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Changes in the Quality of Nile Water in Egypt During the Twenty-Five Years, 1954–1979

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Summary. The study describes the variation in the chemical constituents of the Nile water at Giza, through the twenty-five years from 1954 to 1979 i.e., before and after the construction of the High Dam at Aswan.

The total soluble salt content increased significantly by 29% after the construction of the High Dam, mainly due to the seepage of drainage water from the cultivated land of the Nile Valley. The SO_4^{--}, Cl^-, K^+, Na^+ & Mg^{++} content increased significantly during the period of study, while the increase in pH values, HCO_3^- and Ca^{++} contents was not significant.

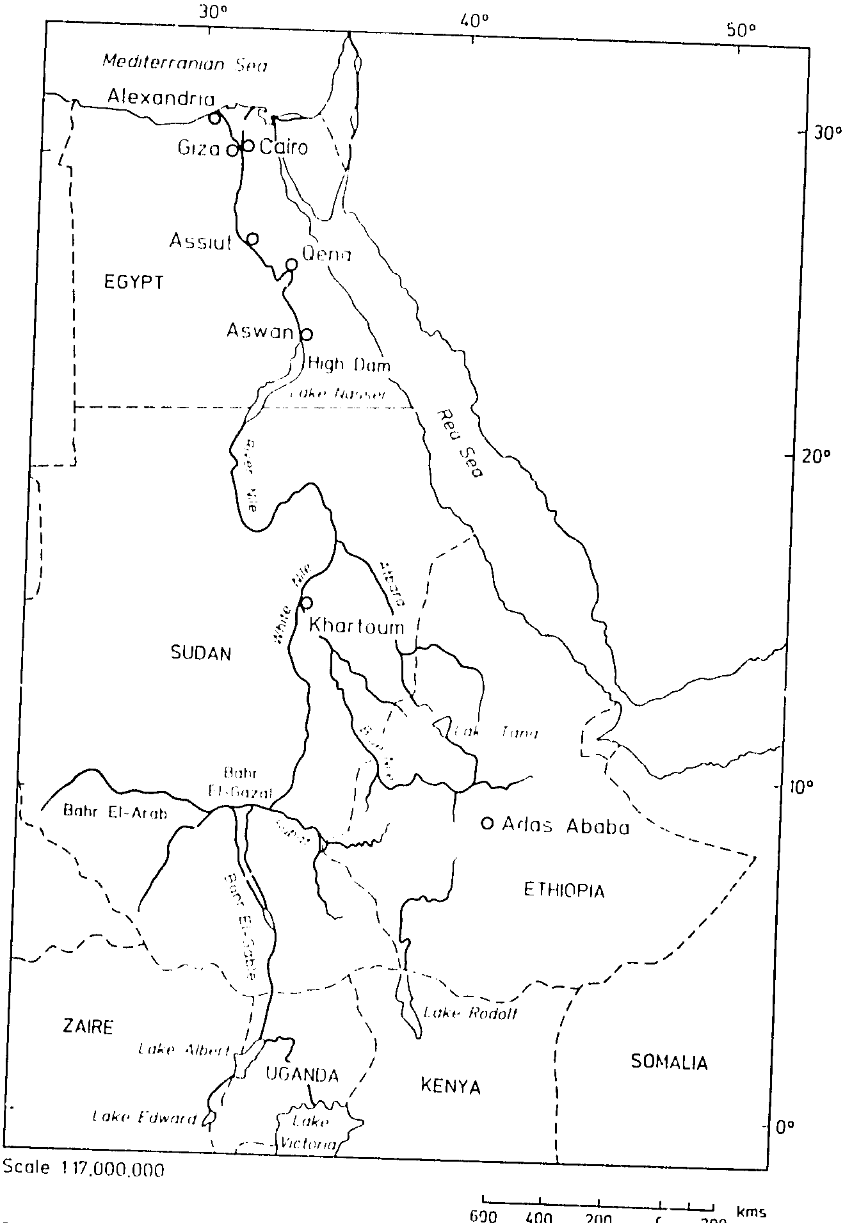
The suspended matter content decreased significantly by 94% from 1964 to 1979 due to the effect of the High Dam. The increase in silica content was significant while the decrease in oxygen content was not significant. No obvious variations were detected in chloride content, total alkalinity and total hardness during the study period.

According to the ionic coefficients ratios and the geochemical classification, Nile water currently can be evaluated for irrigation purposes as falling within the class excellent – good and highly satisfactory for domestic purposes.

Introduction

The Nile receives its waters from the Equatorial lakes and the Ethiopian plateau throughout the year. During the autumn flood period the river carries large amounts of water due to the heavy rainfall on the Ethiopian plateau.

The total length of the Nile from its source near lake Tanganika to its mouth in the Mediterranean is more than 6700 km; the final sector of nearly 1530 km lies within the borders of Egypt (Map 1). After entering Egypt at Wadi Halfa, the Nile flows for more than 300 km till it reaches Aswan in a narrow valley, with cliffs of sandstone and granite on both sides. Downstream of Aswan, the valley begins to broaden and flat strips of cultivated land appear, gradually increasing in width northwards. The average width of the flood plain of the Nile between Aswan and Cairo is 10 km. After passing Cairo the Nile pursues a north-westerly direction for



Map. 1. The Nile Basin

some twenty km and then divides into the Damietta and Rosetta branches. Cultivation in the Nile Valley and Delta is totally dependent on irrigation from the Nile.

The Aswan High Dam was constructed to utilise the large amounts of the Nile water which previously flowed into the sea at the flood time. Its construction was completed in 1970 and consists of a rock filled body, 11 km south of Aswan. It is 3600 m long, of which 250 m is between the two banks of the river, with a sand foundation and aprons. Its total height is 111 m with a width of 40 m at the top. The dead storage capacity of the Dam is about 120×10^9 m^3. The water is stored in a wide artificial lake stretching to the north of Sudan. The lake is 500 km in length, 10 km in average width and 95 m depth. The capacity of the lake is about 157×10^9 m^3, four times the annual flow of the Nile.

It is worth noting that the High Dam was planned to provide sufficient water to reclaim about 0.526 million hectares and to convert 283,000 ha from the basin to the perennial irrigation system. It generates 10×10^9 kWh per year of hydroelectric power and its storage capacity protects the country from the effects of both high and low floods.

The chemical composition of Nile water has been studied by several authors: Kaddah (1954), Hamdi (1959), Mostafa et al. (1959) Hafez (1962) Nabhan (1966), Fathi and Soliman (1972) and Hilal and Rasheed (1976).

Materials and Methods

Water samples were collected monthly from the Nile midstream at Giza, during the years 1954, 1964, 1973 and 1979. The samples were analyzed with regard to the following properties: pH, total soluble salts, soluble cations and anions, the amount of suspended matter, silica, chlorine, oxygen, total alkalinity and hardness. The methods used for analysis are those of the Amer. Public Health Association (1971).

Results were statistically analysed using the F test to test for significance.

Results and Discussion

pH

Table 1 indicates that all the water samples are slightly basic due to the presence of carbonate and bicarbonate salts. pH generally varied from 7.8 to 8.0 with an average of 8.0 during the flood period and from 7.8 to 8.3 with an average of 8.1 during the rest of the year. After the High Dam's construction pH values varied from 8.0 to 8.3 with an average of 8.2. This slight increase, probably due to the increase of carbonate and bicarbonate ions, is not statistically significant.

Total Soluble Salts

Table 1 shows that before the construction of the High Dam the values of total soluble salts varied from 154 ppm in September 1964 to 259 ppm in July 1964. During the flood season, August to November, the soluble salt content decreased generally, with an average value of 182 ppm. During this season, the flood water, which results from the high rainfall on the Ethiopian plateau, reaches the Nile stream through the Blue Nile and Atbara river. The slight increase in soluble salt content in the low season, with an average of 194 ppm, probably results from the fact that the major water source is the White Nile which contains relatively more soluble salts. In addition, the calculated 2300×10^6 m^3 per year of drainage water which makes its way to the river in southern Egypt also affects the water salinity.

Table 1. Changes in the chemical composition of Nile water at Giza and at Lake Nasser

Date of sampling month	year	pH value	TDS ppm	(ppm) Cations				Anions			
				Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	SO_4^{-2}	Cl^{-}
January	1954	8.1	190	30	9	16	3	10	134	11	18
	1964	8.0	172	26	9	25	3	26	100	10	13
	1973	8.3	225	31	13	39	5	22	139	33	27
	1979	8.0	237	26	10	21	7	6	140	7	26
February	1954	7.9	188	28	7	24	3	11	110	17	17
	1964	7.9	176	27	10	28	4	36	99	9	18
	1973	8.3	238	28	10	34	4	36	100	22	23
	1979	8.0	237	20	12	24	6	6	134	24	19
March	1954	8.0	210	32	9	23	3	12	132	4	24
	1964	8.1	183	28	10	32	3	22	144	10	16
	1973	8.3	208	27	13	32	5	19	127	25	23
	1979	8.1	240	26	12	26	5	7	140	15	22
April	1954	8.0	216	32	10	22	4	7	141	6	25
	1964	8.1	190	29	11	39	4	7	195	11	20
	1973	8.3	208	27	13	30	5	13	134	24	22
	1979	8.1	235	20	12	32	5	8	159	11	27
May	1954	8.1	207	31	10	24	4	23	122	14	21
	1964	8.1	204	29	13	37	6	31	154	12	22
	1973	8.3	210	25	13	34	6	28	112	22	24
	1979	8.1	252	24	14	35	7	10	130	18	25
June	1954	8.1	176	28	9	23	5	29	98	3	16
	1964	8.2	242	28	14	44	6	17	203	13	20
	1973	8.3	180	25	10	41	5	38	89	20	20
	1979	8.1	240	22	12	32	6	10	153	19	27
July	1954	8.3	165	32	4	14	3	7	112	3	14
	1964	8.3	259	27	12	48	6	38	166	13	20
	1973	8.3	175	25	9	41	4	42	79	21	20
	1979	8.0	232	28	9	20	8	6	122	19	20
August	1954	8.0	200	27	8	16	3	7	117	14	7
	1964	8.0	251	26	11	30	6	19	149	11	15
	1973	8.2	175	28	8	34	4	38	87	22	20
	1979	8.3	230	28	10	21	8	9	131	8	15
September	1954	8.1	167	31	9	11	4	13	139	12	7
	1964	7.9	154	32	11	14	5	12	116	8	11
	1973	8.3	200	27	11	37	6	17	135	22	22
	1979	8.0	234	24	11	23	6	5	128	12	25
October	1954	8.0	169	33	7	14	3	13	139	13	10
	1964	7.9	172	22	10	14	3	12	115	10	12
	1973	8.3	226	28	12	39	5	37	106	21	27
	1979	8.0	250	28	12	23	6	6	134	19	27
November	1954	8.0	169	28	7	16	3	8	132	14	6
	1964	7.9	172	21	9	18	3	10	110	9	10
	1973	8.3	226	29	12	39	6	34	112	24	26
	1979	8.1	240	22	12	30	6	6	153	16	26

Table 1 (continued)

Date of sampling month	year	pH value	TDS ppm	(ppm) Cations				Anions			
				Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3	SO_4^{-2}	Cl
December	1954	8.0	155	23	11	12	3	12	107	8	7
	1964	7.8	166	21	10	21	3	29	95	9	10
	1973	8.3	230	32	10	39	5	23	126	22	26
	1979	8.1	240	22	12	30	6	7	140	24	27
L.S.D.			26	3.2	1.8	7.6	1.1	4.4	24	4.5	5.0
At Giza Before High Dam	average during flood	8.0	182	27	9	17	4	9	128	12	10
	during low season	8.1	194	28	10	27	4	20	132	10	18
At Giza After High Dam		8.2	223	26	11	31	6	16	126	23	23
Lake Nasser before flood	1972	8.2	171	19	9	19	4	9	122	7	7
Lake Nasser after flood	1972	8.1	168	17	10	24	6	18	104	10	8

After the High Dam's construction, the total soluble salt concentration measured at Giza increased markedly, ranging between 175 and 250 ppm, with an average of 225 ppm during 1973. Its continued increase from 1973 (average of 209 ppm) to 1979 (average of 238 ppm) was probably due to the continuous seepage of ground water from the adjacent Pleistocene aquifer with its higher level and salt concentration to the Nile with its relatively lower level and salt concentration. The level difference between the two water bodies which is more than 40 cm, explains the fact that the Nile acts as a drain to the Nile valley system.

The seasonal fluctuation in salt concentration in the Nile water during the year may be due to the variation in the quantity and quality of the drainage water throughout the year, as well as the variation in water discharge rate of the river in different seasons documented in Table 2.

In summary, it may be concluded that the total soluble salt content of Nile water increased by 23% from 1964 (before the High Dam) to 1973 (after the High Dam) while this increase reached 29% during the entire twenty five years of study from 1954 to 1979. This increase is statistically significant.

Ion Concentration and Distribution

Table 1 shows the variation in the ionic concentration throughout the twenty five years of study, before and after the High Dam. The results are as follows:

Table 2. Water discharge of the Nile throughout the year (10^6 m^3 per day)

Year	Months											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1958	74	50	52	45	48	70	96	491	680	420	270	116
1970/75 (average)	93	85	89	86	89	126	141	133	106	79	79	82

Before the Construction of the High Dam: During the non-flood period (December to July), the water discharge in the river was low and a relative increase in the different ion concentrations occurred, especially in sodium, chloride and sulphate ions. This may be attributed to the effect of drainage water which enters the river in upper Egypt.

During the flood season (August to November) the contrary occurs, i.e., the ion concentration decreased relatively, due to the higher water discharge rate of the river which in turn dilutes the salt concentration.

After the construction of the High Dam: As a general trend, a relative increase in the ion concentration was noted. However, the small increases and decreases of the major constituents from one month to another do not show any marked trends. In fact, the obvious decrease in ion concentration through the period of January September especially in 1973 was mostly related to the relative increase in the water discharge during this period. On the other hand, the dominance of sodium ions, which are mostly combined with chlorides and sulphates, may well be due to recharge of the river from the ground water.

As the water now in the Nile mainly represents the composition of water stored in the High Dam lake, the chemical analysis of the lake water is given in Table 1 for comparison with that of the Nile water. The lake water is subject to different environmental processes. The high temperature in the region of the lake accelerates evaporation and weathering processes. In addition the production of CO_2 from the aquatic plants in the lake help the transformation of calcite and dolomite to soluble calcium and magnesium bicarbonate. Such biological activity may considerably affect the chemical properties of the water in the lake. Table 1 shows that sulphate and chloride salts are higher in the Nile water than in the lake water. This may be due to the effect of the water draining into the Nile during its flow through upper Egypt.

Suspended Matter

The suspended matter in the Nile originates from the disintegration and weathering products of the igneous and metamorphic rocks of the Ethiopian plateau. In the present work the content of suspended matter was determined in 1964 (before the High Dam) and in 1979 (after the High Dam) as in Table 3.

In 1964 the content of suspended matter was variable throughout the year, reaching a maximum of 3000 ppm during the flood season in September and gradually decreasing to 1800 ppm in October and to 300 ppm in November, during the same year. During the low season the values range between 22 and 80 ppm.

Table 3. Some chemcial properties of Nile water before and after the construction of the High Dam

(ppm)	Month Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
Suspended matter	1964	61	40	24	26	22	25	45	1700	3000	1800	300	80	594
	1979	100	80	30	30	25	20	20	15	18	30	28	25	35
Silica	1954	12	10	14	9	12	7	15	14	8	17	15	13	12
	1964	8	8	12	14	14	8	12	16	10	10	20	10	12
	1973	17	16	20	21	18	16	16	17	13	13	16	16	17
Chlorine	1954	0.5	0.4	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.4	0.4
	1964	0.4	0.4	0.3	0.4	0.4	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.4
	1973	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.4
Oxygen (consumed)	1964	6	5	5	5	5	7	10	11	9	8	6	6	7.5
	1973	6	7	5	5	4	4	5	4	3	2	6	6	5
Total Alkalinity	1954	127	109	128	127	139	129	104	108	136	136	122	108	114
	1964	126	141	155	172	178	195	200	154	115	95	107	127	147
	1973	151	142	136	121	139	137	135	135	139	149	149	142	140
	1979	125	120	...	132	...	125	110	122	113	120	125	114	121
Total Hardness	1954	112	99	117	121	119	107	97	100	115	111	99	103	108
	1964	138	109	111	118	126	128	117	110	125	96	90	94	114
	1973	131	111	121	121	116	104	100	103	113	119	122	121	115
	1979	106	99	...	99	...	105	107	111	105	119	104	104	106

After the construction of the High Dam, the content of suspended matter dropped markedly through the period from March to December 1979. It ranged between 15 ppm in August to 100 ppm in January. The increase recorded in January and February of 1979 was the result of the unusually heavy rainfall in upper Egypt that year which filled many of the Eastern desert wadis. These later drained into the Nile carrying large amounts of weathered materials. The average of suspended matter during the year 1979 was 35 ppm. The relative decrease in suspended matter content from 1964 to 1979 was 94% which is highly significant.

Silica

The presence of silica in Nile water comes from the decomposition of silicate minerals which occur in large amounts in many rocks surrounding the river. They eventually break down into clay minerals, resulting in free silica. The temperature and amount and rate of water movement through the rock all effect the weathering processes and consequently the silica content in water. Silica and also alkali in the Nile water is mainly derived from the weathering of metamorphic and igneous rocks in southern Sudan and the basic volcanic rocks of the Ethiopean plateau. Table 3 shows that the silica content of the Nile water varied from 7 to 21 ppm during the whole period of study. Before the High Dam, during the years 1954 and 1964, the average content of silica was 12 ppm. After the High Dam, the average content increased to 17 ppm, an increase of 42%. This increase is significant and probably due to the weathering of silicate formations surrounding the High Dam Lake.

Residual Chlorine

Table 3 indicates that during the whole period of study the residual chlorine varied from 0.3 to 0.6 ppm. Before the High Dam the averages recorded were: 0.36 and 0.39 ppm for the flood and the low season, respectively. No significant variation was detected after the High Dam, the average being approximately 0.4 ppm.

Oxygen

The values of oxygen consumed shown in Table 3 range between 2 and 11 ppm during the whole period of study. During the flood season of 1964 the consumed oxygen had an average value of 8.5 ppm, which decreased slightly during the low season to 6.0 ppm with an average of 7.0 ppm. However in 1973, after the High Dam's construction, this average decreased to 5.0 ppm. This decrease was not significant and was probably due to the decrease of organic matter in water after the High Dam.

Total Alkalinity

Table 3 indicated that before the High Dam the total alkalinity of the Nile water during the year 1954 and 1964 varied from 95 to 200 ppm, with an average of 119 ppm during the flood season and 142 ppm during the low season. After the High Dam's construction, during the years of 1973 and 1979, the alkalinity varied from 110 to 151 ppm with an average of 131 ppm. Before the High Dam, alkalinity increased from 114 ppm in 1954 to 147 ppm in 1964, an increase of 29%. After the Dam's construction the contrary occurred and the alkalinity decreased from 140 ppm in 1973 to 121 ppm in 1979, a change of 13%. As a general trend, the increase in alkalinity content from 1954 to 1979 was not significant.

Total Hardness

In the present study, hardness (Ca + Mg) was calculated by multiplying the concentration of both Ca and Mg cations (mg/L) by the factor equivalent to $CaCO_3$ concentration.

$$Hardness\ (ppm) = Ca^{++} \times 2.497 + Mg^{++} \times 4.116 = CaCO_3\ Equivalent$$

Table 3 shows that the hardness values for the Nile water samples varied from 90 to 138 ppm during the period before the High Dam's construction. Hardness values varied from 105 ppm during the flood seasons to 111 during the low seasons of 1954 and 1964. The total average for these years was 108 and 114 ppm respectively. After the High Dam's construction, significant seasonal variation was detected. The average content decreased slightly from 115 ppm in 1973 to 106 ppm in 1979. No obvious trend in variation was detected over the whole 25 years of study.

Bicarbonate

Bicarbonate ions generally have the highest concentration of the anions showing a gradual increase through the low water flow season (Table 1), and a marked drop to its lowest concentration in the flood season as in the year 1964. After the High Dam's construction, bicarbonate concentration generally increased through the years 1973 and 1979. The increase during October to December is related to the reduction of river water discharge rate at this period. Generally bicarbonate combines with Calcium, Magnesium and Sodium ions as shown in Fig. 1.

Sulphate

No marked variation with time was detected before the construction of the High Dam. However, after the High Dam, sulphate content increased, especially during 1973 due to drainage to the river of ground water rich in sulphate. Sulphate is present mainly in its sodium and potassium forms (Table 1 and Fig. 1).

Chloride

Chloride ions increased markedly within the low season of 1954 and 1964. The opposite occurred within the flood period of the same years. After the construction of the High Dam, chloride concentrations showed a general increase over the years 1973 and 1979. Chloride is present mainly in the forms of sodium and potassium chloride (Fig. 1).

Salt Type and Concentration

The hypothetical salt combination of the Nile water before and after the High Dam construction and also that of the High Dam Lake water is represented

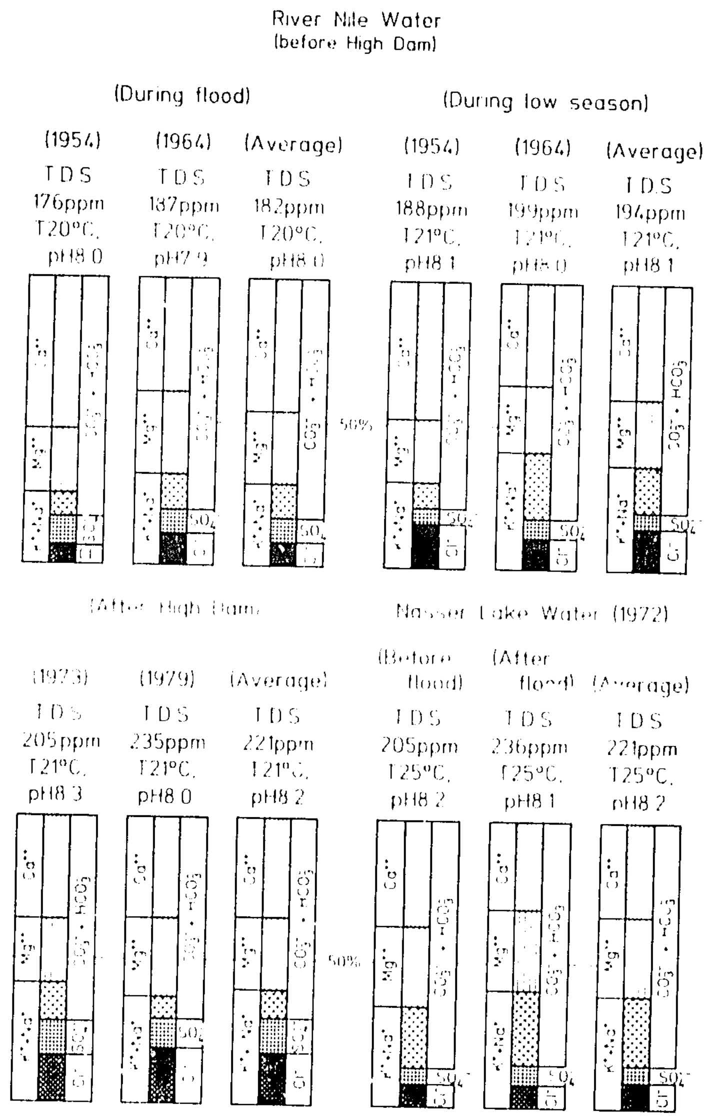


Fig. 1. Graphical representation of water chemical analyses

$Ca(HCO_3)_2$

$Mg(HCO_3)_2$

$(Na+K)_2\ HCO_3$

$(Na+K)_2\ SO_4$

$(Na+K)\ Cl$

graphically according to Palmer's method (Geological Survey of USA 1959) in Fig. 1. From this Figure it can be stated that Nile water is composed mainly of $Ca(HCO_3)_2$ followed by lesser amounts of $(Na+K)HCO_3$, $(Na+K)Cl$ and $(Na+K)SO_4$. Seasonal and spatial variations in the content of these salts were also detected. The average content of $Ca(HCO_3)_2$ salts decreased markedly from 45.8% (during the flood season) and 40.4% (during low season) before the construction of the High Dam to 34.9% after the High Dam. Also the $Mg(HCO_3)_2$ salts decrease slightly from 25.4% (during flood) to 23% (during low season) before the High Dam and slightly increased to 24.9% after the construction of the High Dam.

The content of $(Na+K)HCO_3$ salts increased markedly from 10.9% (during the flood) to 16.6% (during the low flow season) then again decreased to 9.9% after the construction of the High Dam. $(Na+K)Cl$ content showed a gradual increase from 9.6% during the flood season to 14.2% during the low season and to 17.7% after the High Dam. While the $(Na+K)_2CO_4$ content showed a slight decrease from 8.3% (during flood) to 5.6% (during low season) before the High Dam, it markedly increases to 12.6% after the High Dam.

It may be concluded from the above salt concentrations and distributions that after the construction of the High Dam, Nile water is generally characterized by a higher sodium chloride and sulphate content and a lesser sodium hydrocarbonate content.

On the other hand, the waters of the High Dam Lake is generally characterized by a lower calcium hydrocarbonate and sodium bicarbonate salt content compared to that of the Nile water at Giza. It can be assumed that the variation in the concentration of the above-mentioned salts in the lake water and the Nile water at Giza (at a distance of about 1000 km from the lake) is due mainly to the effect of the ground water draining into the Nile during its flow between the two locations.

The variation in salt concentrations of the Nile water through twenty-five years can be briefly summarized increases of 46% for $(Na+K)SO_4$, 37% for $(Na+K)Cl$, 25% $Mg(HCO_3)_2$ and 9% for $(Na+K)HCO_3$ and a decrease of 29% in $Ca(HCO_3)_2$ salts.

Hydrochemical Formula and Coefficients

The mean hydrochemical formula of the Nile water can be represented as follows according to the prevalence of the current ion concentration in decreasing order of abundance during the different seasons.

From the above formulae, the rank order of ion abundance before and after the High Dam construction can be established and is presented in Table 4.

Geochemical Classification of the Nile Water

The Nile water has been classified geochemically using the methods of Ovichinikov (1955) and Alukin (1946). According to the first method Nile water occupies the triangle 10 which defines surface water: the second method indicates that the Nile water fills in the bicarbonate class, calcium group and first type i.e., $HCO_3{}^{CA}_{I}$

Water Quality Evaluation

Determination of water quality is very important for both irrigation and domestic purposes. For irrigation purposes the standards proposed by U.S. Salinity Labora-

Table 4. Hydrochemical formulae and coefficients

	Total soluble salts gL^{-1}					
Nile at Giza during flood season (1954, 1964)		HCO_3 82.1	Cl 9.6	SO_4 8.3		
	0.18					T 20 °C, pH 8.0
		Ca 45.8	Na 25.4	Mg 25.4	K 3.4	
Nile at Giza during low season (1954, 1964)		HCO_3 80.2	Cl 14.2	SO_4 5.6		
	0.19					T 21 °C, pH 8.1
		Ca 40.4	Na 33.5	Mg 23.2	K 2.9	
Nile at Giza after the High Dam (1973, 1979)		HCO_3 69.7	Cl 17.7	SO_4 12.6		
	0.22					T 21 °C, pH 8.1
		Ca 36.2	Na 34.9	Mg 24.9	K 4.0	
High Dam Lake before flood season (1973)		HCO_3 86.9	Cl 7.5	SO_4 5.6		
	0.17					T 25 °C, ph 8.3
		Ca 36.2	Na 31.8	Mg 28.2	K 3.8	
High Dam Lake after flood season (1973)		HCO_3 84.8	Cl 7.7	SO_4 7.4		
	0.17					T 25 °C, pH 8.2
		Ca 36.4	Na 29.7	Mg 28.7	K 5.2	

tory Staff (1954), the Wilcox method (1955) and the Doneen method (1958) were used. Applying the Wilcox method the water falls in the 'excellent - good' class of irrigation water, while the Doneen method shows that this water is of second class for irrigation.

On the other hand, the suitability of the Nile water for domestic and drinking purposes was evaluated according to the standards of the U.S. Public Health Services (1962) indicating that the sampled waters are highly satisfactory.

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