Chapter 4
Chemical Environment

OXYGEN CONTENT

The main channel

The oxygen concentration of Lake Nasser varies seasonally, vertically and horizontally, and in general, ranges between 3 and 12 mg/l for the surface water, and from 0 to 8 mg/l for the bottom waters (Latif 1984a). In winter and spring the water column is well oxygenated. The oxygen concentration shows a rapid increase in the upper water layers with an increase in water temperature in April, when values above 150 % or even 200 % saturation are recorded, but it exhibits regional and seasonal differences with depth (Entz 1976).

Elewa (1980) and Latif (1984a) point out that thermal stratification coincides with the formation of an oxygenated epilimnion and oxygen-free hypolimnion. They add that the depth of the oxygenated epilimnion becomes deeper southwards. Thus, in the northern part of Lake Nasser the oxygenated layer is 8 m deep compared with 20 m at Adindan. In the northern part of Lake Nubia, the epilimnion was 23 m deep, while the southern part was completely oxygenated from the surface to the bottom (Table 29, Fig. 48).

In autumn the drop in temperature is accompanied by the initiation of destruction of oxygen stratification or, in other words, a gradual increase in thickness of the oxygenated layer (Fig. 50). In winter, the whole water column becomes oxygenated and thus the oxygen concentration does not show great variation between surface and bottom waters, as it is the case in summer (Fig. 50). Thus, through a year, a single overturn takes place in winter.

It is worth mentioning that, the destruction of thermal and oxygen stratification starts with the incoming flood in the southern part of Lake Nubia and progresses northwards along its whole length and further to the southernmost part of Lake Nasser. Here, the epilimnion becomes thicker than that in the remaining northern part of the reservoir. The metalimnion is at 50 m at Adindan (300 km from the High Dam) as compared with 25 m at Allaqi (100 km from the HD) and only 15 m in Khor El Ramla (9 km from the HD) in September 1970 (Entz 1976). Therefore, with the incoming flood in July 1974 (Fig. 49) the difference in temperature and oxygen content with depth becomes narrower up to the Second Cataract (near Wadi Halfa) than in the remaining northern part of the reservoir (Elewa 1980).

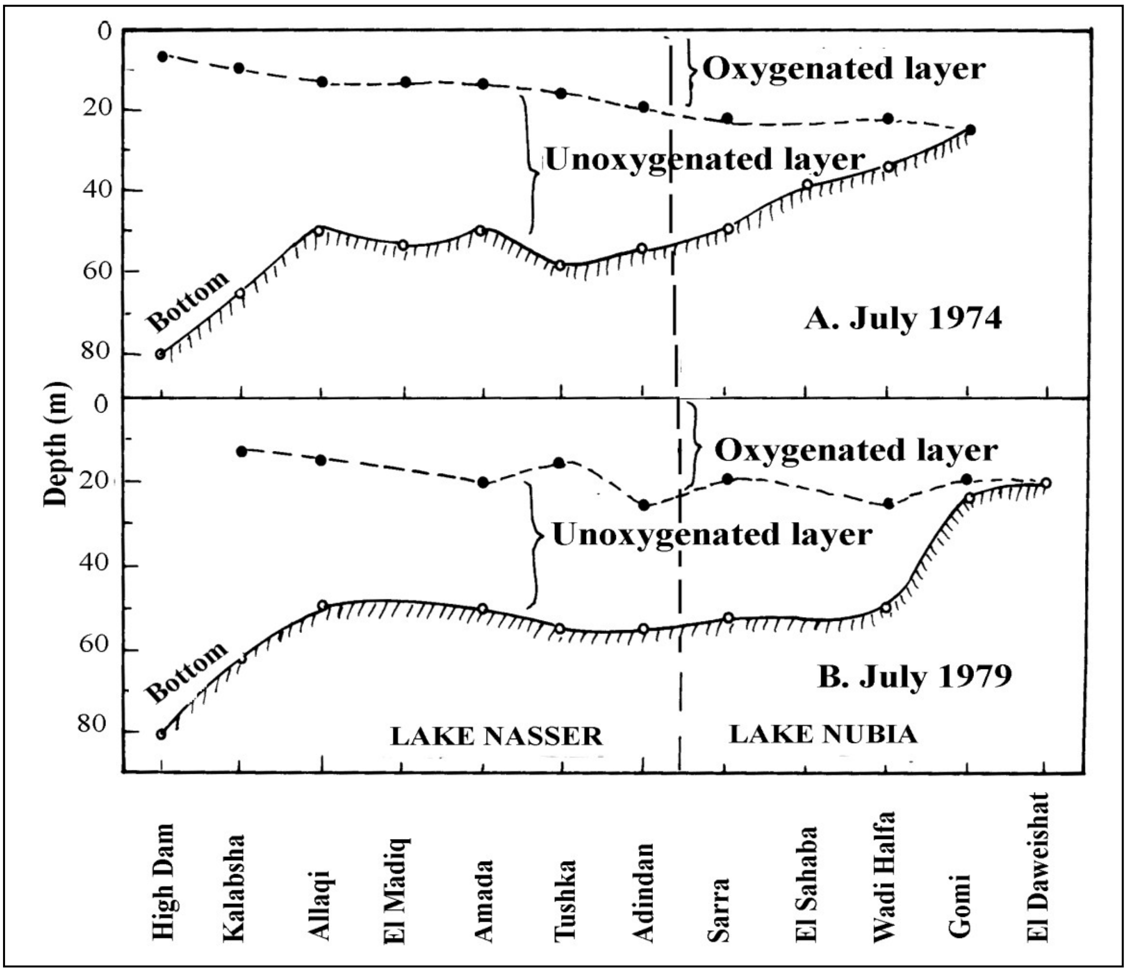

Fig. 48 **Depths of oxygenated and non-oxygenated layers along the main channel of the Aswan High Dam Reservoir in July 1974 and 1979 (Elewa 1980).**

Studies on the vertical and seasonal variations of the dissolved oxygen at six stations in Lake Nasser during 1985 (Abdel-Rahman & Goma 1992c) indicated that the water column was well oxygenated and was almost homogeneous from January to March (Fig. 51). During this period there were slight vertical variations of the dissolved oxygen, which may be related to difference in photosynthesis. The maximum value of dissolved oxygen was 8.3 ml/l (123.5 % saturation) at the surface layer at Abu Simbel in January. The minimum dissolved oxygen was 3.0 ml/l (43.5 % saturation) at the near bottom water layer at El Ramla. During the warm season, from May to August, the amount of dissolved oxygen showed significant vertical changes due to the summer stratification. There was a slight vertical variation of the dissolved oxygen from September to December at all stations except September and October at station 1 (Elewa 1980).

Table 29 **Oxygenated layer and total depth (m) at different stations along the main channel of Lake Nasser and Lake Nubia in July, 1974 and 1979 (Latif 1984a).**

Site	Distance from HD (km)	Total Depth (m)	Depth (m) Oxygenated layer (epilimnion) 1974	1979
Lake Nasser				
High Dam	3	82	8	--
Kalabsha	50	63	10	13
Allaqi	100	50	13	15
El-Madiq	130	53	13	18
Amada	200	50	13	20
Tushka	250	60	16	15
Adindan	300	55	20	25
Lake Nubia				
Sarra	310	50	23	20
El-Sahaba	340	40	23	--
Wadi Halfa	360	35	23	25
Gomi	375	25	25	20
El-Daweishat	410	20	--	20
Melik El-Nasser	448	20	20	20 (riverine)

In their study on the vertical distribution of dissolved oxygen at El Ramla (station 1) (Fig. 52) and Abu Simbel (station 6) (Fig. 53), Abdel-Rahman & Goma (1993) recorded maximum concentrations of dissolved oxygen (7.2 ml/l) at 5 m depth at station 6 in April (Fig. 52) and 6.2 ml/l at the surface of station 1 in May (Fig. 53). From August to September complete oxygen depletion was recorded at El Ramla (station 1) at 30-60 m depth, being the same as that recorded in 1985. Also, at depths 40 m or more in October and 50 m depth or more in November. It is considered that the low oxygen water mass exerts a harmful influence on the aquatic fauna of Lake Nasser.

Considering the vertical and seasonal distribution of dissolved oxygen at six stations during the period 1987 - 1992 (Tables 30 - 35 and Fig. 54), the maximum concentration of dissolved oxygen (10 ml/l) was recorded in spring 1991 at 5 m depth at Kalabsha. Generally, high oxygen concentrations were recorded at all stations in spring 1987 - 1992, particularly in 1991 and 1990. Thus, the concentration of dissolved oxygen was very high in spring 1991: 10 ml/l (at 5 m), 9.9 ml/l (at 5 m) 9.9 ml/l (at 0 m); 9.4 ml/l (at 5 m); 9.3 ml/l (at 5 m) and 9 ml/l (at 5 m) at Kalabsha, Korosko, Abu Simbel, Tushka, Allaqi and El Ramla, respectively. Nearly, the same picture was observed in spring 1990, being 9.5 ml/l (at 5 m), 9.4 ml/l (at 0 m), 8.9 ml/l (at 0 m), 8.9 ml/l (at 5 m), 8.7 ml/l (at 5 m), 8.5 ml/l (at 0 m), at Kalabsha, El Ramla, Allaqi, Korosko, Tushka and Abu Simbel respectively. Generally, in winter, the whole water mass is well oxygenated and almost homogeneous (Fig. 54). However, there is a slight variation of dissolved oxygen among the different depths in winter, and this is clearly observed at Kalabsha during 1991. Thus, the oxygen concentrations ranged between 7.9 and 8.2 ml/l at depths 80 to 0 m. A different picture was observed in summer (Fig. 53). Thus, moderate or high oxygen concentrations (4.1 - 8.7 ml/l) were recorded in surface water layers (0 - 5 m). With increase of depth, a sharp decrease in oxygen concentration was observed reaching 0 ml/l in bottom water layers. In different years and at different stations of Lake Nasser and during autumn, moderate and sometimes high concentrations of oxygen (3.7 - 9.1 ml/l) were recorded in the surface water layers. But, a slow decrease of oxygen concentration was observed with the increase of depth, sometimes reaching 0 ml/l in bottom layers.

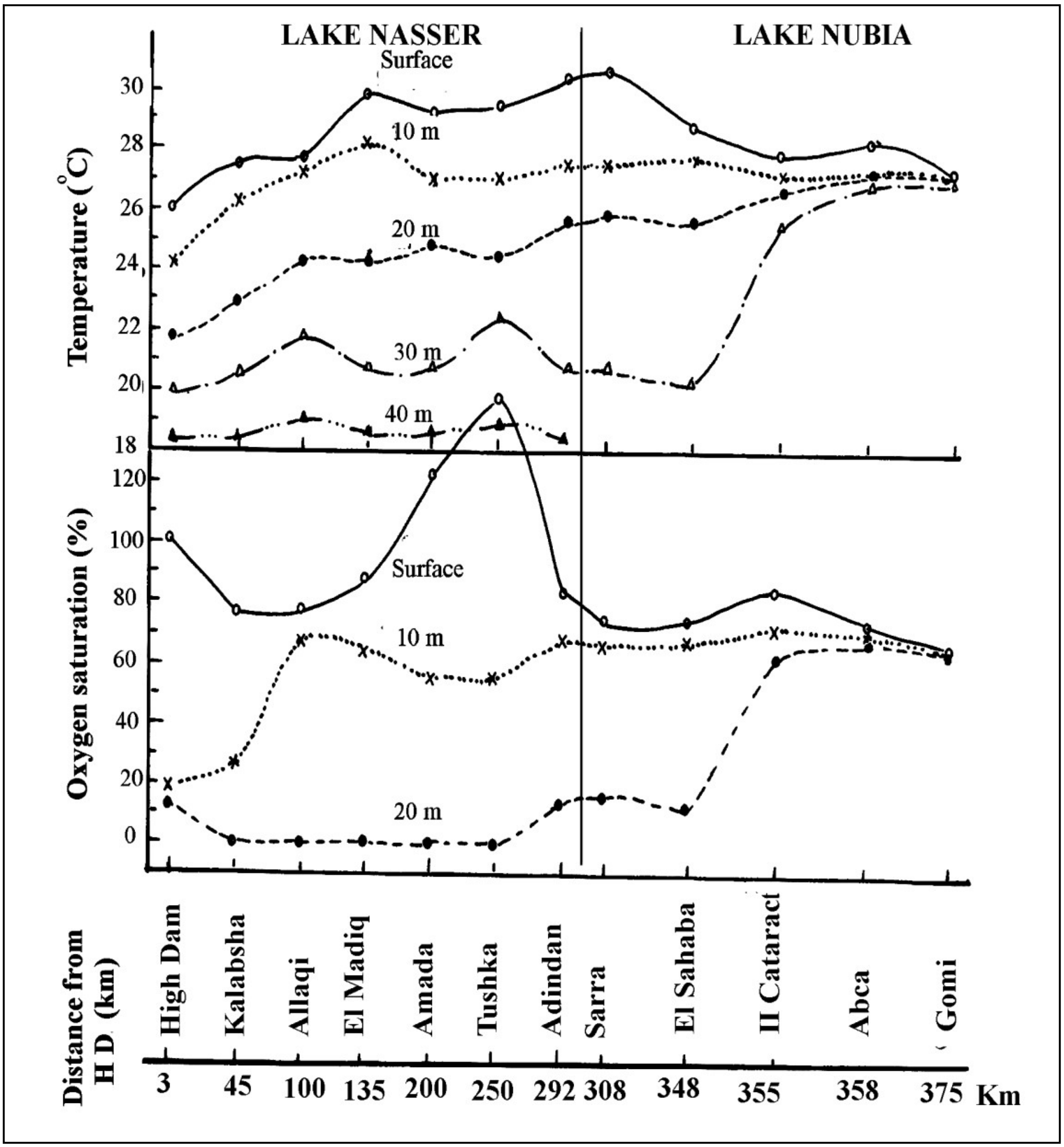

Fig. 49 **Water temperature and oxygen saturation (percent) of Lake Nasser and Lake Nubia during July 1974 (Elewa 1980).**

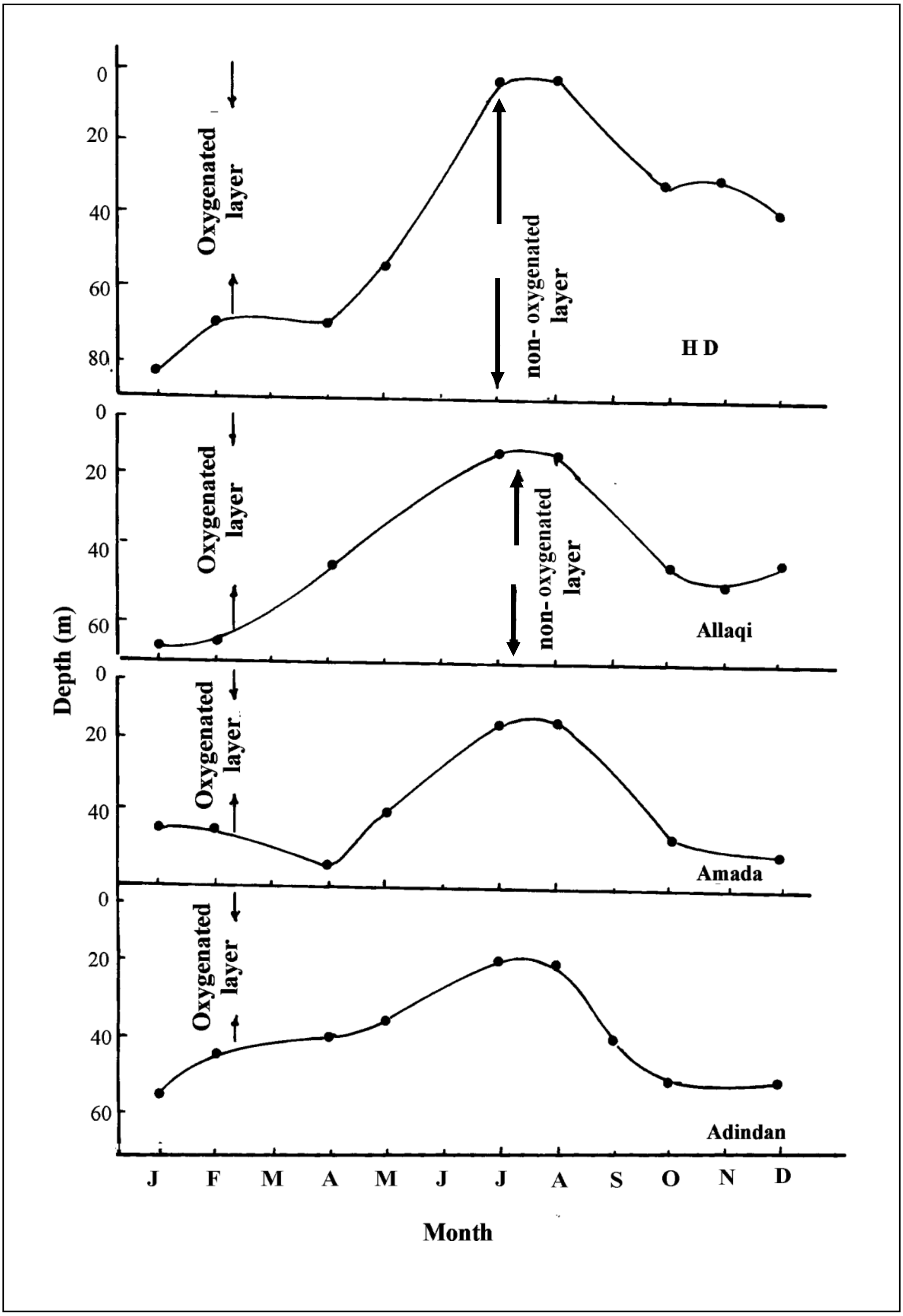

Fig. 50 **Oxygenated and non-oxygenated layers of Lake Nasser during different months of the year (Elewa 1980).**

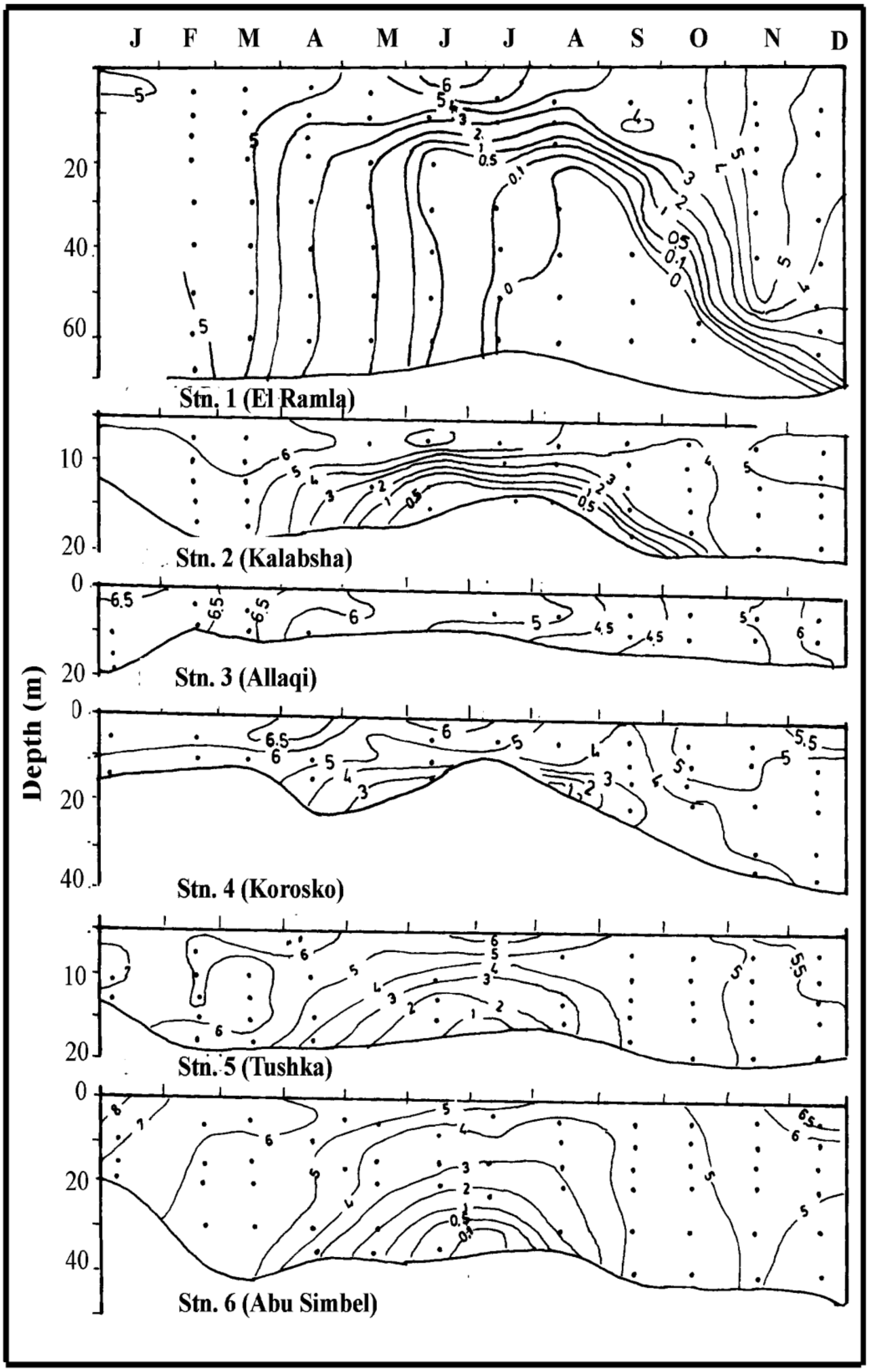

Fig. 51 **Vertical and seasonal variations of dissolved oxygen (ml/l) at six stations in Lake Nasser in 1985 (Abdel-Rahman** & **Goma 1992c) [**For stations refer to Fig. 4**].**

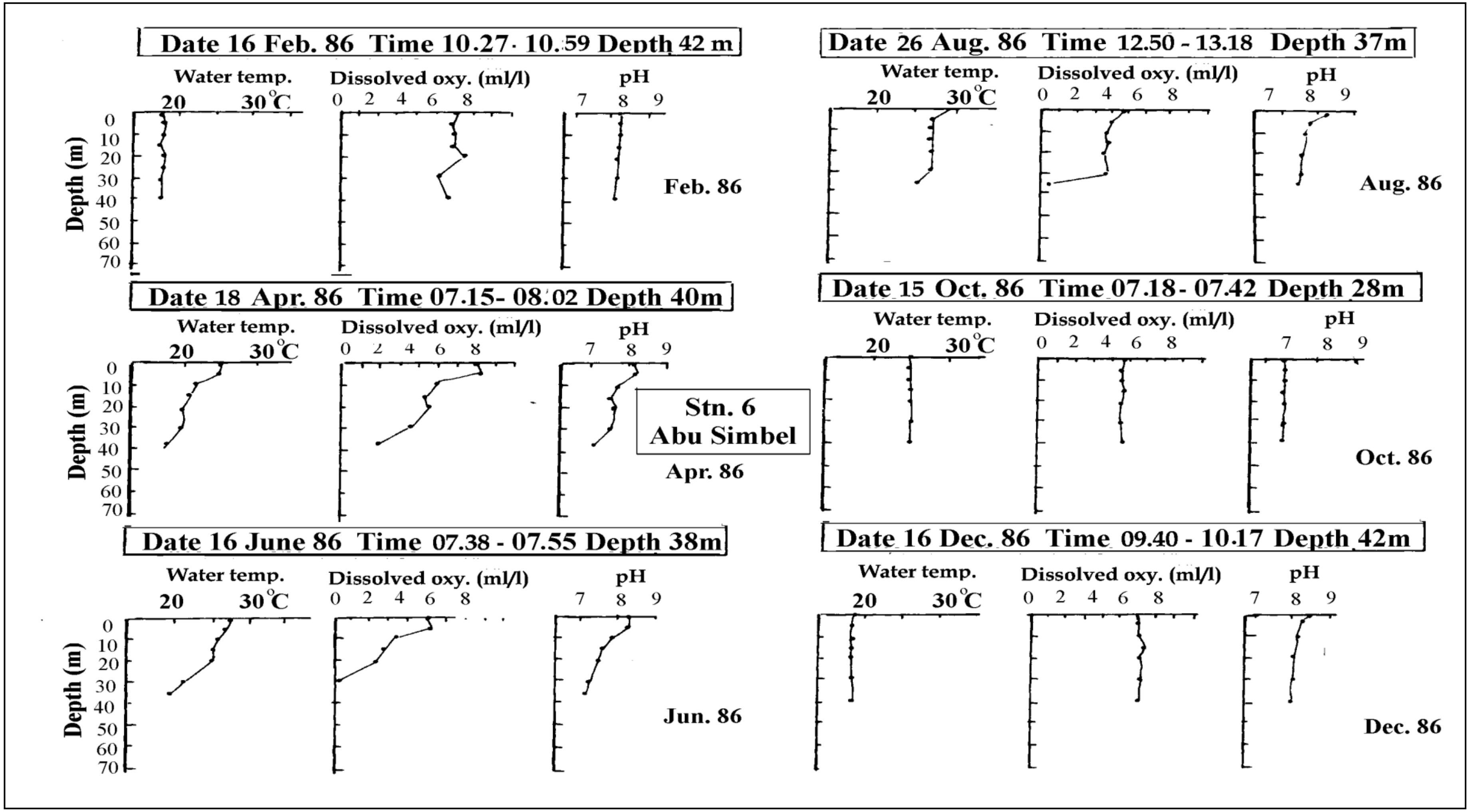

Fig. 52 **Vertical distribution of water temperature, dissolved oxygen and pH during February, April, June, August, October, and December 1986 at stn. 1 (El Ramla) in Lake Nasser (Abdel-Rahman & Goma 1993).**

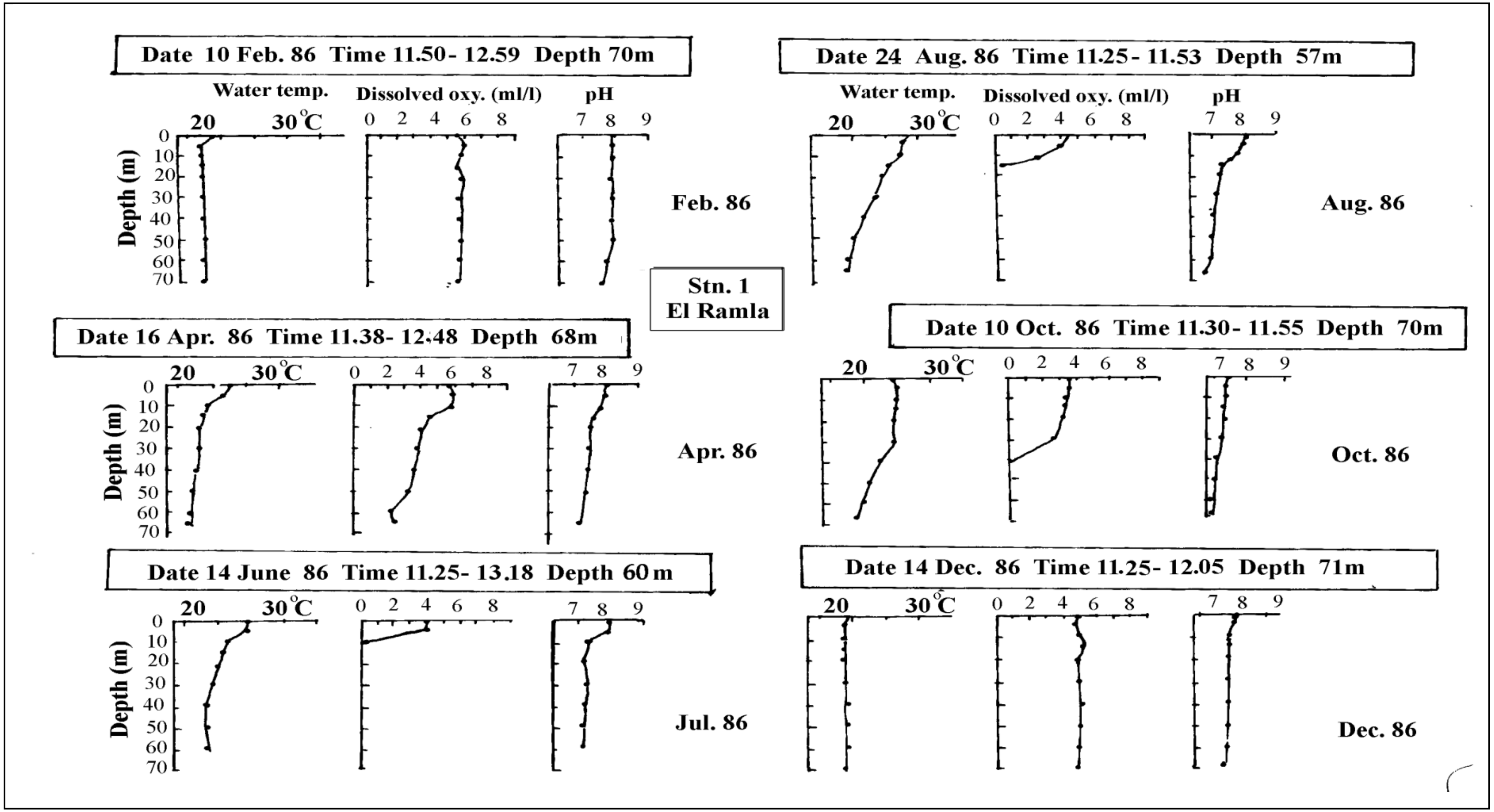

Fig. 53 **Vertical distribution of water temperature, dissolved oxygen and pH during February, April, June, August, October, and December 1986 at stn. 6 (Abu Simbel) in Lake Nasser (Abdel-Rahman & Goma 1993).**

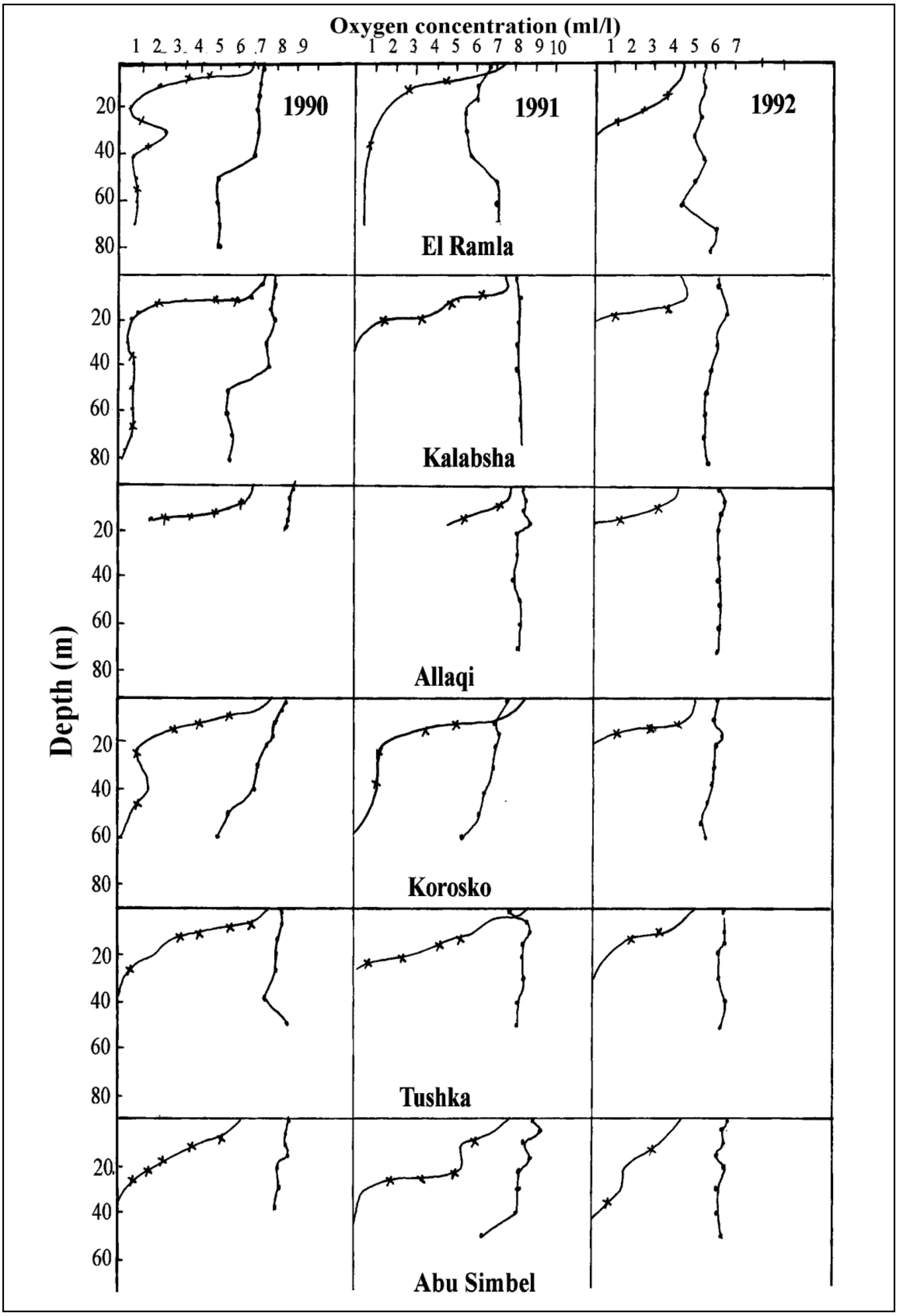

Fig. 54 **Vertical distribution of oxygen concentration during winter and summer (1990, 1991 and 1992) [•—• winter, x—x summer].(Abdel-Rahman & Goma 1993).**

Table 30 **Vertical and seasonal distribution of dissolved oxygen at El Ramla station (1987 - 1992).**

Depth (m)	Dissolved oxygen (ml/l)																							
	1987*				1988*				1989*				1990*				1991**				1992**			
	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.
0	5.7	6.3	4.6	4.0	5.7	5.6	4.8	3.9	6.1	6.2	5.5	4.3	7.2	9.4	6.5	6.0	6.5	5.8	7.4	5.9	5.5	6.4	4.4	4.0
5	5.5	6.3	2.4	4.1	5.8	5.7	4.5	3.9	6.1	5.9	3.9	4.0	7.1	8.8	5.5	5.7	6.4	9.0	6.9	5.3	5.2	6.5	4.5	3.8
10	5.5	4.9	1.6	3.6	5.8	4.9	0.7	3.8	6.0	5.2	0.8	3.5	7.0	6.7	2.2	5.2	5.9	7.0	3.0	4.6	5.3	6.0	4.4	3.5
15	5.4	4.6	0.1	2.1	5.5	4.4	0.04	3.6	5.9	4.6	0.4	1.8	7.0	5.9	0.7	3.9	6.0	6.5	2.0	4.1	5.5	5.5	2.5	3.1
20	5.4	4.4	0	1.9	5.8	3.9	0.04	3.2	5.9	4.2	0.2	2.2	6.8	5.6	0.4	1.1	5.6	6.4	1.4	2.4	5.3	5.3	0	1.2
30	5.0	4.1	0	1.2	5.5	3.8	0.0	2.4	5.9	4.1	0.3	1.25	7.0	5.0	2.3	0	5.6	4.8	0.8	0.5	5.2	5.2	0	0.6
40	5.1	3.9	0	1.2	5.7	3.7	0.04	2.4	5.9	4.0	0.3	0.3	6.8	5.3	0.5	0	5.7	5.2	0.5	0	5.4	5.1	0	0
50	5.1	3.4	0	0.9	5.7	3.4	0.02	2.1	5.7	4.1	0.2	0	4.9	5.4	0.7	0	7.0	5.0	0.4	0	4.9	5.1	0.1	0
60	5.0	3.1	0	0	5.7	4.1	0.02	1.3	4.3	4.0	0.1	0	4.8	5.2	0.8	0	6.9	4.9	0.4	0	4.2	5.1	0	0
70	5.3	--*	0	0	4.4	--	--	--	4.3	4.0	0.0	0	5.0	4.9	0.7	0	7.0	5.0	0.4	0	6.0	4.8	0	0
80	--	--	--	--	--	--	--	--	--	--	--	--	5.0	--	--	0	--	--	0	0	5.6	4.2	0	0

***Abdel-Rahman & Goma (1995 a, b, c & d). **Abdel-Rahman (1995 a & b). For stations refer to Fig. 21. *(--) not recorded.**

Table 31 **Vertical and seasonal distribution of dissolved oxygen at Kalabsha station (1987 - 1992).**

Depth (m)	Dissolved oxygen (ml/l)																							
	1987*				1988*				1989*				1990*				1991**				1992**			
	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.
0	6.2	7.0	5.3	4.7	6.3	6.7	5.5	5.3	5.6	7.1	5.6	4.7	7.9	9.4	7.4	6.6	8.0	8.7	7.5	4.7	6.3	7.1	4.3	4.5
5	6.2	6.2	5.4	5.0	6.3	6.3	5.4	4.9	6.3	7.1	5.8	4.9	7.9	9.5	7.2	6.0	8.0	10.0	7.8	6.1	6.2	7.0	4.5	4.1
10	5.9	4.5	0.9	4.7	6.2	3.9	1.9	4.3	6.3	5.9	3.5	4.4	7.8	7.9	6.7	6.2	8.2	6.4	5.2	5.8	6.4	5.9	4.6	4.4
15	5.9	4.2	0.1	4.2	6.5	4.1	0.1	3.9	5.9	3.9	0.4	3.9	7.6	6.3	0.9	5.1	8.1	5.6	4.2	5.4	6.6	5.3	2.1	4.3
20	5.6	3.1	0	3.1	6.3	3.6	0.1	3.8	6.2	--	--	4.2	7.8	5.7	0.5	2.3	8.0	5.1	0.8	4.8	6.2	5.2	0	4.4
25	--	--	--	--	--	--	--	3.4	5.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	5.6	3.1	--	--	--	--	--	--	5.9	--	--	2.5	7.4	5.4	0.4	4.4	8.0	4.8	0	2.1	6.1	5.1	0	3.7
35	--	--	--	--	--	--	--	--	5.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
40	--	--	--	--	--	--	--	--	--	--	--	2.3	7.6	4.9	0.7	0	7.9	4.4	0	0	5.8	4.9	0	3.8
50	--	--	--	--	--	--	--	--	--	--	--	0	5.4	5.1	0.6	0	8.1	4.2	0.1	0	5.6	4.7	0	0
60	--	--	--	--	--	--	--	--	--	--	--	0	5.4	4.8	0.6	0	8.2	3.9	0.3	0	5.6	4.8	0	0

ertical and seasonal distribution of dissolved oxygen at Allaqi station (1987 - 1992).

	Dissolved oxygen (ml/l)																							
Depth (m)	**1987***				**1988***				**1989***				**1990***				**1991****				**1992****			
	Wint.	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**
0	6.4	6.7	5.0	4.9	6.7	6.6	5.1	4.6	6.4	6.6	5.1	4.8	8.8	8.9	6.7	7.0	8.4	9.2	7.7	7.1	6.2	6.8	4.1	3.7
5	6.3	7.1	5.1	5.2	6.7	6.6	5.2	4.7	6.5	6.9	4.9	4.8	8.6	8.8	6.6	7.2	8.5	9.3	7.7	6.7	6.5	6.9	3.0	4.5
10	6.3	5.1	2.4	5.0	6.7	5.8	3.1	4.7	6.6	6.0	2.4	5.3	8.6	7.6	5.5	7.3	8.3	7.5	6.3	6.4	6.3	6.5		3.4
15	6.3	--	--	4.7	7.0	--	--	4.6	6.5	4.9	0.7	4.6	8.5	6.5	1.6	7.1	8.7	7.0	4.4	6.5	6.2	5.8	0.0	2.2
20	--	--	--	--	7.0	--	--	--	7.1	4.5	--	--	8.3	--	--	--	8.0	--		5.8	6.1	5.7	0.0	0
30	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.1	--	--	0.2	6.2	5.2	0.1	0
40	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.8	--	--	0	6.2	5.1	0.1	0
50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.2	--	--	0	6.3	5.1	0.1	0
60	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.2	--	--	0	6.2	4.9	0	0
70	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.1	--	--	0	6.2	4.9	0	0

***Abdel-Rahman & Goma (1995 a, b, c & d). **Abdel-Rahman (1995 a & b). For stations refer to Fig. 21. *(--) not recorded.**

Table 33 **Vertical and seasonal distribution of dissolved oxygen at Korosko station (1987 - 1992).**

Depth (m)	Dissolved oxygen (ml/l)																							
	1987*				1988*				1989*				1990*				1991**				1992**			
	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.
0	6.2	6.6	5.8	5.4	6.5	6.6	6.4	7.4	6.5	6.6	5.4	5.8	8.6	8.8	7.7	8.1	7.6	9.3	8.5	6.4	6.1	7.2	5.0	4.7
5	6.3	6.4	5.4	5.2	6.4	6.8	4.6	4.4	6.3	7.0	5.1	5.5	8.3	8.9	7.4	7.9	7.3	9.9	8.3	8.3	6.0	7.1	5.0	3.9
10	6.1	4.4	0.6	4.9	5.8	6.1	3.8	4.1	5.9	5.9	2.0	3.7	7.9	7.9	4.6	6.1	6.9	7.3	7.6	7.4	6.0	6.4	4.6	2.9
15	5.8	4.4	0.3	4.7	6.1	5.3	1.8	4.1	5.8	5.7	1.6	3.0	7.9	6.8	1.8	5.2	7.2	6.4	2.5	5.4	6.4	5.7	3.0	3.5
20	5.4	4.0	0	2.7	5.4	4.3	0.6	4.1	6.0	4.5	1.0	3.1	7.5	6.1	0.8	5.2	7.0	5.8	1.2	4.2	6.1	5.4	0.1	0
30	5.3	3.7	--	--	5.6	4.0	0.3	4.2	5.6	5.4	0.4	3.0	7.0	5.6	1.3	3.0	6.9	4.5	1.2	5.1	6.0	5.1	0.04	0
40	5.2	--	--	--	5.6	--	--	--	6.3	4.2	0	2.1	6.8	5.6	1.6	1.9	6.4	4.7	1.1	4.4	5.9	5.2	0.2	0
50	5.3	--	--	--	--	--	--	--	--	--	--	0.6	5.5	4.6	0.5	0	6.1	4.4	0.6	1.6	5.5	4.9	0	0
60	--	--	--	--	--	--	--	--	--	--	--	0.2	5.0	--	0.2	0	5.3	3.5	0	0	5.5	4.8	0.1	0
70	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	0	0	--	--	0	0
80	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	--	--	--	--

***Abdel-Rahman & Goma (1995 a, b, c & d). **Abdel-Rahman (1995 a & b). For stations refer to Fig. 21. *(--) not recorded.**

Table 34 **Vertical and seasonal distribution of dissolved oxygen at Tushka station (1987 - 1992).**

	Dissolved oxygen (ml/l)																							
Depth (m)	**1987***				**1988***				**1989***				**1990***				**1991****				**1992****			
	Wint.	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**	**Wint.**	**Spr.**	**Sum.**	**Aut.**
0	6.3	6.9	4.8	5.0	6.5	6.4	5.4	4.7	6.6	6.6	5.4	5.6	8.3	8.4	7.8	7.1	7.7	9.2	8.7	9.1	6.4	7.2	5.0	5.1
5	6.3	6.3	4.7	4.8	6.5	6.4	3.9	4.6	6.6	6.3	5.1	4.8	8.3	8.7	7.3	6.8	8.6	9.4	6.5	6.7	6.6	7.0	4.4	4.2
10	6.2	5.2	3.8	4.7	6.4	5.6	2.6	4.6	6.5	5.8	3.2	4.5	8.2	8.2	4.6	6.6	8.7	7.6	6.2	6.7	6.5	6.6	3.7	3.9
15	6.0	4.5	2.4	4.7	6.1	4.8	2.3	4.7	6.5	5.3	3.2	4.5	8.1	7.9	2.2	6.5	8.4	6.3	4.4	6.7	6.5	5.9	1.0	3.9
20	6.0	4.4	0.1	4.6	6.0	4.8	1.8	4.6	6.5	5.0	2.0	4.5	8.0	6.4	1.8	6.0	8.4	6.0	3.0	7.7	6.2	5.3	0.7	0.7
30	6.0	--	--	--	5.9	--	--	4.5	6.4	4.4	0.3	4.6	8.1	6.2	0.2	4.3	8.5	4.6	0.1	6.4	6.2	5.2	0.1	0
40	--	--	--	--	--	--	--	--	--	--	--	3.7	7.7	5.9	0.1	1.6	8.2	3.4	0.1	5.2	6.5	4.8	0.1	0
50	--	--	--	--	--	--	--	--	--	--	--	2.0	8.6	4.7	0.1	0.2	8.1	2.7	0	3.4	6.4	4.3	0.1	0
60	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	0	0	--	--	--	0
70	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	--	--	--	--

***Abdel-Rahman & Goma (1995 a, b, c & d). **Abdel-Rahman (1995 a & b). For stations refer to Fig. 21. *(--) not recorded.**

Table 35 **Vertical and seasonal distribution of dissolved oxygen at Abu Simbel station (1987 - 1992).**

Depth (m)	Dissolved oxygen (ml/l)																							
	1987*				1988*				1989*				1990*				1991**				1992**			
	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.	Wint.	Spr.	Sum.	Aut.
0	6.5	7.6	5.7	5.3	6.5	6.1	4.6	4.9	6.8	6.7	4.8	5.1	8.7	8.5	7.4	7.6	8.9	9.9	7.9	6.7	6.7	7.2	4.6	5.3
5	6.6	6.1	4.7	4.7	6.4	6.0	3.9	4.9	6.9	6.5	4.7	5.1	8.6	8.2	7.0	7.1	9.2	8.7	6.9	6.7	6.5	6.9	4.1	4.4
10	6.3	4.7	2.9	4.4	6.4	5.1	2.8	4.9	6.9	5.5	3.6	5.0	8.5	8.1	4.9	7.0	8.4	6.9	5.3	7.0	6.5	6.4	3.5	4.0
15	6.3	4.7	2.5	4.8	6.5	5.0	2.5	4.9	6.9	5.4	3.3	4.9	8.6	7.1	2.9	6.7	8.9	6.8	5.3	7.2	6.1	6.1	2.5	3.9
20	6.2	4.7	1.6	4.7	6.4	4.9	1.5	4.9	6.9	4.6	2.8	4.8	8.1	6.9	2.0	6.3	8.4	6.5	5.3	6.8	6.5	6.0	1.5	0
30	6.1	4.2	0.2	4.6	6.2	3.5	0.6	5.0	6.9	--	--	4.8	8.2	5.8	0.3	4.3	8.2	4.6	0.5	6.7	6.2	5.2	1.5	0
40	5.9	--	--	--	6.2	--	0	--	--	--	--	4.5	8.1	5.5	0.1	2.2	8.2	3.5	0.1	6.3	6.2	4.8	0.2	0
50	--	--	--	--	--	--	0	--	--	--	--	--	--	4.9	0.1	2.0	6.3	--	0	3.6	6.4	4.3	--	0
60	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	0	0	--	--	--	0
70	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	0	0	--	--	--	--

***Abdel-Rahman & Goma (1995 a, b, c & d). **Abdel-Rahman (1995 a & b). For stations refer to Fig. 21. *(--) not recorded.**

Fishar (1995) estimated the dissolved oxygen in Lake Nasser during 1993 in the eastern side, main channel and western side and his results showed differences in the three regions. The oxygen profiles were, more or less, homogeneous in the bottom water and varied from 5.86 to 7.47 mg /l in the eastern stations, and from 2.31 to 3.66 mg/l at the main channel stations and from 5.67 to 8.18 mg/l in the western stations. Amada and Abu Simbel sections sustained the highest oxygen concentration, where the same value of 6.03 mg/l was recorded for each station. The seasonal variations of dissolved oxygen in Lake Nasser during 1993 (Fig. 55) indicate that in the bottom water, the dissolved oxygen attained their maximum values during spring (aggregates of 7.55, 7.22 and 8 mg/l for the eastern side, main channel and the western side respectively). On the other hand, the lowest concentrations of dissolved oxygen for the entire Lake were recorded in autumn and summer, where aggregate values were 4.71 and 4.68 mg/l respectively.

Khor El Ramla

Goma & Abdel-Rahman (1996) studied the dissolved oxygen variations in Khor El Ramla during 1985 - 1989. The surface waters (0 - 5 m depth) were well oxygenated all the year round and during the period of study. From January to April, the dissolved oxygen content was high (4 - 6 ml/l) in the whole water mass of Khor El Ramla. In May, of almost all years, the dissolved oxygen concentration started to decrease in the water layer below 10 m depth. In summer stratification period (June - September) the dissolved oxygen concentration ranged between 3 and 5 ml/l followed by lower values (0 - 3 ml/l) in the metalimnion layer (5 - 20 m depth) and the dissolved oxygen disappeared from the deepest waters. In October, the dissolved oxygen had a similar trend as in the summer period, but the thickness of metalimnion depth varied from 5 to 40 m in different years. The oxygenated water mass increased gradually in November, until the whole water mass became reoxygenated in December.

Comparing Lake Nasser with Lake Volta the level of oxygen saturation in the latter is mainly influenced by the wind. Because of the relatively low assimilation intensity and the strong dissimilation processes (the bottom is covered with decomposing trees, bush, grass or soil with high organic matter content, etc.) there is still continuing reduction in the oxygen taking place in the water mass as a whole. Consequently, oxygen supersaturations seldom occurred, and when they occur they are slight. The values were usually 80 - 95 % of the air saturation level at the surface. Oxygenation through the surface was found to be the main source of dissolved oxygen for Lake Volta. During completely calm weather a slow decrease in the amount of dissolved oxygen was observed during daytime. As an oxygen-increasing factor wind plays an unusually important role. Because of only slight temperature differences between surface and bottom, wind of a speed of 4-5 m/sec., blowing for one hour, could cause the oxygen content in Volta Lake to be increased by 0.45 mg/l, down to 40, 50 or 55 m. This would be the equivalent of about 70 g O_2/m^2 in the total water column.

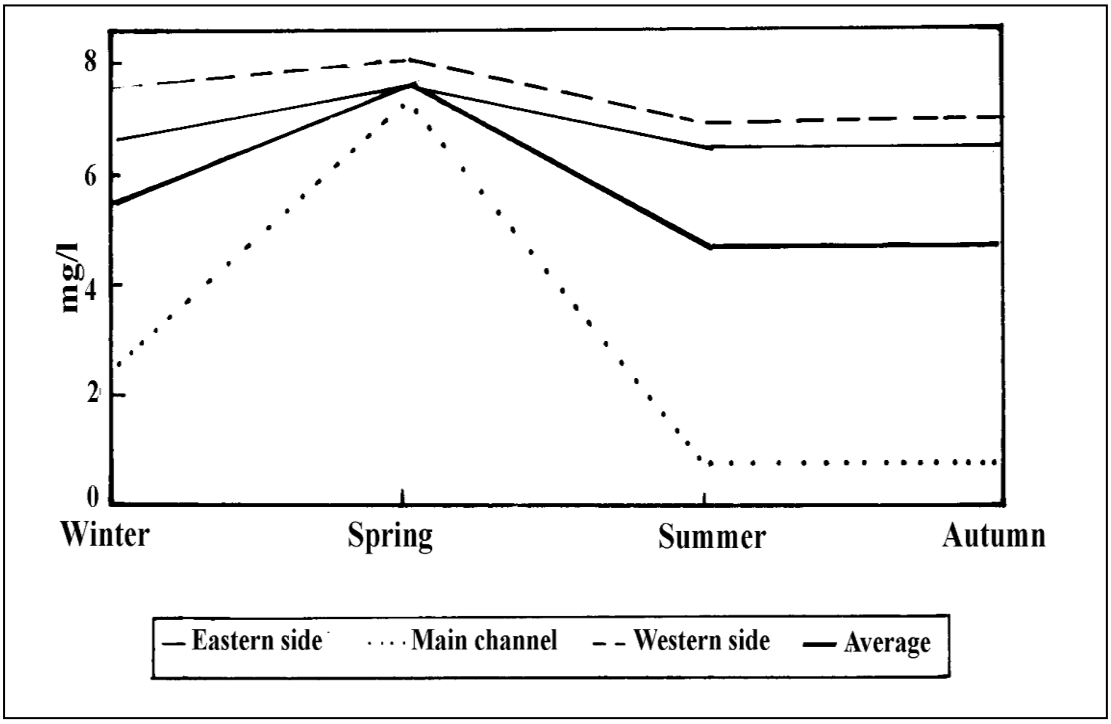

Fig. 55 **Seasonal variations of dissolved oxygen in Lake Nasser during 1993 (Fishar 1995).**

ELECTRICAL CONDUCTIVITY

Entz (1974b) and El-Shahawy (1975) pointed out that the variation in electrical conductivity in Lake Nasser follows, to a certain extent, the movement of water masses of the flood water. The highest conductivity values were recorded just in front of the flood water. El-Shahawy (1975) explained that the low conductivity of the Lake water during the flood period is due to the low water conductivity of the flooded Blue Nile which contributes about 84 % of the Nile flood. So, variations in conductivity in Lake Nasser can be taken as an indication of the movement of the water masses in the Lake. Entz (1976) pointed out that in 1970 the electrical conductivity of the Lake ranged between 235 and 290 µmhos cm^{-1} and suggested that on the basis of conductivity values it took about six months, for the front of the flood to pass through Lake Nasser from Adindan to the High Dam. Elewa (1980) studied the conductivity along the main channel of Lake Nasser for the surface and 50 m depth in different seasons in 1978. The latter author recorded values ranging from 190-245, 210-252, 210-228, 199-245 µmhos cm^{-1} for surface waters in winter, spring, summer and autumn respectively (Fig. 56), denoting the prevalence of lowest maximum in summer. In winter and spring, conductivity generally decreases southwards but in summer, the value showed gradual decrease from HD to Amada, but increased at Tushka, which had values comparable to that of Adindan

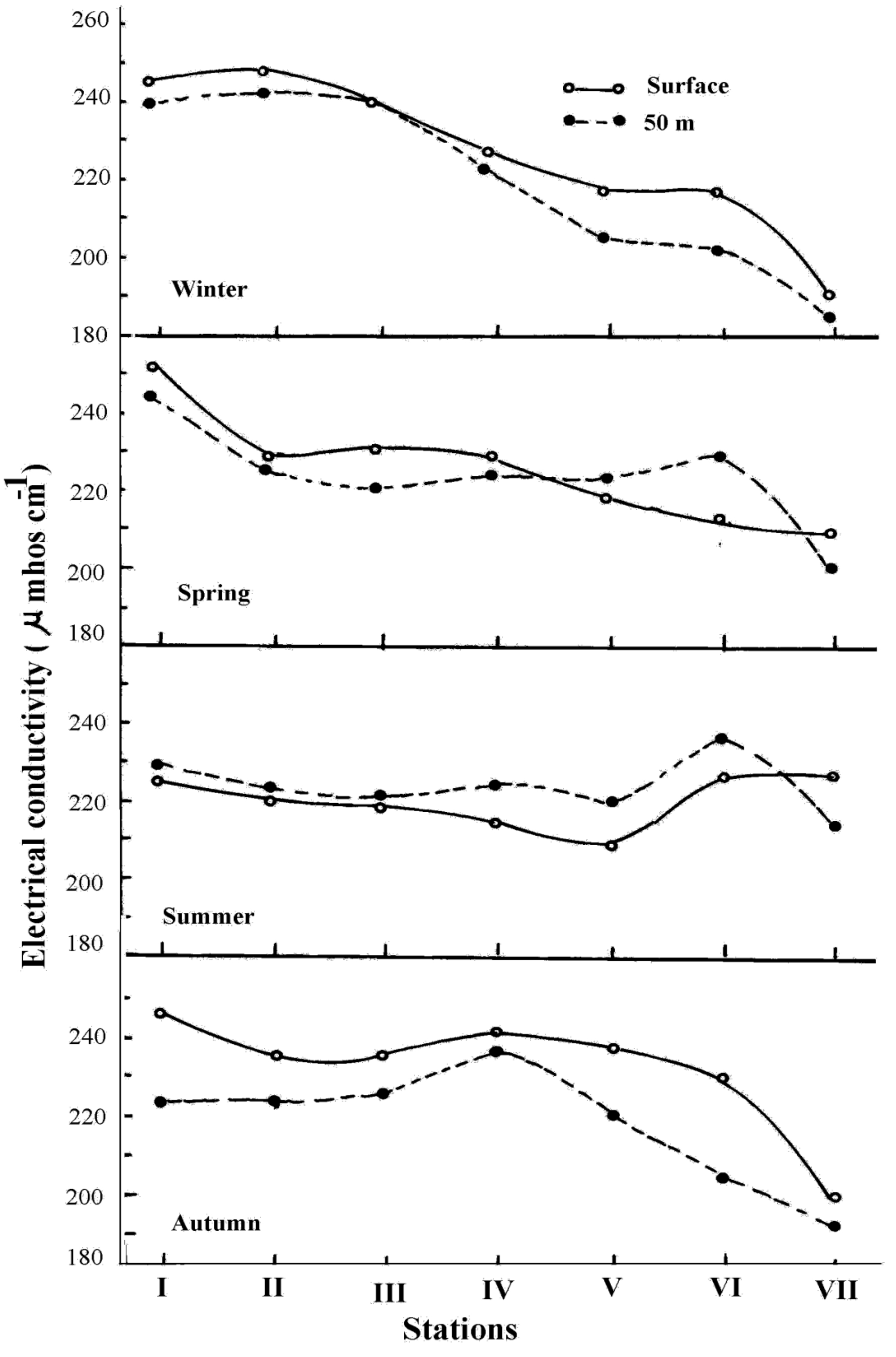

Fig. 56 **Seasonal variations of the average values of electrical conductivity of Lake Nasser at the surface and 50 m depth in different stations (Elewa 1980)** **[**For stations refer to Table 18**].**

(227 µmhos cm^{-1}). In autumn, the conductivity of surface water decreased from HD to Kalabsha but increased southwards to El-Madiq (240 µmhos cm^{-1}) which was followed by a gradual decrease to Tushka (229 µmhos cm^{-1}) and greater decrease at Adindan (199 µmhos cm^{-1}). In addition, the conductivity of deep water (50 m depth) had lower values than the surface water in winter and autumn and the difference is usually greater in the latter season (Fig. 56)

Latif (1984a) mentioned that the flood water usually pushes masses of water of relatively high electrical conductivity in front of it, thus appearing at different localities of Lake Nubia and the southern part of Lake Nasser at different times after the inception of the flood (Fig. 56). Later on, the electrical conductivity becomes lower in the flood affected region. Hence, the conductivity ranges from the surface to bottom at Adindan (300 km from the High Dam) was 242-260, 185-190, 195-185 and 196-171 µmhos cm^{-1} in July, November, January and April respectively, as compared with 241-235, 215-202, 220-200 and 215-228 µmhos cm^{-1} at Tushka (235 km from the HD) and 207-227, 235-225, 225-515 and 237-222 µmhos cm^{-1} at El-Madiq (140 km from the H D) (Latif 1984a).

Nour El-Din (1985) showed that the relative decrease in the electrical conductivity values in winter and spring of 1983 and 1984 were in good concordance with those of temperature during the same seasons. This might be principally attributed either to the uptake of dissolved salts by phytoplankton, as a result of upwelling and continuous mixing of water column, or to the lack of soluble salts in the region as a result of sedimentation or adsorption by silt.

Abdel-Monem (1995), recorded the highest conductivity value in 1993 (299 µmhos cm^{-1}) during winter at the bottom of Mariya site, and the lowest value (173 µmhos cm^{-1}) during spring at the bottom of Adindan site. It seems that Lake Nasser can be classified among lakes with moderate conductivity hence the predominant zooplankters are typically planktonic species. Morales-Baquero *et al.* (1989) pointed out that low conductivity lakes yielded greater densities of typical planktonic species, while high conductivity lakes contained predominantly benthic and periphytic species.

The values of electrical conductivity of some **khors** fluctuate between 155 µmhos cm^{-1} (in bottom waters of Khor Kalabsha) and 290 µmhos cm^{-1} (in surface water of Khor El Ramla). A marked increase of electrical conductivity values of the khors surface waters was observed from south to north (Gindy 1991 - Figs. 58 and 59).

At Khor Tushka, the inflow of flood from the south lowers the electrical conductivity due to the precipitation of the suspended matter leaving the water nearly free of electrical minerals containing ionic salt (Elewa 1987a).

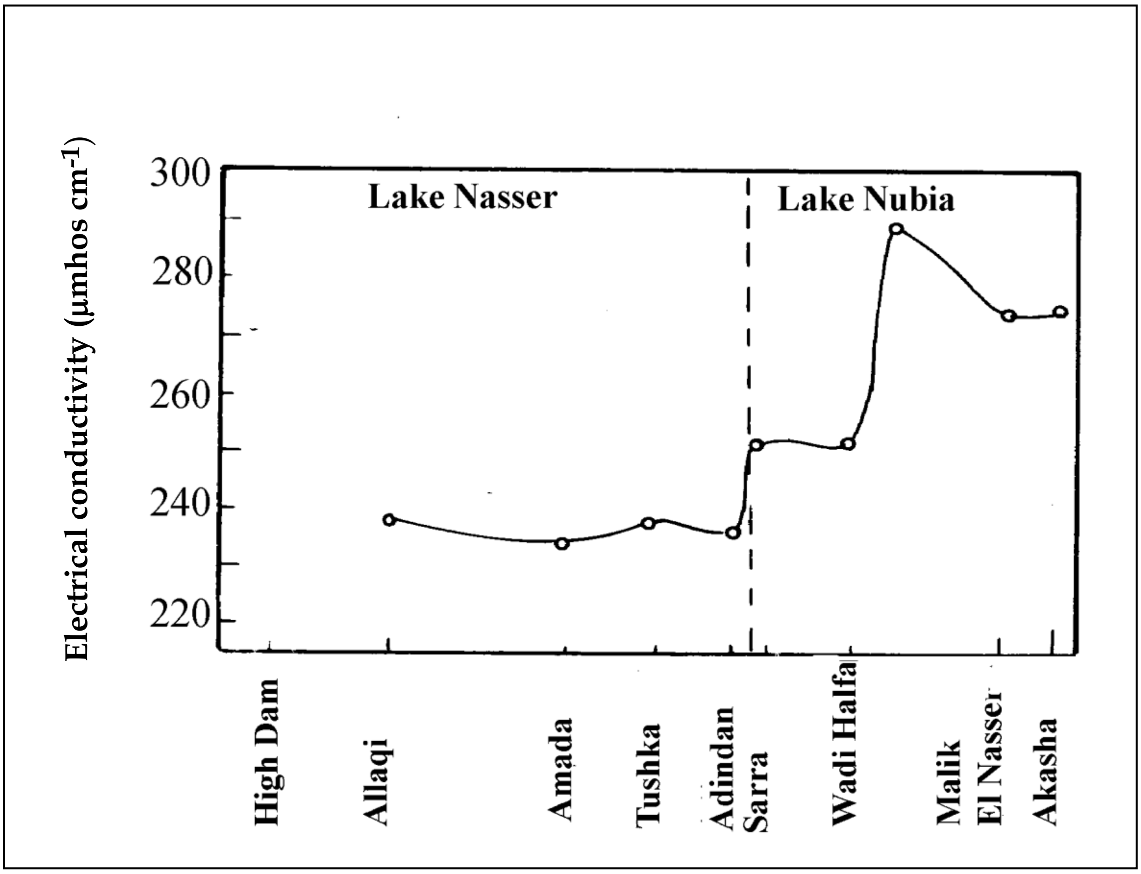

Fig. 57 **Electrical conductivity (µmhos cm^{-1}) of Lake Nasser and Lake Nubia in July/August 1976 (Latif 1984a).**

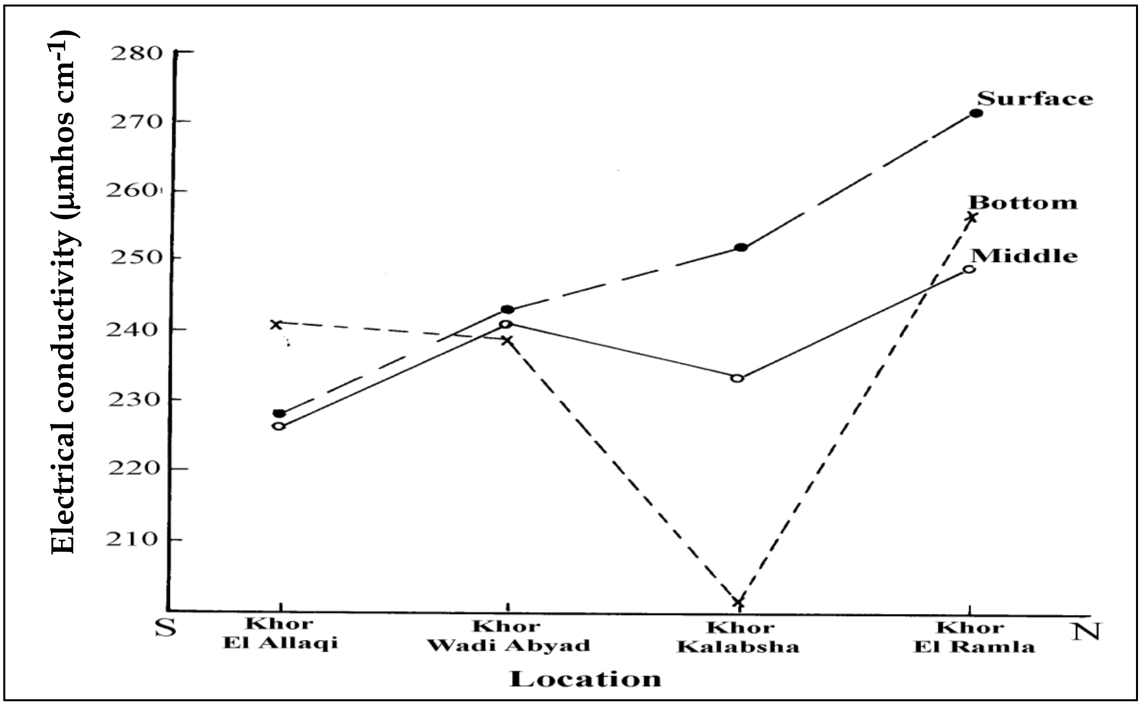

Fig. 58 **Average distribution of electrical conductivity (µmhos cm^{-1}) at various khors at Lake Nasser (June, 1987) (Gindy 1991) [**For stations refer to Fig. 59**].**

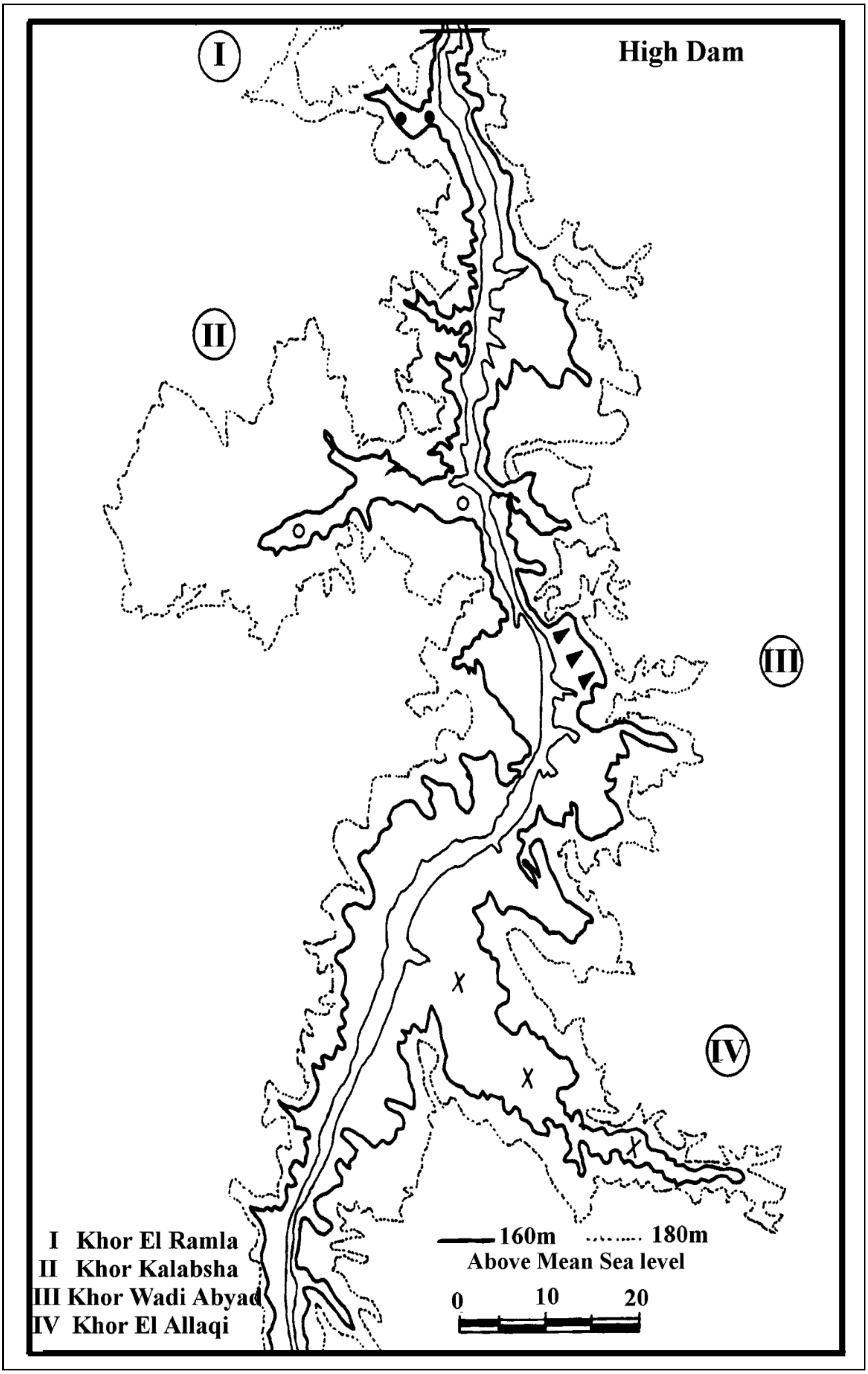

Fig. 59 **Location map showing water sampling sites (Gindy 1991).**

The seasonal variations of electrical conductivity in the eastern and western sides as well as in the main channel were studied by Fishar (1995). The latter author pointed out that the maximum conductivity was recorded in the eastern and western stations of Abu Simbel (232.3 and 262.8 µmhos cm^{-1}) and the main channel at El-Madiq (232.5 µmhos cm^{-1}). The maximum average values of electrical conductivity were recorded during summer being 240.5, 239.1 and 250.8 µmhos cm^{-1} in the eastern side, main channel and western side respectively. The lowest values were observed during winter and spring (Fig. 60, Fishar 1995).

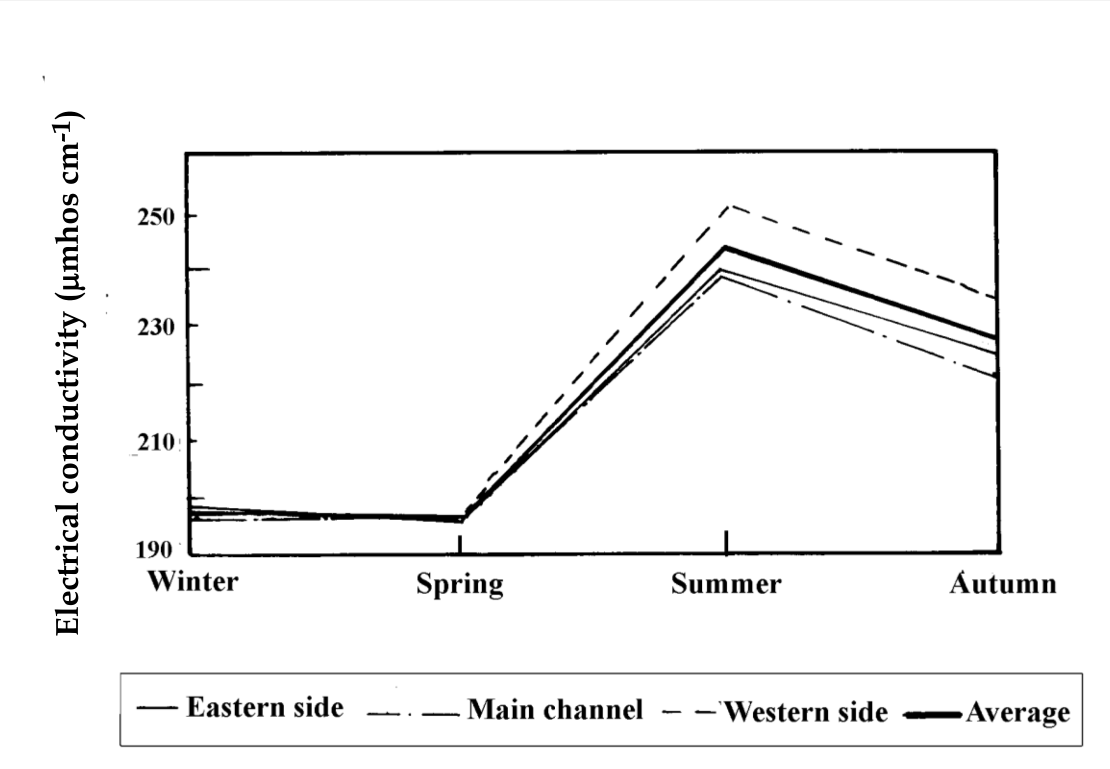

Fig. 60 **Seasonal variations of electrical conductivity (µmhos cm^{-1}) in Lake Nasser during 1993 (Fishar 1995) [**For localities refer to Fig. 15**].**

HYDROGEN ION CONCENTRATION (pH)

The pH values of the Lake water are on the alkaline side. Thus, in the main channel, the pH value varies between 7.8 and 9.6 in the surface waters, while it ranges between 6.8 and 8.6 in the bottom waters. Entz (1976) reported that in the surface layer, pH values up to 9.6 were recorded due to intensive assimilation processes. Elewa (1976) mentioned that in most localities pH values decreased with depth and the difference was greatest during July in many localities and in November in others. The same author postulated that, in spring khors showed higher pH values and wider range of difference with depth than in the main channel. In summer, however, the values of surface waters of open and khor waters were comparable to some extent.

Goma & Abdel-Rahman (1992a) pointed out that in 1983, the monthly variations of pH values at stations 2 (Kalabsha) and 3 (Allaqi) in the main channel of Lake Nasser showed a range between 7.9 and 8.9 (Table 36 and Figs. 61 and 62). The pH values seem to be uniform through the water column from 0 to 10 m depth. Comparatively low pH values (8.2-8.3) were recorded in November and December at both stations (Goma & Abdel-Rahman 1992a). This may be due to low density of phytoplankton and consequently low photosynthesis. This is correlated with high transparency during these two months (Fig. 62). Maximum pH values of 8.6-8.9 were recorded from May to July 1983 at the two stations. It seems that phytoplankton bloom and intensive photosynthesis during these months may be one of the causes of high pH values. This is correlated with low transparency during these months.

Table 36 **Monthly variations of pH values at two stations in the main channel (at 0 - 10m depth) of Lake Nasser during 1983.**

Month	Stn. 2 (Kalabsha)			Stn. 3 (Allaqi)		
	0.0	5.0	10.0	0.0	5.0	10.0 (m)
January	8.4	8.4	8.4	8.2	8.4	8.2
February	8.2	8.2	8.2	8.8	8.8	8.6
May	8.9	8.9	7.9	8.8	8.8	8.4
June	8.3	8.6	8.6	8.3	8.7	8.7
July	8.7	8.7	8.0	8.9	8.8	8.8
November	8.2	8.2	8.2	8.2	8.2	8.3
December	8.2	8.2	8.2	--	--	--

(Goma & Abdel-Rahman, 1992a).

In 1985, the vertical and seasonal variations of pH values at six stations on Lake Nasser indicates that they ranged between 6.9 and 9 (Abdel-Rahman & Goma 1992c - Fig. 64). The low range of pH fluctuation is supposed to imply that the Lake water has relatively high buffering capacity, which prevents abrupt changes of pH. The pH values were high from January to April 1985 at most stations, while they were low from September to October 1985. The decrease in pH coincided with the arrival of the flood water from the south. However, pH values were relatively low almost throughout the year at station 1 (Abdel-Rahman & Goma 1992c).

The above results indicate that pH values were above 8.5 measured mostly at the surface waters (Fig. 63), where photosynthesis seemed to be particularly active. Generally, the water of Lake Nasser is slightly alkaline. Therefore, it is favourable for biological processes in general and fish production in particular.

The seasonal, vertical and regional variations of pH values along the main channel of Lake Nasser during different years (1987 -1992) were studied

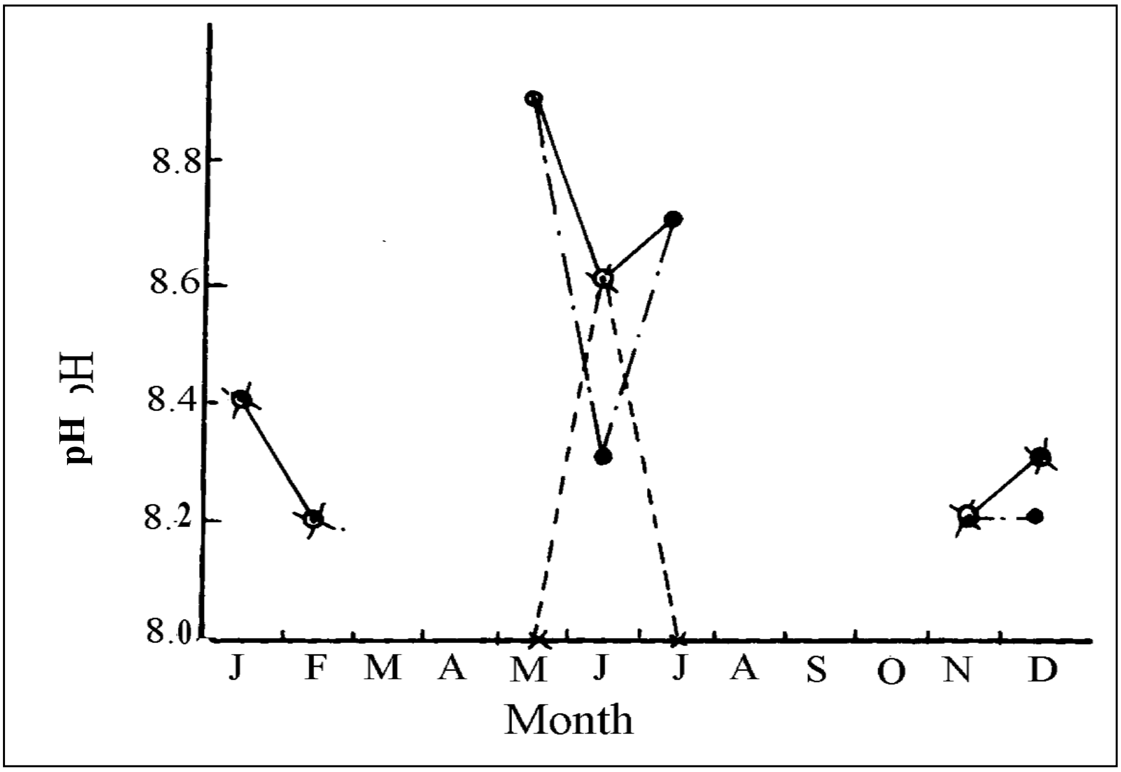

Fig. 61 **Monthly variations of pH values at Allaqi in 1983 (Goma & Abdel-Rahman 1992a)**

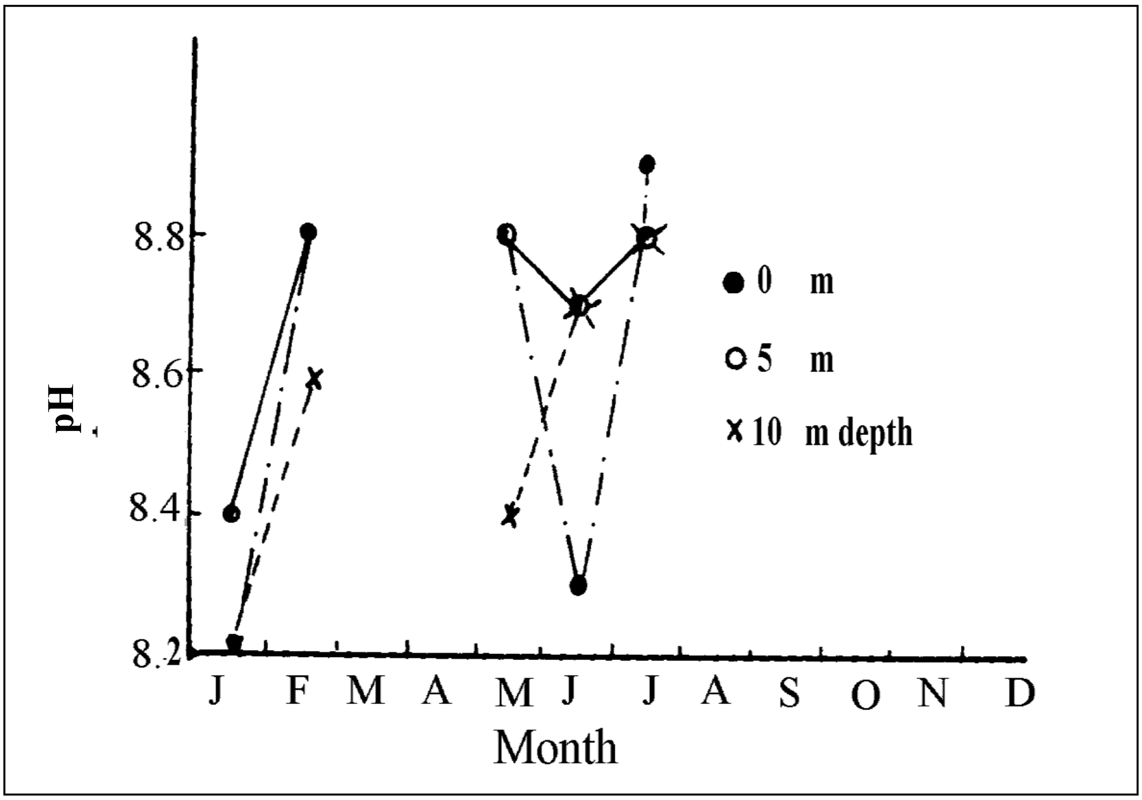

Fig. 62 **Monthly variations of pH values at Korosko in 1983 (Goma & Abdel-Rahman 1992a) [**For stations refer to Fig. 4**].**

by Abdel-Rahman & Goma (1995 a, b, c and d) and Abdel-Rahman (1995 a and b) and their results are summarized in Table 37. The highest values were recorded always at the surface and the lower in deep waters.

The seasonal variations of pH values in Lake Nasser during 1993 indicate high pH values in the two sides of the Lake in summer (8.47 and 8.35 for the eastern and western sides), while the highest pH value (8.05) was recorded during spring in the main channel. For the two sides and the main channel, the lowest pH values were recorded during winter (Fishar 1995 - Fig. 65).

Comparing the pH values of Lake Nasser with those of Volta Lake, it is found that, the mean pH values in the latter lake were much lower, mainly between 6.8 and 7.2, and sometimes less than 6. In this lake the pH never surpassed 8.1 in the open water. Free CO_2 was always present in Volta Lake at the surface, but especially in deep water where it sometimes surpassed 40-55 mg/l.

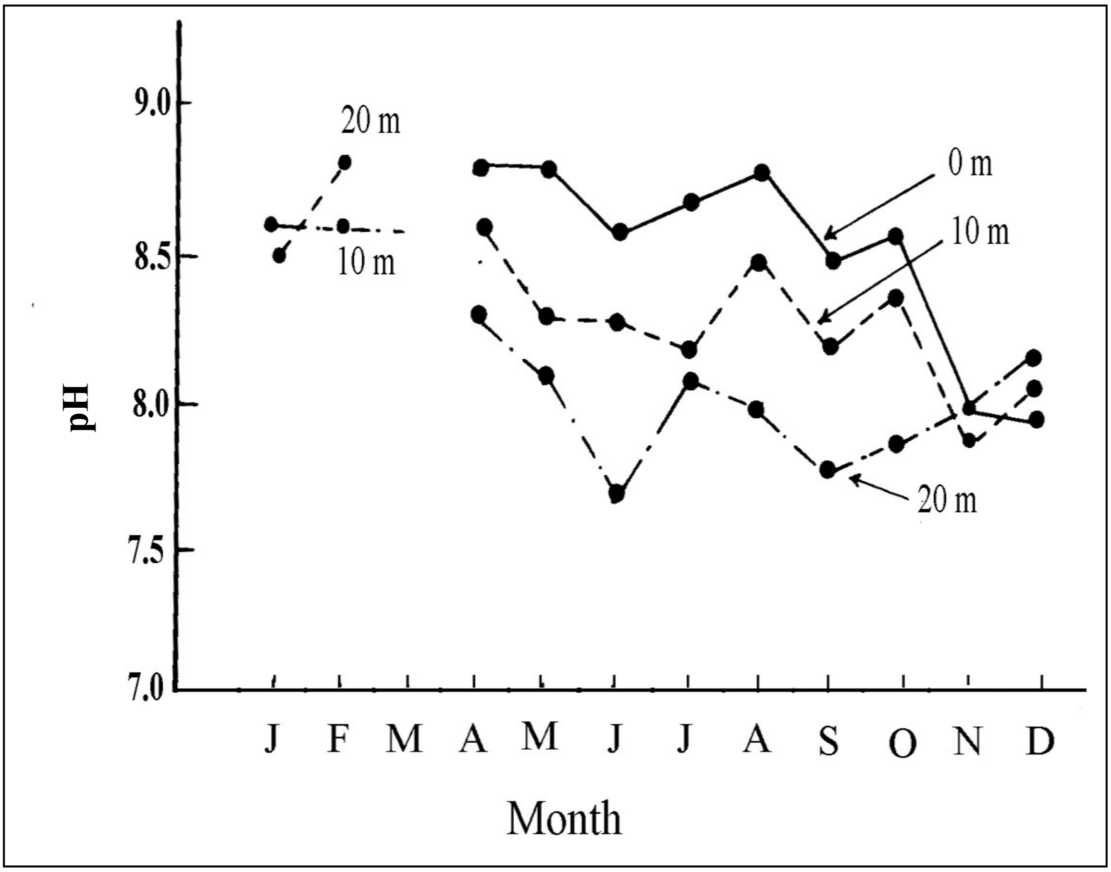

Fig. 63 **Monthly variations of pH values at 0, 10 and 20 m depth in Lake Nasser in 1984 (Goma & Abdel-Rahman 1992b).**

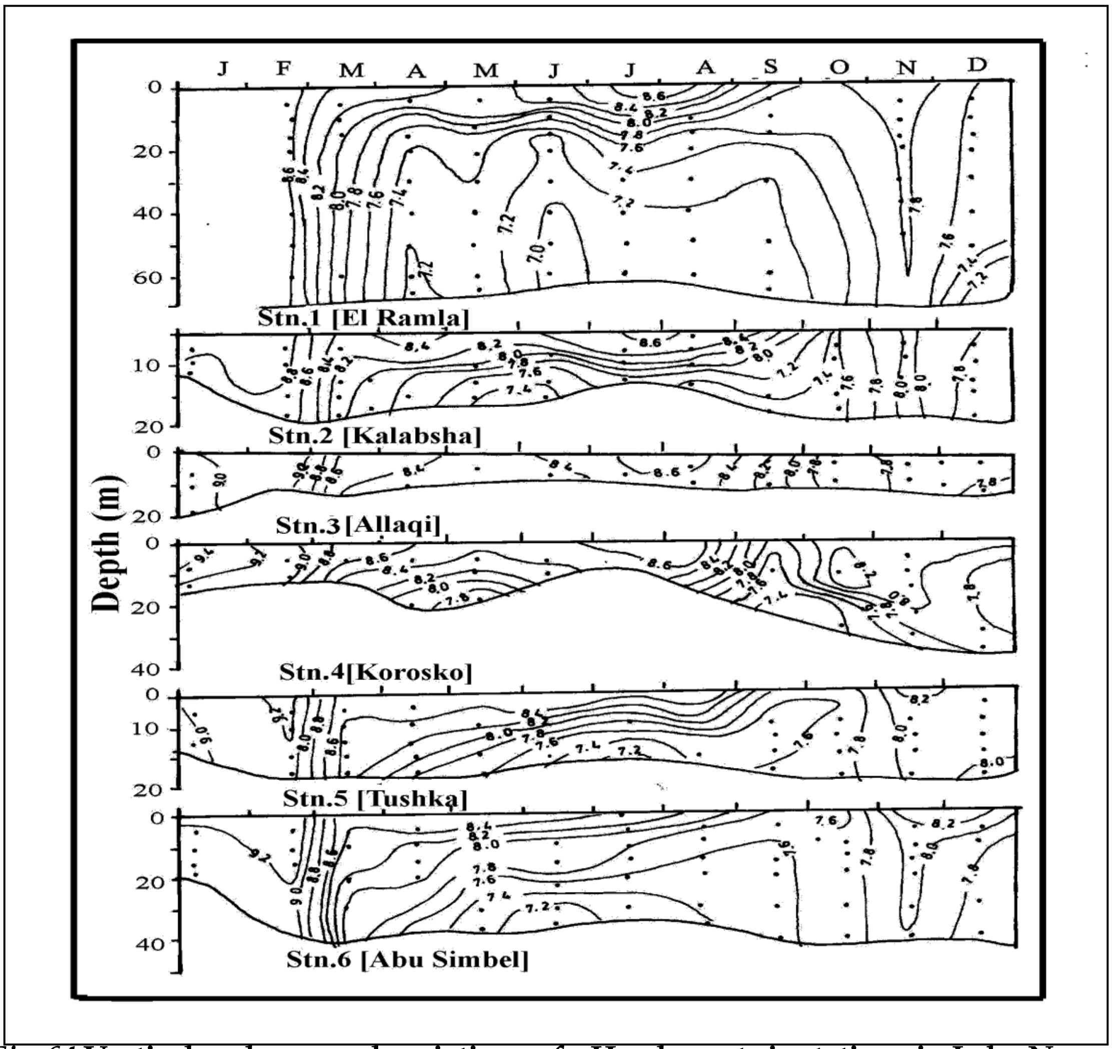

Fig. 64 **Vertical and seasonal variations of pH values at six stations in Lake Nasser in 1985 (Abdel-Rahman & Goma 1992c)** [For stations refer to Fig. 4].

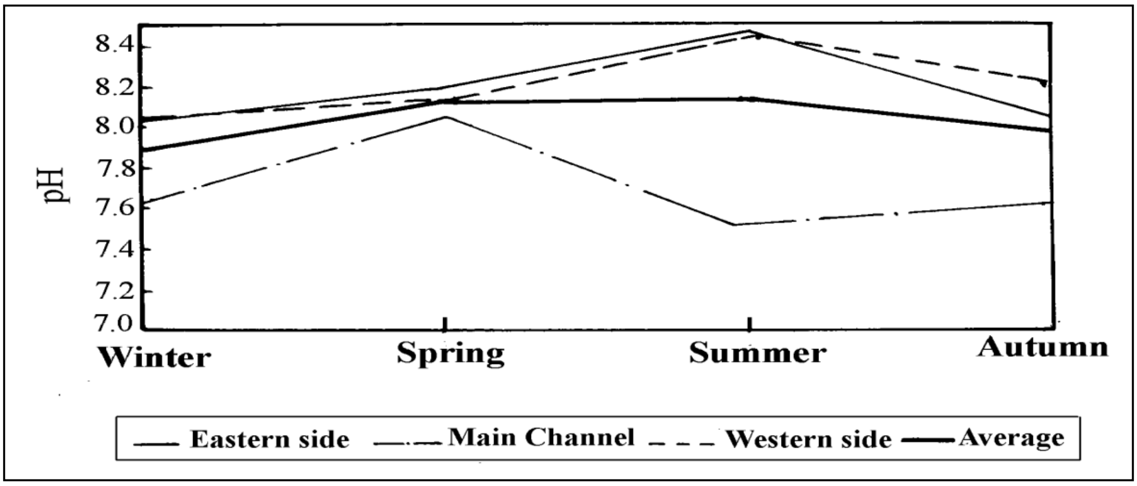

Fig. 65 **Seasonal variations of pH values in Lake Nasser during 1993 (Fishar 1995).**

Table 37 **Seasonal, vertical and regional variations of pH values along the main channel of Lake Nasser (1987-1992) [For stations refer to Fig. 4].**

	1987*	1988*	1989*	1990*	1991**	1992**
Range	6.8-8.9	7.44-9.18	7.14-9.09	7.17-8.94	7.47-8.92	7.07-8.92
High value	8.9	9.18	9.09	8.94	8.92	8.92
Stn.	6	4	6	4	6	4 & 6
Depth (m)	10	5	5	0	10	0
Month	(Dec.)	(June)	(April)	(July)	(Dec.)	(April)
Low value	6.8	7.44	7.14	7.17	7.47	7.07
Stn.	1	1	2	4	1	1
Depth	60	30	15	60	70	70
Month	(Oct.)	(Sept.)	(Sept.)	(July)	(Sept.)	(Aug.)
PH < 7						
Stn.	St. 1					
Depth	(bottom layers)	-------	-------	-------	-------	-------
Month	(June, Oct. & Nov.)					

* Abdel-Rahman & Goma (1995a, b, c and d). **Abdel-Rahman (1995a and b).

ALKALINITY

The alkalinity of Lake Nasser is mostly due to bicarbonate; the carbonate concentration is very limited. In the early years (1970) the **carbonate** concentration was 28 mg/l (Entz 1972). Elewa (1976) pointed out that the carbonate values decreased to about 17 mg/l for the surface waters, while bottom waters had lower or no CO_3^{2-} content. Aly (1992) showed that the carbonate concentration ranged from 0 to 32 mg/l with a mean of 15.5 mg/l. Abdel-Monem (1995) found that alkalinity as carbonate ranged from 0.0 - 28 mg/l, the maximum value was recorded at the bottom waters of Kalabsha. Higher values were usually encountered in the upper 3 m compared to 15 m depth and bottom (except in winter where the bottom layer had the highest concentration).

The **bicarbonate** concentration, however, is much higher and has shown a reverse pattern. For the main channel, the concentration had a range from 53.9 to 110.57 mg/l in 1970 (Nessim 1972) as compared to a range of 117 to 203.4 mg/l in 1974 - 1975 (Elewa 1976). For bottom waters the range was recorded as 110 to 174.5 mg/l in the latter period (Elewa 1976). Aly (1992) recorded lower bicarbonate concentrations ranging from 8 to 120 mg/l (mean of 76.5 mg/l). Abdel-Monem (1995) studied the bicarbonate concentration at 10 sites in the main channel at 3, 15m depth as well as at the bottom waters. He found that the bicarbonate concentrations fluctuated between 16.6 to 134.3 mg/l, the highest mean values at the three layers were recorded during autumn (98.2, 96.8 and 129.5 mg/l respectively) and the lowest values were

found during summer. It is obvious that the bicarbonate concentration of Lake

Nasser since 1970 uptill now remained almost constant with fluctuations within narrow limits.

Entz (1972) pointed out that the Lake is generally free from **CO_2**, while Elewa (1976) recorded low values (3.3 mg/l) in the deep waters at some localities of the lake.

In **Khor El Ramla**, the water **alkalinity** (**CO_3**) showed slight monthly fluctuations, being very low during summer (1.42 mg/l), slightly increasing in autumn (2.16 mg/l), attaining its highest value in winter (2.32 mg/l), then decreasing in spring (2.03 mg/l). No significant differences in alkalinity with water depth were observed (Abdel-Mageed 1992). Gindy (1991) found that the **carbonate** values ranged from 1.0 (bottom waters of Khor El Ramla) to 15.0 mg/l (surface waters of Khor El-Allaqi). The maximum average value of carbonate was encountered in the surface waters of Khor Al-Allaqi (13.0 mg/l), whereas the minimum was observed in the bottom waters of Khor El Ramla (1.5 mg/l). Generally, the carbonate values decrease from south (Khor El-Allaqi) to north (Khor El Ramla).

Gindy (1991) mentioned that the **bicarbonate** of **khor waters** fluctuated between 92 mg and 119 mg/l at the bottom and surface water of Khor El-Allaqi, whereas the relatively low values were recorded at the bottom waters of Khor Wadi Abyad (96 mg/l).

MAJOR IONS

Latif (1984a) reported that **chloride** concentration decreased mostly with depth. In the main channel, for the surface water, the chloride values recorded were 9.4, 18.0, 24.0 mg/l in 1974, 1976 and 1977 respectively (Latif & Elewa 1980). The lowest value so far recorded was 2.9 mg/l (Latif 1984a). Belal *et al.* (1992) pointed out that chloride concentrations were relatively high and varied between 7.29 to 19.22 mg/l with an average of 10.04 mg/l.

The **sulphate** concentration ranged form 5 to 15 mg/l and remained relatively constant during 1972 and from 1975 to 1977 (Latif 1984a). It seems that sulphate concentration remained nearly constant since the early filling of the Lake. Thus, Belal *et al.* (1992) showed that sulphate concentration in the Lake ranged from 1.0 to 15 mg/l. Shoreit *et al.* (1992) pointed out that sulphate concentration in the Lake decreased rapidly with depth and fluctuated between 12 mg/l at the surface and 3.0 mg/l at the bottom. Abdel-Monem (1995), however, recorded low sulphate values ranging from 0.90 to 9.86 mg/l with a minimum average of 1.63 mg/l near the bottom during summer. The low sulphate content of bottom layers may be attributed to low oxygen content leading to increase of sulphate-reducing bacterial activities i.e., sulphate to H_2S. Abdel-Monem (1995) found a positive correlation between SO_4^{2-} and chlorophyll *a* ($r \approx 0.78$), a finding which agrees with Beauchamp (1953), who suggested that the growth of plankton in Lake Victoria and probably other African lakes, is restricted by the low sulphate content.

The concentrations of **Ca^{2+}** and **Mg^{2+}** were 25.26 and 10 - 11 mg/l respectively (Entz 1972). Latif & Elewa (1980) pointed out that during 1974 - 1976 the concentrations of the major cations, Na^{+}, K, Ca^{2+} and Mg^{2+} were 6.2-27.8, 1.9-8.0, 14.3-27.5 and 4.5-12.5 mg/l respectively. Thus, the basic ratio (Na+K): (Ca + Mg) is generally less than 1.0 in the Lake. Gindy (1991) mentioned that in the Lake waters the concentration of Ca^{++} ranged between 14.0 and 28.8 mg/l. The average distribution of Ca^{++} shows that the highest concentration of Ca^{++} (i.e. 26.3 mg/l) was recorded at the surface waters of Khor El-Allaqi as compared with the lowest value (i.e. 14.6 mg/l) in bottom waters of Khor Wadi-Abyad (Gindy 1991). The distribution of Ca^{++} in the middle waters denotes an increase from north to south, which is similar to the trend of $CO_3^{- -}$ content. This indicates that calcium occurs in the form of carbonates. A seasonal variation of calcium concentration in the lake water was observed, with a minimum of 12.8 mg/l in October and a maximum of 38.5 mg/l in February and the mean value was 21 mg/l (Belal *et al*. 1992).

Magnesium values fluctuated between 2.88 and 10 mg/l (Gindy, 1991) compared with 10-11 mg/l as recorded by Entz (1972). The lowest and highest values were recorded in the bottom waters of Khor El Ramla and middle waters of Khor Wadi Abyad respectively. The average distribution shows that the highest concentration of Mg^{++} (6.92 mg/l) was recorded in the middle waters of Khor Wadi Abyad, whereas the lowest concentration (3.34 mg/l) was recorded in the surface waters of Khor Wadi Abyad (Gindy 1991). Belal *et al*. (1992) showed that the magnesium concentration in the Lake water ranged from 5.8 to 19.5 mg/l.

Abdel-Monem (1995) found a positive correlation between Mg^{2+} and phytoplankton biomass as represented by chlorophyll *a* ($r \approx 73$). These results confirm the findings of Goldman (1960 and 1961) and Loffler (1964) who showed that Mg^{2+} is a major factor limiting photosynthesis in an Alaskan lake and Mount Kenya.

In khors **sodium** values varied between 11.1 mg/l (bottom waters of Khor El-Allaqi) and 15.1 mg/l (surface waters of Khor El-Ramla) (Gindy 1991). The average distribution of sodium shows that the highest concentration (13.8 mg/l) was recorded in the surface waters of Khor El-Ramla, whereas the lowest one (11.33 mg/l) was found in the bottom waters of Khor El-Allaqi (Gindy 1991). However, higher concentrations (6.2-27.8 mg/l) were previously recorded by Latif and Elewa (1980).

Much lower concentrations of sodium were recorded in 1993 (Abdel-Monem 1995) in the main channel of the Lake ranging from 3.15 mg/l at 3 m depth at Mariya in spring and a minimum of 0.89 mg/l at Adindan at 15 m depth during autumn. There were no significant changes of sodium values at all stations during the four seasons (annual average 1.62 mg/l).

Potassium concentrations along the main channel ranged between 5.08 mg/l in summer and 2.13 mg/l at Adindan at 3 m depth. The average annual value was 4.03 mg/l at 3 m depth during summer and a minimum of 3.19 mg/l near the bottom in autumn (Abdel-Monem 1995).

NUTRIENTS

Among the four African man-made lakes (Volta, Nasser, Kainji and Kariba), Lake Nasser is the richest in nutritive salts. The concentrations of phosphate, nitrate nitrogen and silicon range between 0.02 to 0.52; 0.50 to 3.0 and 10 to 35 mg/l.

Nitrogen

a. Ammonium nitrogen (NH_4-N). Abdel-Monem (1995) found regional, seasonal and vertical variations of NH_4-N along the main channel of the Lake. The highest values were recorded near the bottom during autumn (range between 78.1 to 273.3 μg/l), while it was not detected in most localities at other depths in summer. The seasonal average fluctuated between a maximum of 178.4 μg/l near the bottom layer in autumn to a minimum of 6.8 μg/l at 3 m depth during the same season. The increasing NH_4-N level in the hypolimnion compared with the epilimnion in autumn may be attributed to liberation of NH_3 from the sediment/water interface (Harris 1986). Abdel-Monem (1995) explained the decrease in NH_4-N during summer as being due to nitrification processes that lead to oxidation of NH_4 to NO_2 and NO_3 as manifested by their average high values at the bottom layers which amounted to 22.6 μg/l for NO_2 and 111.9 μg/l for NO_3. In winter, nitrification is temperature limited so that the NH_4-N may build up in the Lake waters (Harris 1986).

b. Nitrite-nitrogen. Latif (1984a) pointed out that the nitrite nitrogen ranged between 5 and 180 μg/l. In his study of NO_2-N along the main channel Abdel-Monem (1995) recorded maximum values (66.7 μg/l) near the bottom in the vicinity of HD during summer which decreased to an undetectable value (0.0) in some stations in spring and autumn. The seasonal average values ranged from 28.4 μg/l near the bottom layer in winter and 1.3 μg/l near the bottom in autumn (annual average value = 10.7 μg/l).

c. Nitrate nitrogen (NO_3-N). Latif (1984a) found that the concentration of nitrate nitrogen in Lake Nasser range from 0.50 to 3.0 mg/l. In the **main channel**, high nitrate nitrogen concentrations were recorded in November, when it was 2-3 mg/l at the northern sector and 3.0 mg/l at El-Birba (Zaghloul 1985). Lower nitrate nitrogen concentrations were recorded in May, as they were 1.5, 0.6 and 0.4 mg/l at the northern sector, Adindan and Amada respectively. In August the lowest values were observed at the northern sector, while it was somewhat high in the southern sector and this is attributed to the effect of incoming flood (Zaghloul 1985). During the same month Latif (1984a) recorded the range of nitrate nitrogen concentration as 0-0.8 mg/l in the southern part of Lake Nubia and a range of 0.6-1.0 mg/l in the northern part at Wadi Halfa and Sarra.

Elewa & Azazy (1986) pointed out that the nitrate-nitrogen fluctuated between 64 - 72 μg/l and 290 to 0.0 μg/l during 1974 and 1984. The zero value recorded in spring 1984 may be correlated with the high rate of photosynthesis by phytoplankton. This high activity of phytoplankton was correlated with nutrients, as measured by increase in electrical conductivity during summer and winter (Elewa & Azazy 1986). Ahmad *et al* (1989) recorded maximum levels of NO_3-N in June 1983 amounting to 301.2 μg/l at 15 - 20 m depth. In 1993 Abdel-Monem (1995) recorded high concentrations in winter and spring with a maximum value of 768.5 μg/l near the bottom at Abu Simbel in winter. Lower values were recorded in summer and autumn with a minimum of 3.9 μg/l at 3 m depth near the HD and Abu Simbel in summer. The obvious decline in NO_3-N in some locations can be principally attributed to its utilization by phytoplankton (Hutchinson 1957) or to the reduction by denitrifying bacteria (Munawar 1970 and Seenayya 1971). Shoreit *et al.* (1992) showed that at the surface no nitrate could be measured but increased considerably with increasing depth and reached a maximum of 1750 μg/l at the bottom.

In **khors**, higher nitrate concentrations were recorded in November than those in May and August (Zaghloul 1985) and generally nitrate concentrations in khors maintained similar values recorded for the main channel. Latif (1984a), however, presented higher values of nitrate concentrations in the main channel than those in the khors. Elewa (1985) recorded a maximum nitrate concentration (406.8 μg/l) in the bottom waters of Khor Tushka and a minimum value (113 μg/l) in the bottom waters of Khor Kalabsha in August 1981 (Table 38). The highest NO_3-N was recorded in May/June 1982, April, June, July 1983 parallel with the minimum value of algal count (Belal *et al.* 1992 - Table 45, Fig. 71).

d. Total organic nitrogen (TON). It was estimated by Abdel-Monem (1995) along the main channel who recorded seasonal, vertical and regional variations. The highest total organic nitrogen concentrations were found in winter at all depths ranging from 14.45 - 9.44 mg/l (average 11.61 mg/l). Minimum values were observed in summer ranging from 5.36 - 0.80 mg/l. Seasonal average values fluctuated between 12.09 to 1.8 mg/l. The high level of organic nitrogen in the Lake may be attributed to the high population densities of phytoplankton. McCarthy (1980) attributed the high content of organic nitrogen in freshwater bodies to the direct fixation of N_2 gas by the nitrogen fixing prokaryotes (bacteria and /or blue-green algae), thus contributing more than 2 - 3 times the nitrogen flux from other resources at a certain period (Horne & Fogg 1970).

Table 38 **Nutrient concentrations in some khors of Lake Nasser during 1982 - 1983 (Elewa 1985a).**

Khor	August, 1982		November 1982		May, 1983		September, 1983	
	Surface	**Bottom**	**Surface**	**Bottom**	**Surface**	**Bottom**	**Surface**	**Bottom**
PO_4- P µg/l								
El-Birba	48.9	48.9	48.9	65.2	32.6	48.9	45.64	55.42
Manam	45.46	48.9	58.68	163	29.34	29.34	52.16	48.9
Kalabsha	29.34	65.2	52.16	48.9	32.6	65.2	29.34	78.24
Tushka	32.6	32.6	58.68	61.94	45.64	48.9	58.68	58.68
NO_3-N µg/l								
El-Birba	203.4	158.2	339	271.2	180.8	316.4	203.4	180.8
Manam	180.8	180.9	180.8	361.6	203.4	271.2	180.8	180.8
Kalabsha	180.8	113	203.4	226	113.0	180.8	226	271.2
Tushka	203.4	226	384.2	406.8	180.8	180.8	180.8	203.4
SiO_2 mg/l								
El-Birba	25	21.3	20.0	14.5	16.3	13	15	18
Manam	12.5	18.8	12.5	20	11.3	8	16.3	15
Kalabsha	30	18.8	20	20	15	12.5	22.5	22.5
Tushka	17.5	17.5	12.5	15	20	20	18	20

Phosphate

In the early years of Lake Nasser filling high concentrations of dissolved phosphate were recorded ranging from 0.02-2.0 mg/l (Entz 1972). In 1976/1977 Latif & Elewa (1977) recorded much lower concentrations ranging from 0.055 to 0.52 mg/l being higher in the bottom than surface water layers. In 1981 Zaghloul (1985) found that the dissolved phosphate in the surface waters in the **main channel**, ranged between 0.07 and 0.52 mg/l, with the lowest value at El-Birba and Amada in winter and the highest one at Adindan in autumn. Such high values appear as due to the effect of flood water. A reverse relation appears to exist between the concentration of dissolved phosphate and water transparency, as for example the high phosphate content (0.52 mg/l) recorded at Adindan in autumn corresponding to a low water transparency with Secchi depth of 65 cm. On the other hand, low concentration of dissolved phosphate at El-Birba in winter (0.07 mg/l) corresponded to high water transparency of 220 cm. (Zaghloul 1985). The latter author pointed out that at 10 m depth, the dissolved phosphate concentration varied between 0.06-0.50 mg/l for the main channel with the minimum value in spring and maximum one in autumn. Its distribution in winter was high at El-Birba (0.2 mg/l) but decreasing to 0.09-0.12 mg/l in the other localities of the main channel (Zaghloul 1985). In summer, the dissolved phosphate concentration decreased southwards from 0.5 mg/l at El-Birba to 0.1 mg/l at Adindan (Zaghloul 1985). Belal *et al.* (1992) recorded a mean value of 0.15 mg/l in surface waters of the Lake.

Abdel-Monem (1995) found that phosphate concentrations in the main channel ranged from 0.193 mg/l near the bottom during autumn at Tushka to nil at various depths and localities in summer and spring. The highest annual average

(0.136 mg/l) was recorded in spring at 3 m depth while the lowest (0.0042 mg/l) in summer at 3 m depth. It seems that during the last two decades the dissolved phosphate concentration remained, more or less, constant.

In the early years of storage in Lake Nasser, Nessim (1972) found that dissolved phosphate concentration in **khor** waters was 0.55 mg/l with maximum values in Khor El-Birba. Zaghloul (1985) mentioned that dissolved phosphate concentration in the surface water of khors ranged between 0.07 and 0.25 mg/l with the lowest value at Khor Kalabsha in March and the highest at Khor Wadi Abyad in August. At 10 m depth the phosphate concentration varied between 0.06 and 0.60 mg/l in khors, with minimum values in spring and maximum in autumn, while in winter it was 0.14 mg/l (Zaghloul 1985). In Lake Nasser the maximum value of phosphate phosphorus (0.163 mg/l= 0.52 mg/l dissolved phosphate) was recorded in the bottom water at Khor Manam in November, and the minimum value (0.0293 mg/l= 0.093 mg/l dissolved phosphate) in the surface water of Khor Kalabsha in August (Elewa 1985b - Table 38). The latter author pointed out that the highest level may be influenced by the biological activity and distribution of cations in the sediments, phyisco-chemical conditions such as pH, redox potential and mineral composition of the sediments. Elewa's findings were in accordance with those of Golterman (1975) who showed that in summer the algal growth may reduce the phosphate. Hutchinson (1957) pointed out that in productive lakes, with clinograde oxygen curves, there is an increase in soluble phosphate in the oxygen-deficient part of the hypolimnion due to decomposition of sinking plankton, but in most cases it is primary caused by liberation of phosphate from sediments.

Adsorption of PO_4^{-3} on colloidal $Fe(OH)_3$, fine particles of $CaCO_3$ and on clay minerals, which occur in most Lake sediments originates from eroded material transported into the Lake by the river (Elewa 1985b). He adds that PO_4^{-3} anions are taken up from water by alumina or by clay minerals through chemical bonding of the anion to positively charged edges of the clays on which substitution of PO_4^{-3} or silicate in clay structure. Adsorption is favoured by lower pH and also by freshly precipitated ferric and aluminum hydroxides (Olphen 1963).

Thomas (1968) showed that the phosphate uptake from the Lake water depends on the presence of phytoplankton and by organic compounds and ferric complexes in the mud, at the same time, phosphate is released into solution from the superficial layer of the mud when a lake is stratified in the anaerobic deep water. The phosphate concentration in the water overlying sediments has a buffering action by solubility and adsorption or ion exchange equilibrium at the sediment-water interface (Stumm & Morgan 1970 and Golterman 1973).

Silicates

In the **main channel** of Lake Nasser, the silica concentration ranged from 10 to 35 mg/l in 1976-1977, with higher concentrations in August and minimum levels in May. These, values are higher than those recorded for 1975-1976, when the range was 8.1-15.5 mg/l (Latif & Elewa 1980). Zaghloul (1985) observed a reverse relation between the concentration of silicate and blooming of diatoms particularly at the southern sector of Lake Nasser, where *Melosira granulata* reached the maximum predominance of 9-17 million cells/l.

Talling (1976a) mentioned that low concentration of silica (2-2.8 mg/l) occurred in the head water lakes, in comparison with 10-24 mg SiO_2/l in the river stretches of Sudan and Egypt. This mainly results from depletion by planktonic diatoms and partially from the dissolution and its transfer of ubiquitous rock and soil silicates in running waters.

Khor waters may contain more silicates than the main channel (Latif & Elewa 1980). In khor waters of Lake Nasser, the silicate concentration (Table 38) varied between 8 mg/l in the bottom water of Khor Manam in May and 30 mg/l in the surface water of Khor Kalabsha in August (Elewa 1985b).

According to Golterman (1975), silicon oxide is of great significance as a major nutrient for diatoms of most lakes. Thus, silica comes to the reservoir from predominantly recycling processes, (diatom decomposition) and river loading. Again, silica usually increases in the deep water of lakes during summer stratification in the anaerobic deep water, having clinograde oxygen curves, which have an important mechanism, by which silica is removed from lake water. Zaghloul (1985), however, observed no particular trend in the concentration of silicate with depth.

CONCLUSIONS

The **oxygen concentration** of Lake Nasser varies seasonally, vertically and horizontally. In winter, the whole water mass is well oxygenated and almost homogeneous. However, there is a slight variation of dissolved oxygen among the different depths. Generally, high oxygen concentrations are recorded at all stations of Lake Nasser in spring of different years. The rapid increase of oxygen concentrations of surface waters (values of 150 % or even 200 % saturation) is mainly due to photosynthesis of rich phytoplankton populations. In summer, high or moderate oxygen concentrations are recorded in surface water layers. With increase of depth, a sharp decrease in oxygen concentration is observed and reaches 0 ml/l at bottom water layers. It is worth mentioning that the thermal stratification coincides with the formation of an oxygenated epilimnion and oxygen-free hypolimnion.

The oxygenated epilimnion becomes deeper southwards, i.e. the depth of oxygenated layer ranges from 8 to 10 m in the northern part of the Lake as compared with about 20 m at Adindan, the southernmost area. In autumn, the drop in temperature is accompanied by the initiation of destruction of thermal and oxygen stratification with the incoming flood in the southern part of Lake Nubia and progresses northwards. The epilimnion becomes thicker than in the remaining northern part of the reservoir. The difference in temperature and oxygen content with depth becomes narrower up to the Second Cataract than in the remaining northern part of the Lake. Moderate and sometimes high concentrations of oxygen are recorded in autumn in the surface water layers. But, a slow decrease of oxygen concentration is observed with the increase of depth and sometimes reaches 0 ml/l in the bottom layers.

It seems that the average oxygen concentration during all seasons, i.e. winter, spring, summer and autumn is higher in the western side of Lake Nasser than in the eastern. Meanwhile, at both sides of the Lake, the average oxygen concentration is higher than in the main channel. In Khor El Ramla the surface waters (0-5 m) are well oxygenated throughout the year. From January to April the whole water column is well oxygenated. In May the oxygen content shows a decrease below 10 m depth. In summer, thermal stratification is well pronounced with an upper oxygenated epilimnion, a poorly oxygenated metalimnion (5-20 m) and a completely oxygen depleted deep layers.

Electrical conductivity in Lake Nasser exhibits seasonal, vertical, horizontal and local variations ranging from 186 to 299 µmhos cm^{-1} for surface waters of the main channel. Conductivity of deep waters (50 m depth) show lower values than those of surface waters in winter and autumn and the difference is usually greater in autumn. For surface waters, the electrical conductivity values ranged in 1979 from 190 to 245, 210 to 252, 210 to 228 and 199 to 245 µmhos cm^{-1} in winter, spring, summer and autumn respectively, compared with 190 - 218 (average 198.8), 186 - 222 (average 204.5), 219 - 242 (average 238.3) and 215 - 260 (average 229.7) in 1993/1994 in winter, spring, summer and autumn respectively. The electrical conductivity values of Lake Nasser since its early filling remained, more or less, constant affected yearly by the flood water. In winter and spring, the conductivity values decrease southwards; while in summer the values show a gradual decrease from the HD to Amada, but increases at Tushka. In autumn the electrical conductivity decreases from the HD to Kalabsha, then increases southwards to El-Madiq, followed by a gradual decrease to Tushka and greater decrease to Adindan. Variation of electrical conductivity follows water movements of the floods. Highest concentrations are recorded in front of flood waters. Lower conductivity during the flood is due to low conductivity of flooded water from Blue Nile, which contributes about 84 % of Nile water.

In khors, the electrical conductivity is low in bottom waters (155 µmhos cm^{-1} at Khor Kalabsha) and high in surface waters (290 µmhos cm^{-1} at Khor El Ramla). Generally, in surface water of khors, a marked increase in the values of electrical conductivity is observed from south to north. The inflow of flood from the south lowers the electrical conductivity at Khor Tushka due to the precipitation of the suspended matter leaving the water nearly free of electrical minerals containing ionic salt.

Generally, the **pH values** of Lake Nasser lie on the alkaline side. Thus, in the main channel, the pH value varies between 7.8 and 9.6 in the surface waters; while it ranges between 6.8 and 8.6 in the bottom waters. In most localities, pH values decrease with depth. In spring, khors show higher pH values and wider range of difference with depth than in the main channel. However, in summer the values of surface waters of open and khor waters are comparable to some extent.

The **alkalinity** of the Lake is mostly due to bicarbonate, while the carbonate concentration is very limited. The **carbonate** values of surface water of the main channel ranged from 0 - 32 mg/l with a mean of 15.5 mg/l. In Khors it ranged from 4 mg/l (bottom waters of Khor El Ramla) to 13 mg/l (surface water of Khor El Allaqi). Generally, the carbonate values decrease form south (Khor El-Allaqi) to north (Khor El Ramla).

It seems that a decrease in **bicarbonate** concentration occurred in recent years. Thus, while Elewa (1976) recorded a range of 117-203.4 mg/l in 1974 - 1975, Ali (1992) recorded lower bicarbonate concentrations (8 - 120 mg/l). In the early years of Lake Nasser filling studies showed that it is generally free of CO_2 (Entz 1972), but later low values of CO_2 (3.3 mg/l) was recorded in deep waters in some localities (Elewa 1976).

The concentration of **major cations** i.e. Na^+, K, Ca^{++} and Mg^{++} range between 6.2 - 27.8, 1.9 - 8.0, 14.3 - 27.5 and 4.5 -12.5 mg/l respectively. Chloride concentrations were relatively high and varied between 7.29 and 19.22 mg/l with an average of 10.04 mg/l. It seems that sulphate concentration is nearly constant (0.90 - 15 mg/l) since the early filling of the Lake.

The **dissolved phosphate** concentration in surface water range between 0.02 and 0.52 mg/l being generally higher in the bottom than surface water layers. Lowest concentrations were recorded in February associated with the highest algal counts in winter (Table 45), while the highest values were in November. In summer phosphate concentrations decreased southwards where the highest phytoplankton standing crop was recorded. It seems that khors are richer in phosphate than the main channel. During the last two decades the phosphate concentration in Lake Nasser remained, more or less, constant.

The concentrations of NH_4-N, NO_2-N, NO_3-N and total organic nitrogen range from 0.078 to 0.237; 0.05 to 0.180; 0.0 to 3.0 and 1.8 to 14.45 mg/l. The decrease of NO_3-N in summer may be attributed to its utilization by phytoplankton or to the reduction by denitrifying bacteria. Increase of NO_2-N and NO_3-N may be due to the nitrification processes that lead to oxidation of NH_3 to NO_2 and NO_3 as manifested by average high values at the bottom layers. High NO_3-N values recorded in August in the southern region may be due to the effect of incoming water rich in nitrates.

Silicon concentrations range between 10 to 35 mg/l, khors being richer in silicon than in the main channel. A reverse relationship was observed between silicon concentrations and diatom blooms especially in the southern region of the Lake.