Hafez (1962).

The concentration of soluble ions in the water before and after the High Dam construction is shown in descending order as under:

Before the High Dam construction

Low season : $(CO_3^= + HCO_3^-) > Na^+ > Ca^{++} > Mg^{++} > Cl^- > SO_4^= > K^+$

Flood season: $(CO_3^= + HCO_3^-) > Ca^{++} > Na^+ > Mg^{++} > Cl^- > SO_4^= > K^+$

After the High Dam construction

$(CO_3^= + HCO_3^-) > Na^+ > Ca^{++} > Mg^{++} > Cl^- > SO_4^= > K^+$

After construction of the dam, the order of ions remained the same as during the low season before construction of the dam. In order to further expand the analysis, the water quality was studied in the High Dam lake as well as along the Nile course up to Cairo. The curves in Figure 1 illustrate variations in salinity concentration (ppm) in the Nile water along the course between Aswan and Cairo. The figure indicates that:

(i) the salt concentration in the waters 30 Km downstream from the High Dam amounts to 178 ppm and

(ii) the salt concentration increased until it reached a maximum of 208 ppm at the Naga-Hammadi barrages, beyond which it decreased gradually reaching a minimum of 168 ppm at the Assiut barrages, thereafter increasing again to 227 ppm at Cairo.

The concentration of salts in the Nile water at Cairo has risen due to the discharge from factories and other sources of pollution. Nevertheless, the salt concentration remains less than 300 ppm; hence, it is suitable for all irrigation purposes. The tolerance limit of 500 ppm may be reached after an estimated period of 100 years. However, it is expected that an equilibrium level concentration will be reached long before.

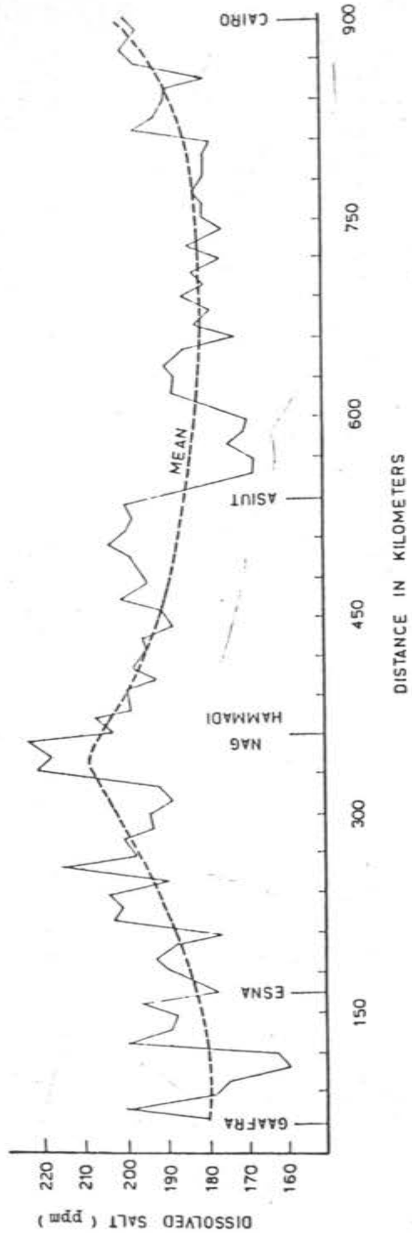

Fig.1. Salinity concentration of Nile water between Aswan and Cairo

CURRENT RATES OF SALINIZATION AND PREDICTION OF FUTURE TRENDS IN LAKE NASSER

As shown in Table 3, the levels of dissolved salts in Lake Nasser water in the month of May, before the flood season, during the years 1975, 1976 and 1977 were recorded as 175, 151 and 146 ppm, respectively. Prior to the High Dam construction, the salt concentration ranged between 115 ppm during the flood period and 204 ppm before it. This means that at present the average concentration of salts in the lake water is far lower than what it was prior to the High Dam construction in the period preceeding the floods.

TABLE 3. Salt Concentration in Lake Nasser Before Floods 1975-1977

(ppm)

Date	Depth in metres						
	Surface	10	20	30	40	50	60
25 May 1975	172	169	175	166	176	179	175
25 May 1976	151	151	142	152	157	150	154
23 June 1977	145	149	145	146	147	146	141
Mean	157	156	154	154	160	158	157

Source: The Aswan High Dam Authority

It has been estimated that the salt concentration in the lake water will rise to about 235 ppm by the time the lake is completely filled. Thereafter, it would rise at lower rates, depending on the volume of annual releases and the river yield during flood seasons (El-Gabaly, 1978). The concentration of 235 ppm is not harmful. Therefore, the aim in the following sections is to calculate the salt balance and rate of salinization. This information is analysed in terms of alternate strategies of storage and releases of water from the lake.

The impoundment of Lake Nasser /Nubia (Figure 2) started in 1964 and reached the highest level (120×10^9 m^3) in October 1975. The first 30×10^9 m^3 are "dead storage". The live storage up to the spillway level of 183 m above sea level, is about 45×10^9 m^3 which is meant for storage of floods and annual regulation. As the lake filled up and the lake surface expanded, a considerable volume of the stored water was lost due to evaporation. A 2.5 metre-thick sheet of water is lost each year due to evaporation. Infiltration into the permeable parts of the lake banks account for about 10 percent of total losses. At an average concentration of 200 ppm, the lake waters converted into vapor over an assumed lake surface of 5 000 Km^2 (already exceeded by the present lake level), will leave behind 2.2 million tons of dissolved solids per year1/. For the remaining volume of 110×10^9 m^3 of water in the lake, this increase is equal to:

$$\frac{2.2 \times 10^6 \text{ tons}}{110 \times 10^9 \text{ m}^3} = 20 \text{ g/m}^3 \text{ or } 20 \text{ ppm.}$$

1/ It is intended to maintain the water level in the lake between 170 m and 180 m above sea level, corresponding to a lake surface of 4,500 Km^2 and 6,840 Km^2 , respectively.

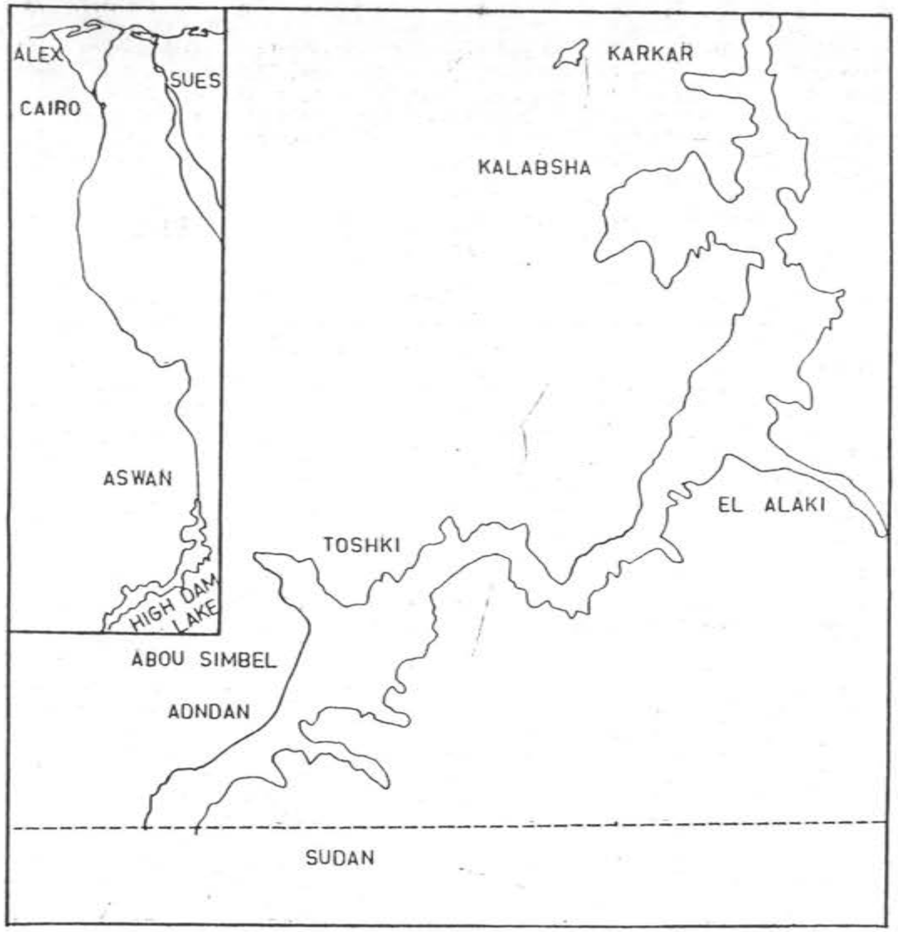

Fig.2. High Dam lake

Thus, if the water entering the lake contains 200 ppm dissolved solids, this will increase to 220 ppm as a result of evaporation losses. The concentration will keep increasing until the dissolved solids building up in the lake are equal to those released from the lake, i.e.,

$$\sum_{t=1}^{n} Q_{1_t} \cdot C_{1_t} = \sum_{t=1}^{n} Q_{2_t} \cdot C_{2_t} \qquad (1)$$

(inflow) = (outflow)

where Q_1 and C_1 are discharge and concentration of inflow in year t
Q_2 and C_2 are discharge and concentration of outflow in year t

This applies on the assumption that dissolved solids will stay in solution inside the lake. However, two factors need to be considered in this respect:

a) In addition to dissolved solids, the river carries considerable sediment load, which gets deposited as the flow velocity decreases after the river enters the lake. On an average, 100 million tons of silt are deposited each year. This consists of about 60 percent montmorillonite clay particles, which are a weathered product of the Ethiopian plateau basalts. The montmorillonite has an absorption capacity of 80-100 meq./100g. During the complex colloidal process of deposition of sediments, dissolved solids are withdrawn from the aquatic environment and deposited with the silt. The salt absorption of the solid phase is more effective if the surrounding solution is more diluted. This absorption has been demonstrated by the measurements carried out by the Aswan High Dam Authority during the 1975-77 period at different depths from the surface down to 60 m (Table 3). Data show that absorption values are constant from the surface to the bottom, indicating a perfect mixing of the water as far as conductivity is concerned.

b) The infiltration losses into the permeable lake banks also reduce the salt content. If infiltration losses are considerable, equation (1) should be replaced by equation (2) below, which takes into account the absorption mentioned under a).

$$\sum_{t=1}^{n} Q_{1_t} \cdot C_{1_t} = \sum_{t=1}^{n} Q_{2_t} \cdot C_{2_t} - A - I \qquad (2)$$

where A = salt absorbed (by sediments)
I = salt infiltrated

The salt balance of Lake Nasser in combination with the water balance will provide a means to split up total water losses into evaporation losses (on the basis of salt balance) and infiltration losses (total losses minus evaporation losses). 1/

Due to the effect of leaching during the previous regime of the Nile, the Nile valley downstream of Aswan did not contain excessive amounts of salt. In order to keep the situation as it was before, the following equation has to be satisfied:

1/ The average annual evaporation from the High Dam lake was estimated to be about 10 milliard m^3 of water. The infiltration losses were estimated at 3 milliard m^3 of water per annum.

$$\sum_{t=1}^{n} Q_{i_t} \cdot C_{i_t} = \sum_{t=1}^{n} Q_{M_t} \cdot C_{M_t} \qquad (3)$$

where $Q_{M_t} \cdot C_{M_t}$ is the output in the Mediterranean and

$Q_{i_t} \cdot C_{i_t}$ represents concentrations at different points between the High Dam and the Mediterranean.

A deficit in salt reaching the sea will be an indicator of salt accumulation somewhere in the soils of the Egyptian Nile valley. That would mean that the closure of the Nile by the High Dam might have triggered a process which could result in land going out of production due to salinization.

THE EFFECTS OF THE HIGH DAM ON SOILS

The alluvial soils of Egypt are formed by continuous deposition of decomposed volcanic matter carried by the Nile from the Abyssinian highlands. This deposition process has been taking place over a period of ten thousand years. The average depth of the Nile alluvium is 8.3 m in Upper Egypt and 9.8 m in Lower Egypt. The average annual rate of deposition is about one millimetre. Observations made during the first year after completion of the High Dam indicate that the reservoir is losing about 60 million m^3 of storage capacity per year due to sedimentation. As a result of sedimentation in the reservoir, clear water is now flowing downstream. Therefore, long-term effects of storing the Nile water on its suspension and contents and, in turn, their effect on the fertility of the agricultural land would need to be studied.

Table 4 presents the average concentration of suspended matter at El-Gaafra, 30 Km downstream from Aswan, before and after the construction of High Dam. The concentration of suspended matter in the Nile water, as shown in Table 4 is relatively smaller after the construction of High Dam than before its construction. During the 1968-76 period, it varied between 41 and 51 ppm, while the range was between 42 and 2 702 ppm before the construction of High Dam. In 1964, the first year of harnessing the flood, the suspended matter content was reduced by about 83 percent compared to that in 1963; and in 1976 the reduction was 91 percent. The data also show that the main difference in salt concentration between pre and post-dam period is during the flood season. Hence, the high levels of suspended matter that used to appear in July, August, September and October dropped significantly after the construction of High Dam, while the concentration remained approximately the same in other months of the year. Most of this material is deposited on the bottom of Lake Nasser, due to the long storage of water.

The quantity of suspended matter which the river used to carry every year before the construction of High Dam was about 134 million tons, of which approximately 125 million tons were during the flood months. Most of this load used to flow with flood water to the sea. The actual deposition on land within Egypt did not exceed 12 percent of the total sediment load, which amounted to 16 million tons. After the construction of High Dam, the water released is relatively clear and carries only 3 percent of the total load of suspended matter in the river. Thus, the quantity of sediments deposited on land each year now amounts to 4 million tons only. If this quantity was to be distributed over the commanded agricultural area, the deposition would not have exceeded 0.5 mm in thickness. Thus, the amount of suspended matter deposited on Egyptian lands after the construction of High Dam does not exceed 9 percent of the river's total suspended load. Egyptian soils are, therefore, deprived of 12 million tons of silt each year. Two-thirds of this quantity (i.e., 8 million tons) used to be deposited on the basin land during the flood period. Thus, the amount of suspended matter of which the non-basin Egyptian soils are deprived does not exceed 4 million tons annually.

TABLE 4. Average Amount of Suspended Matter at El-Gaafra Before and After the Construction of High Dam, 1958-63, 1964 and 1968-76

(ppm)

Month a/	1958-1963	1964	1968-1976
January	64	52	44
February	50	48	47
March	45	46	45
April	42	45	50
May	43	49	51
June	85	53	49
July	674	121	48
August	2 702	353	45
September	2 422	215	41
October	925	152	43
November	124	56	48
December	77	44	47
Mean	605	104	46

Source: Ministry of Irrigation

a/ July through October are flood months.

Note: 1963: prior to the High Dam; 1964: the beginning of partial storage upstream of the High Dam and 1968: first year of full-flood water retention.

Numerous chemical anslyses have been conducted for over 100 years to examine the fertility value of the suspended matter (Magdly, 1887; Burns, 1888; Lucas, 1906; Simaika, 1933, Mosseri, 1936 and Nabham, 1966). A comparison of results obtained before the construction of High Dam with those obtained from analyses in 1964 is presented in Table 5. The following conclusions can be derived from these data:

(i) There was a slight decrease in total Ca content from 4.61 percent in 1963 to 4.53 percent in 1964; the decrease in Mg content was from 3.68 to 3.20 percent.

(ii) The total K content increased slightly from 0.79 percent during 1963 to 0.82 percent in 1964.

(iii) A marked decrease occurred in total N and total P contents. Total N decreased from 0.12 to 0.08 percent and total P from 0.18 to 0.12 percent.

(iv) The iron, manganese and zinc contents decreased; iron from 9.01 to 7.97 percent, manganese from 0.15 to 0.11 percent and zinc from 0.03 to 0.02 percent.

However, the drop in the components of suspended matter of the Nile water after the construction of High Dam had almost no effect on the fertility of agricultural soils. Table 6 shows the yield per acre of the main agricultural crops before and after the construction of High Dam. The data show that the drop in the suspended matter of the river water after the High Dam construction has, so far, had no effect on the fertility of the soils. On the contracy, the productivity has increased, partly as a result of improved irrigation and availability of water at the right time and in required quantities throughout the year.

TABLE 5. Chemical Analyses of Suspended Matter in the Nile Water (as element percent)

Element	1925-1927	1963	1964
Ca	2.97	4.61	4.53
Mg	2.07	3.68	3.20
Na	1.35	2.07	1.44
K	0.44	0.79	0.82
Fe	3.47	9.01	7.97
N	0.13	0.12	0.08
P	0.05	0.18	0.12
Mn	0.17	0.15	0.11
Zn	-	0.03	0.02

Source: 1925-27: Mosseri, 1936 and Ball, 1939; 1963: Nabhan, 1966; and 1964: the beginning of partial storage upstream of the High Dam.

TABLE 6. Average Yield per Acre of Main Crops Before and After the Construction of High Dam, 1958/62 and 1970/76

Crop	Unit of production	Before construction 1958/62	After construction 1970/76
Wheat	Ardeb (=150 Kg)	6.75	9.01
Maize	Ardeb (=190 Kg)	9.10	11.95
Cotton	Kentar (= 45 Kg)	4.61	6.25
Rice	Tons	2.11	2.22
Sugarcane	Tons	38.49	36.77
Beans	Ardeb (=155 Kg)	4.44	6.33
Barley	Ardeb (=120 Kg)	8.55	9.42
Peanuts	Ardeb (= 75 Kg)	11.35	11.71
Flax	Kentar (= 45 Kg)	3.32	3.98
Onions	Tons	5.73	8.15
Sesame	Ardeb (= 120 Kg)	3.66	4.31

Source: Ministry of Agriculture

CONCLUSIONS

The results of the chemical analyses of the Nile water before and after the construction of High Dam show that the river is in a state of equilibrium in respect of alkalinity, salinity and hardness. Also, the impoundment of the water behind High Dam has had no significant impact on water quality and suitability for irrigation downstream. While the Egyptian land has been deprived of relatively high amounts of fertile silt, agricultural production has increased as a result of improved irrigation and availability of water at the right time and in required quantities throughout the year.

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