Chapter 2
Water Properties

The water properties of Lake Burullus were evaluated based on one year monitoring (January – December 2001) for 15 stations representing the eastern, middle and western sectors of the lake (Fig. 2.1). The estimated variables were classified into 4 main groups (*Sensu* Greenberg *et al*. 1992): physical and aggregate properties (air temperature, water temperature, transparency, depth, EC, pH, chlorosity and alkalinity), oxygen properties (dissolved oxygen, chemical and biological oxygen demands), dissolved salts (phosphate, nitrate, nitrite and silicate) and heavy metals (copper, iron, cadmium, lead and zinc). The variations were analyzed based on three aspects: 1- the annual means of the estimated variables in the 15 stations (Table 2.1), 2- the east-west variation (Table 2.2) and 3- the north-south variation (Table 2.3).

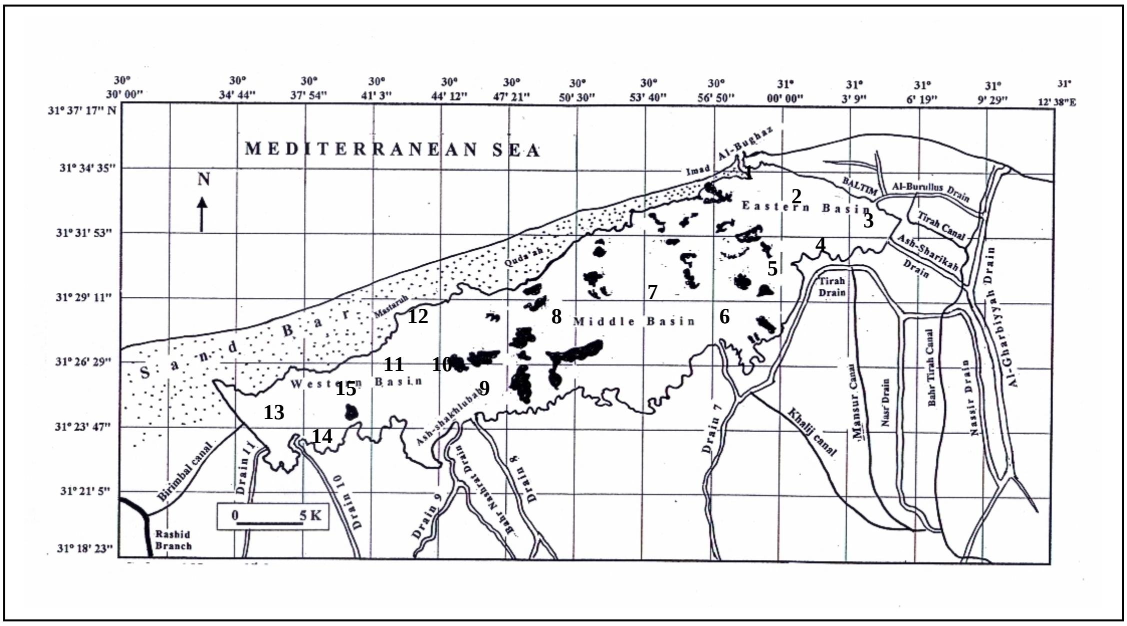

Fig. 2.1. **Location of the 15 stations selected for the monitoring of the water and sediment properties in Lake Burullus**

Table 2.1. **Annual mean of water properties in the 15 stations in Lake Burullus. DO: dissolved oxygen, COD: chemical oxygen demand, BOD: biological oxygen demand, SD: standared deviation. The minimum and maximum values of each variable are underlined.**

Variable	Eastern sector							Middle sector					Western sector			Total mean±SD
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Physical and aggregate properties																
Air temperature (°C)	23.0	23.8	23.3	23.5	22.5	22.8	22.3	21.3	22.7	22.8	22.8	22.2	24.2	24.0	23.0	22.9±4.8
Water temperature (°C)	22.5	22.8	22.2	21.9	22.4	22.9	22.9	22.4	22.8	22.2	21.8	22.0	22.6	23.3	23.0	22.5±5.2
Transparency (cm)	31.7	26.6	23.5	22.3	25.8	22.3	32.1	29.6	24.3	27.8	43.3	31.3	42.5	32.1	49.6	31.0±11.1
Depth (cm)	84.6	67.0	195.3	150.6	80.8	85.0	99.2	110.8	97.1	112.1	133.3	134.2	149.6	99.6	137.5	115.8±38.4
EC ($mS\ cm^{-1}$)	16.8	6.4	4.8	5.3	5.1	5.6	14.5	3.2	3.0	3.1	2.8	3.3	3.1	1.6	2.3	5.4±4.8
Chlorosity ($g\ l^{-1}$)	6.6	2.3	1.8	2.0	1.8	1.9	5.0	1.0	0.9	0.9	0.9	1.1	1.0	0.6	0.6	1.9±1.8
pH	8.7	8.5	8.6	8.4	8.8	8.8	8.9	8.7	8.6	8.6	8.7	8.7	8.5	8.4	8.7	8.6±0.6
Alkalinity ($g\ l^{-1}$)	253.2	256.4	288.5	286.1	281.2	257.8	245.3	244.8	309.6	286.3	275.9	255.5	227.3	211.4	188.0	257.8±53.7
Oxygen properties																
DO	9.1	7.6	8.2	6.6	8.3	7.9	8.9	8.0	9.6	9.4	9.4	9.2	10.4	7.2	9.4	8.6±2.3
COD ($mg\ l^{-1}$)	4.1	5.1	4.9	4.4	4.7	5.4	4.5	3.6	5.1	3.5	4.0	5.3	4.9	5.3	3.9	4.6±1.7
BOD	3.3	4.2	4.0	3.8	3.4	3.9	3.4	2.8	4.6	2.9	2.7	3.2	3.8	4.3	3.7	3.6±1.6
Dissolved salts																
PO_4	0.6	1.7	2.2	2.7	1.0	2.2	0.8	0.6	1.6	1.0	0.6	1.2	0.7	1.9	0.7	1.2±1.1
NO_3	0.8	2.9	5.5	6.5	2.1	3.9	0.8	1.9	3.7	2.0	1.2	1.3	3.3	4.2	2.2	2.8±2.3
NO_2 (µg-at. l^{-1})	0.3	1.1	1.5	2.0	0.8	1.3	0.2	0.5	1.4	1.0	0.8	0.7	1.4	1.5	1.2	1.1±0.8
SiO_2	36.0	37.6	35.0	41.1	29.8	36.0	42.9	37.3	45.0	42.5	49.9	40.8	49.3	49.8	51.9	41.7±25.1
Heavy metals																
Cu	7.1	8.2	8.8	8.4	3.2	8.7	6.4	3.0	6.8	3.0	3.5	2.6	5.4	8.3	5.1	5.9±4.0
Fe	9.6	6.6	10.8	13.7	4.9	8.9	6.7	2.9	5.4	2.5	1.9	2.7	5.3	7.8	4.1	6.2±6.2
Cd (µg-at. l^{-1})	8.4	4.4	3.4	5.8	3.5	6.3	6.7	2.0	3.8	1.6	1.9	1.7	2.5	3.3	1.6	3.8±3.2
Pb	3.6	5.5	5.3	6.2	2.0	4.6	3.5	1.5	4.1	1.7	1.1	1.2	3.4	6.3	3.4	3.6±3.2
Zn	17.2	12.0	10.2	11.4	9.0	12.0	13.1	6.5	7.6	3.7	6.7	4.0	4.9	6.4	3.5	8.5±5.7

Table 2.2. Annual range, mean and standard deviation (SD) of water properties along east-west axis in Lake Burullus. TDS: total dissolved solids, DO: dissolved oxygen, COD: chemical oxygen demand, BOD: biological oxygen demand.

Character		East			Middle			West		
		Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Physical and aggregate properties										
Air temperature (°C)		15.0 – 30.0	23.0	4.1	15.0 – 34.0	22.3	5.3	16.0 – 34.0	23.7	5.4
Water temperature (°C)		15.0 – 31.0	22.6	5.1	14.0 – 31.0	22.2	5.5	15.0 – 32.0	23.0	5.3
Transparency (cm)		10.0 – 80.0	26.3	9.4	15.0 – 55.0	31.3	9.3	15.0 – 65.0	41.4	10.4
Depth (cm)		42.0 – 240.0	108.9	49.5	75.0 – 160.0	117.5	20.1	70.0 – 180.0	128.9	27.0
EC (mS cm^{-1})		1.4 – 25.1	8.4	5.6	1.9 – 5.1	3.1	0.6	1.0 – 4.3	2.4	1.0
Chlorosity (g l^{-1})		0.5 – 9.6	3.1	2.1	0.5 – 1.8	1.0	0.3	0.3 – 1.6	0.7	0.4
pH		7.3 – 9.8	8.7	0.6	7.6 – 10.0	8.7	0.5	7.8 – 9.6	8.5	0.5
Alkalinity (g l^{-1})		32.0 – 370.0	266.9	49.1	140.0 – 380.0	274.4	52.7	95.0 – 280.0	208.9	34.3
Oxygen properties										
DO	**mg l^{-1}**	3.2 – 12.2	8.1	2.0	5.9 – 18.3	9.1	2.3	4.1 – 15.8	9.0	2.8
COD		0.4 – 8.9	4.7	1.7	1.2 – 9.1	4.3	1.7	0.4 – 9.6	4.7	1.8
BOD		0.2 – 8.1	3.7	1.5	0.3 – 9.3	3.2	1.7	0.1 – 8.6	4.0	1.7
Dissolved salts										
PO_4	**µg-at. l^{-1}**	0.1 – 4.8	1.6	1.1	0.1 – 9.3	1.0	1.2	0.1 – 3.8	1.1	0.8
NO_3		0.1 – 13.5	3.2	2.7	0.0 – 6.5	2.0	1.4	0.7 – 9.5	3.2	2.0
NO_2		0.0 – 3.9	1.0	0.8	0.0 – 4.0	0.9	0.7	0.4 – 3.6	1.4	0.8
SiO_2		6.3 – 106.3	36.9	26.8	14.8 – 84.2	43.1	21.5	20.8 – 99.7	50.3	24.9
Heavy metals										
Cu	**µg-at. l^{-1}**	1.4 – 23.2	7.2	4.1	0.4 – 16.5	3.8	3.1	1.6 – 17.0	6.3	3.5
Fe		0.2 – 33.0	8.7	7.6	0.2 – 12.5	3.1	2.9	0.8 – 14.4	5.7	3.9
Cd		0.6 – 13.8	5.5	3.5	0.1 – 9.9	2.2	1.9	0.3 – 5.4	2.4	1.7
Pb		0.4 – 13.9	4.4	3.5	0.1 – 9.6	1.9	2.0	0.9 – 12.5	4.3	3.0
Zn		2.9 – 28.8	12.1	6.1	1.9 – 12.3	5.7	2.7	1.1 – 12.1	4.9	3.1

Table 2.3. **Annual range, mean and standard deviation (SD) of water properties along north-south axis in Lake Burullus. TDS: total dissolved solids, DO: dissolved oxygen, COD: chemical oxygen demand, BOD: biological oxygen demand.**

Character		North			Middle			South		
		Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Physical and aggregate properties										
Air temperature (°C)		15.0 – 34.0	23.0	5.1	15.0 – 34.0	22.5	4.7	16.0 – 34.0	23.1	4.7
Water temperature (°C)		14.0 – 31.0	22.4	5.4	15.0 – 31.0	22.6	5.4	15.0 – 31.0	22.6	5.1
Transparency (cm)		15.0 – 65.0	39.7	10.1	15.0 – 80.0	29.0	10.6	10.0 – 40.0	25.1	6.8
Depth (cm)		65.0 – 180.0	127.8	26.8	42.0 – 140.0	97.3	21.7	42.0 – 240.0	118.1	49.4
EC (mS cm^{-1})		1.5 – 25.1	5.7	5.9	1.9 – 22.7	6.8	5.7	1.0 – 8.9	4.2	1.9
Chlorosity (g l^{-1})		0.3 – 9.6	2.0	2.4	0.6 – 8.1	2.3	2.0	0.3 – 4.1	1.5	0.8
pH		7.3 – 10.0	8.7	0.6	7.4 – 9.6	8.7	0.6	7.5 – 9.7	8.6	0.5
Alkalinity (g l^{-1})		95.0 – 350.0	240.0	46.6	32.0 – 370.0	258.2	63.3	175.0 – 380.0	272.4	48.1
Oxygen properties										
DO	**mg l^{-1}**	6.1 – 15.8	9.5	2.2	4.7 – 18.3	8.5	2.4	3.2 – 13.9	8.0	2.2
COD		0.4 – 9.1	4.5	1.8	1.4 – 8.9	4.2	1.7	1.2 – 9.6	5.0	1.6
BOD		0.1 – 7.9	3.4	1.6	0.6 – 8.1	3.3	1.6	0.9 – 9.3	4.0	1.6
Dissolved salts										
PO_4	**µg-at. l^{-1}**	0.1 – 9.3	0.8	1.2	0.2 – 3.1	1.0	0.7	0.4 – 4.8	1.9	1.1
NO_3		0.0 – 9.5	1.8	1.6	0.1 – 4.6	1.9	1.3	0.7 – 13.5	4.3	2.5
NO_2		0.0 – 3.5	0.9	0.7	0.0 – 2.1	0.7	0.5	0.2 – 4.0	1.4	0.9
SiO_2		6.3 – 91.7	45.6	23.9	7.2 – 106.3	40.0	27.0	8.7 – 99.7	39.5	24.9
Heavy metals										
Cu	**µg-at. l^{-1}**	0.4 – 14.0	4.7	3.1	0.9 – 14.7	5.2	3.5	1.4 – 23.2	7.4	4.4
Fe		0.4 – 24.2	4.6	4.8	0.3 – 18.7	4.7	4.6	0.2 – 33.0	8.6	7.4
Cd		0.1 – 13.8	3.1	3.3	0.4 – 11.7	3.7	2.9	0.3 – 13.2	4.4	3.2
Pb		0.1 – 11.8	2.5	2.4	0.4 – 13.9	3.1	3.0	0.4 – 13.2	4.8	3.4
Zn		1.1 – 26.4	7.1	5.8	1.9 – 20.1	8.8	5.4	1.2 – 28.8	9.4	5.7

The PCA ordination of the 15 stations based on their water properties indicates a clear separation between the stations of the eastern, middle and western sectors (Fig. 2.2). Although there is a heterogeneity between the stations of each sector, some stations are very similar to each other (e.g. stations 2 and 3 in the eastern sector, and stations 10 and 12 in the middle sector).

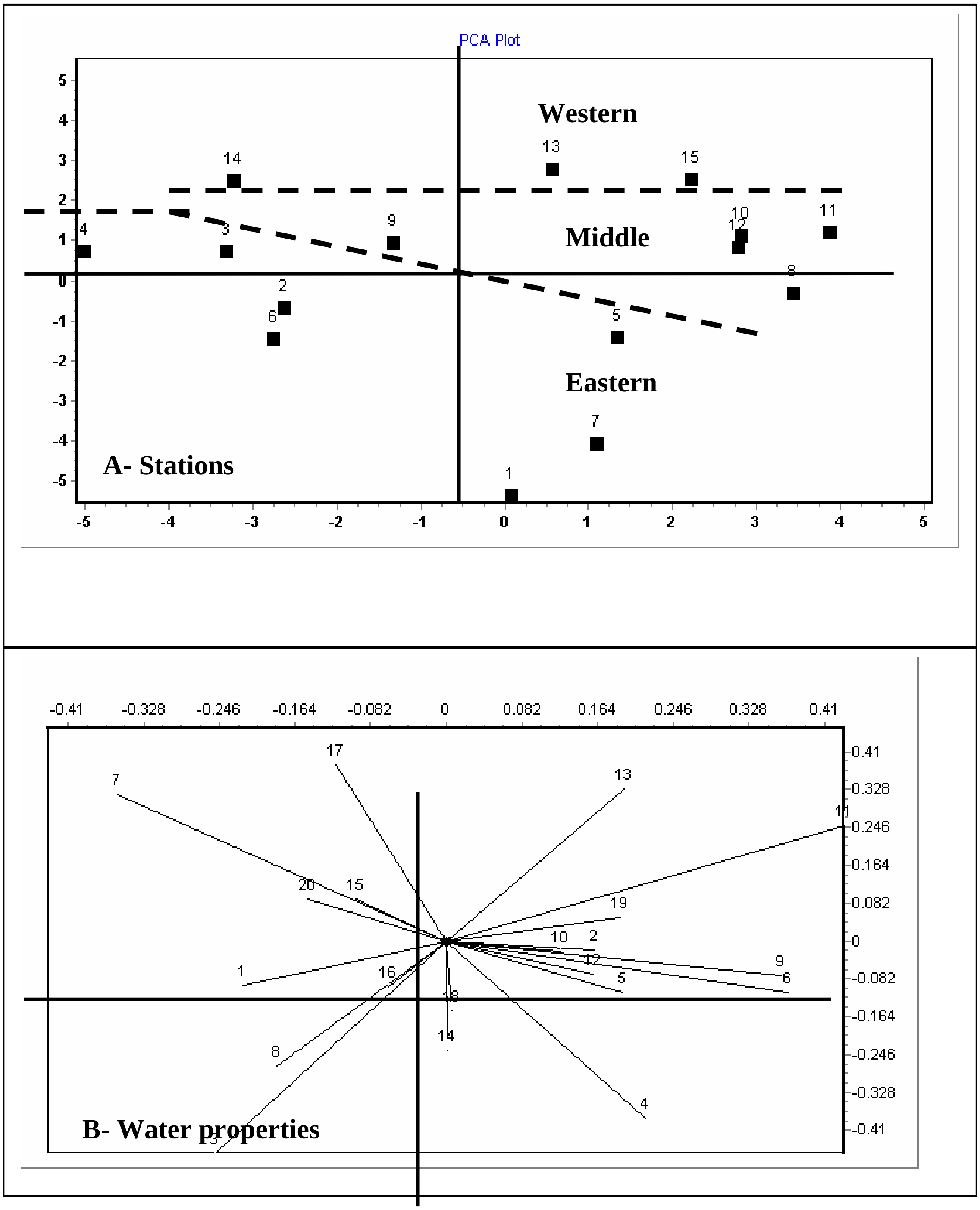

Fig. 2.2. **Principal component analysis (PCA) based on the results of the water properties of the 15 sampled stations in Lake Burullus. The water properties are: 1: air temperature, 2: water temperature, 3: transparency, 4: depth, 5: EC, 6: pH, 7: chlorosity, 8: alkalinity, 9: dissolved oxygen, 10: chemical oxygen demand, 11: biological oxygen demand, 12: phosphate, 13: nitrate, 14: nitrite, 15: silicate, 16: Copper, 17: Iron, 18: Cadmium, 19: Lead and 20: Zinc.**

2.1. PHYSICAL AND AGGREGATE PROPERTIES

Distinguished from the concentrations of the chemical and biological components, this part deals with the physical properties of the water of Lake Burullus at a monthly interval (Jan – Dec. 2001), The estimated properties include, temperature, transparency (i.e. turbidity), water depth, electric conductivity (as a measure of salinity), pH (as a measure of acidity), chlorides (as a measure of chlorosity) and $CaCO_3$ (as a measure of alkalinity). The monthly variations in these properties in the water of Lake Burullus is indicated in Fig. 2.3.

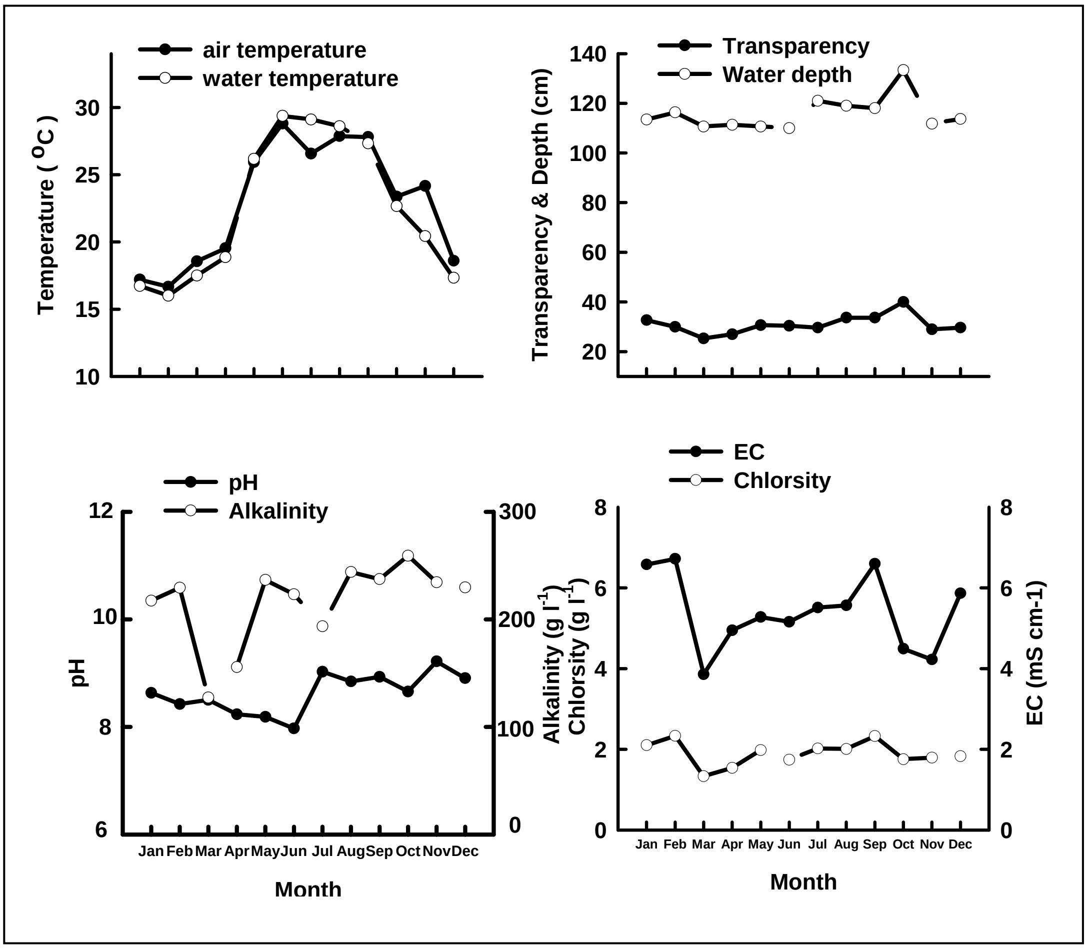

Fig. 2.3. **Monthly variation in the physical and aggregate properties of the water in Lake Burullus.**

2.1.1. Air Temperature

The annual mean of air temperature was 22.9 ± 4.8 °C, with a minimum value of 21.3 °C at station 8 (middle sector) and a maximum of 24.2 °C at station 13 (western sector). Regarding the variation from the eastern to the western sectors of the lake, the mean annual air temperature was 23 °C at the east, 22.3 °C at the middle and 23.7 °C at the west. On the other hand, the air temperature was slightly lower at the north (22.4 °C) than the south (23.0 °C). The monthly mean air temperature ranged between a minimum degree of 16.7 °C during February and a maximum of 28.8 °C during June.

2.1.2. Water Temperature

The annual mean of surface water temperature was 22.3 ± 5.2 °C, with a minimum value of 21.8 °C at station 11 (middle sector) and a maximum of 23.3 °C at station 14 (western sector). Regarding the variation from the eastern to the western sectors of the lake, the annual mean was 22.9 °C at the east, 22.2 °C at the middle and 23.0 °C at the west. On the other hand, the annual mean was 22.4 °C at the north and 22.6 °C at the south. The monthly surface water temperature ranged between a minimum of 16.0 °C during February and a maximum of 29.4 °C during June.

2.1.3. Water Transparency

In general, the transparency of the lake water is affected by inflowing water from sea outlet (Boughaz Al-Burullus) and drains, wind action, and suspended matters (Beltagy 1985). The annual mean of water transparency was 31.0 ± 11.1 cm, with a minimum value of 22.3 cm at station 4 (eastern sector) and a maximum of 49.6 cm at station 15 (western sector). Regarding the variation from the eastern to the western sectors of the lake, the annual mean was 26.3 cm at the east (the most turbid), 31.3 cm at the middle and 41.4 cm at the west (the clearest). On the other hand, the transparency decreased from north (39.7 cm) to south (25.1 cm). The monthly mean ranged between a minimum of 25.3 cm during March and a maximum of 40.0 cm during October.

2.1.4. Water Depth

The water depth in Lake Burullus is subjected to large variation from day to day. The water level is affected by both amount of drainage water and the exchange water with the Mediterranean Sea through the outlet depending on the wind direction (Beltagy 1985). Generally the depth increases from east to west and from south to north. The annual mean of water depth was 115.8 ± 38.3 cm with a minimum of 80.8 cm at station 5 in the eastern sector and a maximum of 195.3 cm at station 3 in the same sector. Regarding the variation from the eastern to the western sectors of the lake, the annual mean increased from the east (108.9 cm) to the west (128.9 cm). On the other hand, the mean was 127.8 cm at the north, 97.3 cm at the middle and 118.1 cm at the south. The lowest monthly average of water depth was recorded during June (110 cm), while the highest was during October (133.3 cm).

2.1.5. Salinity

The salinity distribution in the water of Lake Burullus, as noted in electrical conductivity measurements, is heterogeneous. This depends on the water drained by the drains and the fresh water of Berembal Canal, the water invading the lake from the sea (Boughaz El-Burullus) and the degree of mixing. The annual mean of water salinity was 5.4 ± 4.8 mS cm^{-1}, with a minimum of 1.6 mS cm^{-1} at station 14 in the western section and a maximum of 16.8 mS cm^{-1} at station 1 in the eastern sector (the nearest to the sea outlet). Regarding the variation from the eastern to the western sectors of the lake, the annual mean decreased from the east (8.4 mS cm^{-1}) to the west (2.4 mS cm^{-1}), and from the north (5.7 mS cm^{-1}) to the south (4.2 mS cm^{-1}). The salinity decreased during March (3.9 mS cm^{-1}), and increased during January and February (6.6 and 6.7 mS cm^{-1}, respectively). The sea water inflows to the lake during this period (Radwan *et al*. 1997, El-Shinnawy 2002).

2.1.6. Chlorosity

The chlorosity increases with the increase of salinity (Fig. 2.2). The annual mean of chlorosity was 1.9 ± 1.8 g l^{-1}, with a minimum of 0.6 g l^{-1} at stations 14 and 15 (western sector) and a maximum of 6.6 g l^{-1} at station 1 (eastern sector). Regarding the variation from the east to the west, the annual mean was the highest at the eastern sector (3.1 g l^{-1}), and the lowest at the western sector (0.7 g l^{-1}). On the other hand, the chlorosity was slightly higher at the north (2.0 g l^{-1}) than the south (1.5 g l^{-1}). Temporally, chlorosity had the same trend of salinity where it decreased during March (1.3 g l^{-1}), and increased in January and February having 2.1 and 2.3 g l^{-1}, respectively (Radwan *et al*. 1997, El-Shinnawy 2002).

2.1.7. pH

Water in Lake Burullus is alkaline throughout the year. The annual mean of pH was 8.6 ± 0.6, with a minimum of 8.4 at station 14 (western sector) and a maximum of 8.9 at station 7 (middle sector). The variation from the eastern to the western sectors of the lake indicated an annual mean of 8.7 at the eastern and middle sectors and 8.5 at the western sector. On the other hand, pH was 8.7 at the north and 8.6 at the south. The monthly annual mean ranged between 8.0 during June and 9.2 during November.

2.1.8. Alkalinity

The annual mean of alkalinity was 257.8 ± 53.7 g l^{-1}, with a minimum of 188.0 g l^{-1} at station 15 in the western sector and a maximum of 309.6 g l^{-1} at station 9 in the middle sector. Regarding the variation along the east-west axis, the middle sector had the highest alkalinity (274.4 g l^{-1}), followed by the eastern (266.9 g l^{-1}), while the western sector had the lowest one (208.9 g l^{-1}). On the other hand, the annual mean of alkalinity increased from the north to the south (240.0 g l^{-1} at the north, 258.2 g l^{-1} at the middle and 272.4 g l^{-1} at south of the lake). This variable increased during August (272.0 g l^{-1}) and October (279.6 g l^{-1}) and decreased during March (213.7 g l^{-1}).

2.2. OXYGEN PROPERTIES

These properties include dissolved oxygen (DO), chemical oxygen demand (COD) and biological oxygen demand (BOD). DO levels in natural and waste waters depend on the physical, chemical and biochemical activities. The analysis of DO is a key test in water pollution and waste treatment process control (Greenberg *et al*. 1992). On the other hand, BOD is an empirical test used to determine the relative oxygen requirements needed for the biochemical degradation and oxidation of organic and inorganic materials. COD is a measure of the oxygen equivalent of the organic matter content of a water sample that is susceptible to oxidation by a strong chemical oxidant. For water samples from a specific source, COD can be related empirically to BOD, organic carbon or organic matter (Greenberg *et al*. 1992). The variations in these properties are indicated in Fig. 2.4.

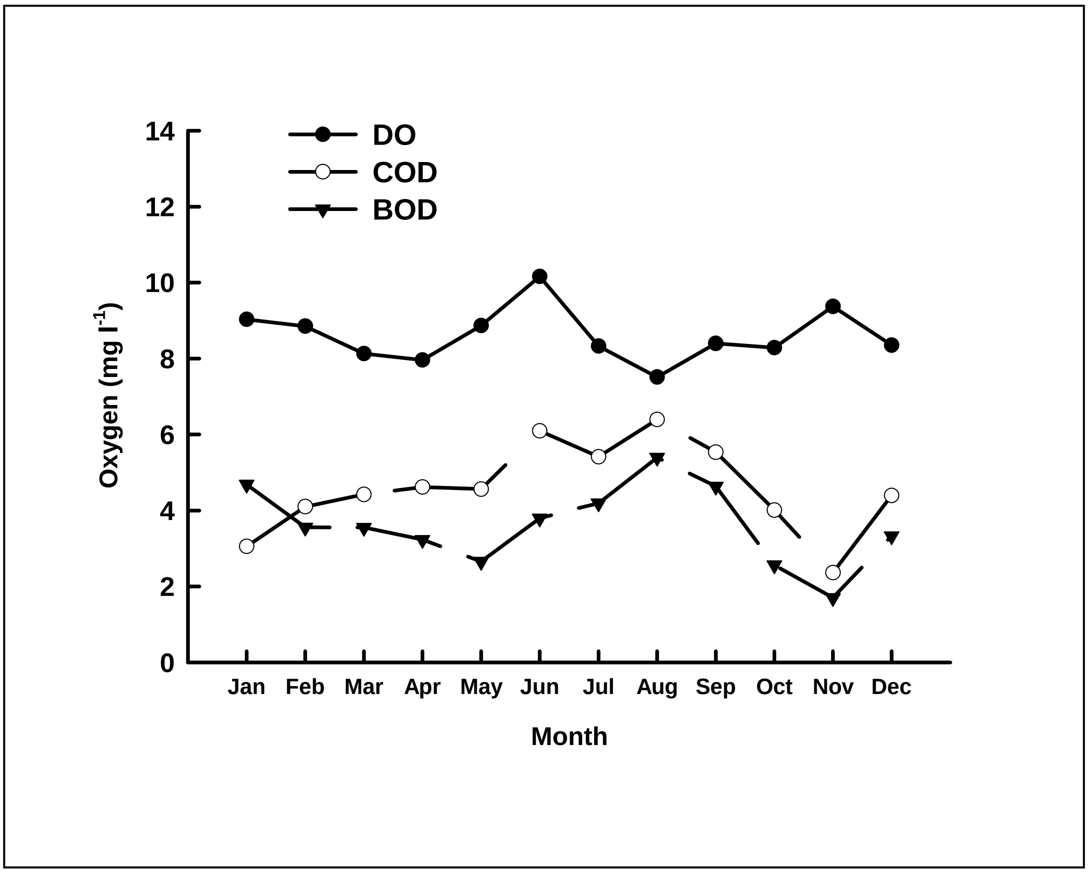

Fig. 2.4. **Monthly variation in the oxygen properties of the water in Lake Burullus.**

2.2.1. Dissolved Oxygen (DO)

The annual mean of dissolved oxygen was 8.6 ± 2.3 mg l^{-1}, with a minimum of 6.6 mg l^{-1} at station 4 (eastern sector) and a maximum of 10.4 mg l^{-1} at station 14 (western sector). Regarding the variation from the eastern to the western sectors of the lake, the maximum dissolved oxygen was observed in the middle and western sectors (9.1 and 9.0 mg l^{-1}, respectively), while the minimum was recorded in the eastern sector (8.1 mg l^{-1}). On the other hand, the dissolved oxygen decreased from north 9.5 mg l^{-1}) to south (8.0 mg l^{-1}). This trend may be related to the oxidation - reduction processes, as well as photosynthetic activities, which in turn correlated with the load of organic matters discharged into the lake through the drains (Radwan 2004). The monthly mean of dissolved oxygen varied between 10.2 mg l^{-1} in June and 7.5 mg l^{-1} in August.

2.2.2. Chemical Oxygen Demand (COD)

The annual mean of chemical oxygen demand was 4.6 ± 1.7 mg l^{-1}, with a minimum of 3.6 mg l^{-1} at station 8 in the eastern sector and a maximum of 5.4 mg l^{-1} at station 6 in the eastern sector. COD was slightly higher in the eastern and western sectors (4.7 mg l^{-1}) than the middle one (4.3 mg l^{-1}). On the other hand, COD was lower at the north (4.5 mg l^{-1}) than the south (5.0 mg l^{-1}). It had the highest value during August (6.4 mg l^{-1}) and the lowest during November (2.4 mg l^{-1}).

2.2.3. Biological Oxygen Demand (BOD)

The annual mean of biological oxygen demand was 3.6 ± 1.6 mg l^{-1} with a minimum of 2.7 mg l^{-1} at station 11 in the middle sector and a maximum of 4.6 mg l^{-1} at station 9 in the same sector. Regarding the variation along the east-west axis, BOD was similar to the chemical oxygen demand, where it was higher in the eastern and western sectors (3.7 and 4.0 mg l^{-1}, respectively) than the middle one (3.2 mg l^{-1}). On the other hand, it was lower in the north (3.4 mg l^{-1}) than the south (4.0 mg l^{-1}). Comparable to COD, BOD had a maximum value during the August (5.4 mg l^{-1}) and a minimum during November (1.7 mg l^{-1}).

2.3. DISSOLVED SALTS

The contents of dissolved salts in the water of Lake Burullus have the following sequence: SiO_2 > NO_3 > PO_4 > NO_2. The presence of silicate may be due to the nature of the sandy bottom sediments of the lake, while the presence of nitrite, nitrate and phosphate may be due to the drainage of fertilizers from the agricultural land into the drains which discharge water into the lake. In general, the nutrient concentrations in Lake Burullus relate to the input of all domestic, industrial and mainly agricultural wastes from the reclaimed lands surrounding the lake (Radwan 2001). The variations in these properties are indicated in Fig. 2.5.

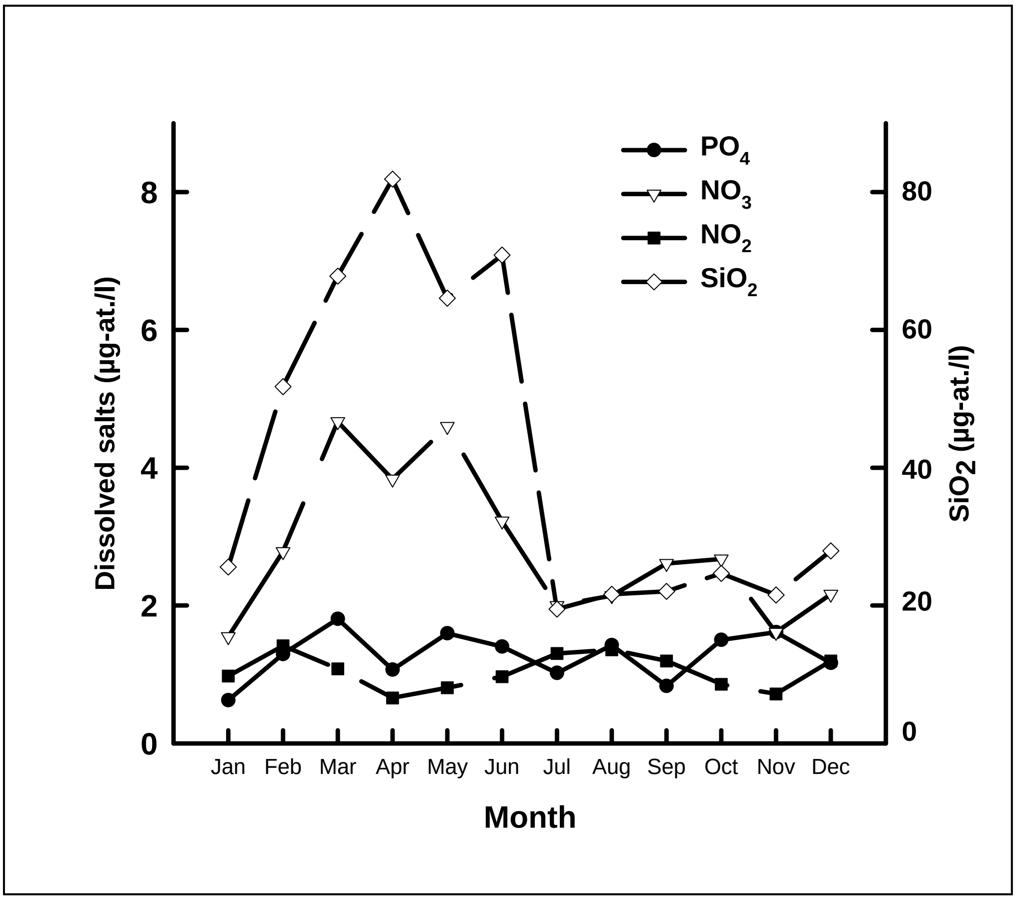

Fig. 2.5. **Monthly variation in the dissolved salts in the water of Lake Burullus.**

2.3.1. Phosphate (PO_4)

The annual mean of phosphate content in Lake Burullus is 1.2 ± 1.1 µg-at. l^{-1}, with a minimum of 0.6 µg-at. l^{-1} at stations 1 (eastern sector), 8 and 11 (middle sector); and a maximum of 2.7 µg-at. l^{-1} at station 4 in the eastern sector. The mean of phosphate content was higher in the eastern sector of the lake (1.6 µg-at. l^{-1}) than in the middle and western sectors (1.0 and 1.1 µg-at. l^{-1}, respectively), it was lower in the north (0.8 µg-at. l^{-1}) than in the south (1.9 µg-at. l^{-1}). On the other hand, the monthly fluctuation indicated a minimum value during January (0.6 µg-at. l^{-1}) and a maximum during March (1.8 µg-at. l^{-1}).

2.3.2. Nitrate (NO_3)

The annual mean of nitrate in the water of Lake Burullus is 2.8 ± 2.3 µg-at. l^{-1}, with a minimum of 0.8 µg-at. l^{-1} at stations 1 and 7 (eastern sector) and a maximum of 6.5 µg-at. l^{-1} at station 4 in the same sector. The mean of nitrate content in the eastern and western sectors of the lake (3.2 µg-at. l^{-1}) was higher than in the middle sector (2.0 µg-at. l^{-1}). On the other hand, it increased from north (1.8 µg-at. l^{-1}) to the south (4.3 µg-at. l^{-1}). Regarding the monthly variation, the minimum value was recorded during January (1.6 µg-at. l^{-1}) and the maximum during March and May (4.7 and 4.6 µg-at. l^{-1}, respectively).

2.3.3. Nitrite (NO_2)

The annual mean of nitrite in Lake Burullus is 1.1 ± 0.8 µg-at. l^{-1}, with a minimum of 0.3 µg-at. l^{-1} at station 1 (eastern sector) and a maximum of 2.0 µg-at. l^{-1} at station 4 in the same sector. Regarding the variation from the eastern to the western sectors of the lake, the mean nitrite was higher in the western sector of the lake (1.4 µg-at. l^{-1}) than the eastern and middle sectors (1.0 and 0.9 µg-at. l^{-1}, respectively). On the other hand, the nitrite increased in the north (0.9 µg-at. l^{-1}) than the south (1.4 µg-at. l^{-1}). The monthly mean had a minimum value during April (0.7 µg-at. l^{-1}) and a maximum during February (1.4 µg-at. l^{-1}).

2.3.4. Silicate (SiO_2)

The annual mean of silicate in Lake Burullus is 41.7 ± 25.1 µg-at. l^{-1}, with a minimum of 29.8 µg-at. l^{-1} at station 5 (eastern sector) and a maximum of 51.9 µg-at. l^{-1} at station 15 in the western sector. It increased from the east (36.9 µg-at. l^{-1} to west (50.3 µg-at. l^{-1}), and decreased from the north (45.6 µg-at. l^{-1}) to south (39.5 µg-at. l^{-1}). On the other hand, the minimum value was obtained (19.5 µg-at. l^{-1}) during July, while the maximum (81.9 µg-at. l^{-1}) was during April.

2.4. HEAVY METALS

The content of heavy metals in the water of lake Burullus had the following sequence: Zn > Fe > Cu > Cd > Pb. Generally, most of the estimated heavy metals of the water near to the southern shore of the lake were higher than those near the northern shore. This trend could be attributed to the effect of sewage effluents from the drains at the south particularly at the stations near to the mouths of drains with increasing levels of organic matter and the clay nature of the sediments. In addition, the trend of variation along east-west axis is as follows: eastern sector > western sector > middle sector for all the estimated heavy metals except Zn (east > middle > west). On the other hand, the period from February to May had the peak of heavy metals increase, while the period from June to September was characterized by a remarkable decrease in heavy metals (Fig. 2.6).

2.4.1. Copper (Cu)

The annual mean of copper was 5.9 ± 4.0 µg-at. l^{-1}, with a minimum of 2.6 µg-at. l^{-1} at station 12 (middle sector) and a maximum of 8.8 µg-at. l^{-1} at station 3 in the eastern sector. Regarding the variation from the eastern to the western sectors of the lake, the mean values were 7.2 µg-at. l^{-1} at the east, 3.8 µg-at. l^{-1} at the middle and 6.3 µg-at. l^{-1} at the west. On the other hand, the copper increased from the north (4.7 µg-at. l^{-1}) to the south (7.4 µg-at. l^{-1}). The monthly mean of copper ranged between 3.6 µg-at. l^{-1} during June and August and 11.5 µg-at. l^{-1} during May.

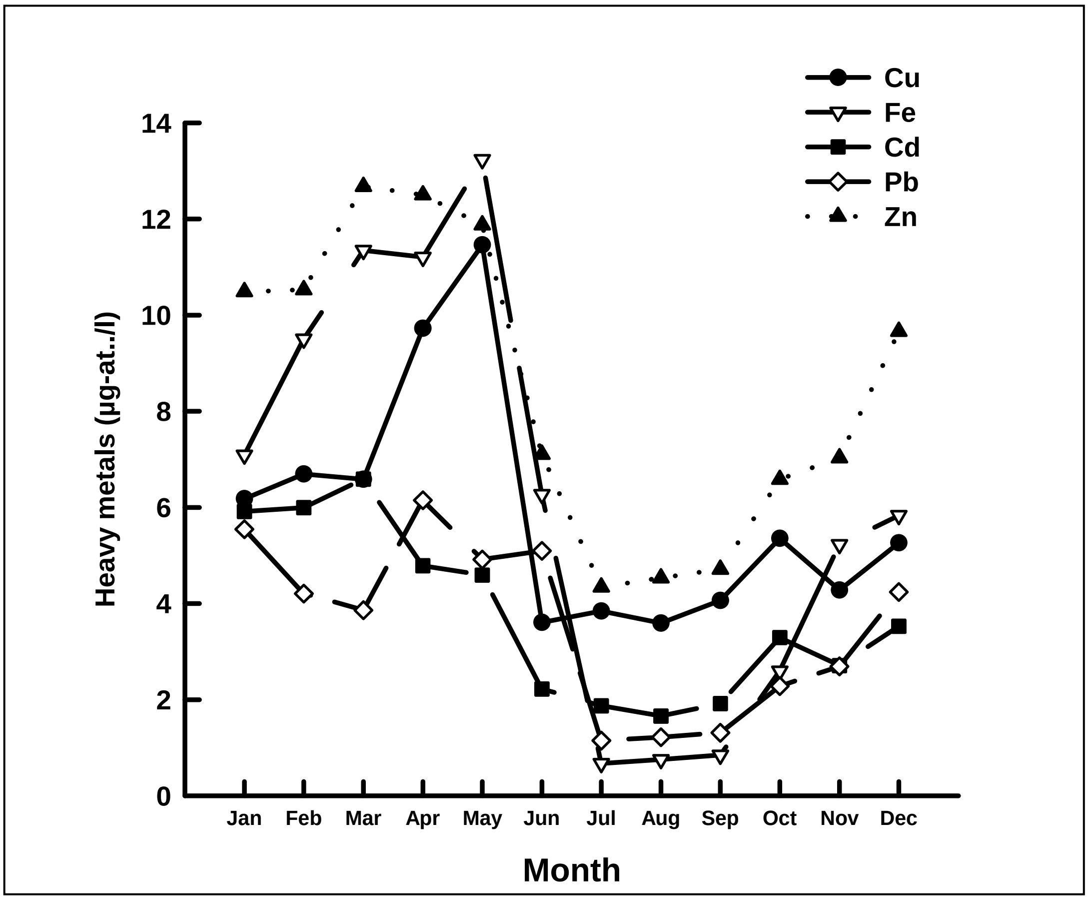

Fig. 2.6. **Monthly variation in the heavy metals in the water of Lake Burullus.**

2.4.2. Iron (Fe)

The annual mean of iron was 6.2 ± 6.2 µg-at. l^{-1}, with a minimum of 1.9 µg-at. l^{-1} at station 11 (middle sector) and a maximum of 13.7 µg-at. l^{-1} at station 4 in the eastern sector. Regarding the variation from the east to the west, the mean values were 8.7 µg-at. l^{-1} in the east, 3.1 µg-at. l^{-1} in the middle and 5.7 µg-at. l^{-1} in the west. On the other hand, the iron, similar to the other heavy metals, increased from the north (4.6 µg-at. l^{-1}) to the south (8.6 µg-at. l^{-1}). The monthly mean of iron ranged between 0.7 µg-at. l^{-1} during June and 13.2 µg-at. l^{-1} during May.

2.4.3. Cadmium (Cd)

The annual mean of cadmium was 3.8 ± 3.2 µg-at. l^{-1}, with a minimum of 1.6 µg-at. l^{-1} at station 10 (middle sector) and a maximum of 8.4 µg-at. l^{-1} at station in the eastern sector. Regarding the variation from the east to the west, the mean value in the east (5.5 µg-at. l^{-1}) was higher than that of the middle (2.2 µg-at. l^{-1}) and west (2.4 µg-at. l^{-1}). On the other hand, the cadmium, similar to the other heavy metals, increased from the north (3.1 µg-at. l^{-1}) to the south (4.4 µg-at. l^{-1}). The monthly mean ranged between 1.7 µg-at. l^{-1} during August and 6.6 µg-at. l^{-1} during March.

2.4.4. Lead (Pb)

The lead had the lowest value of all the estimated heavy metals in Lake Burullus, with an annual mean of 3.6 ± 3.2 µg-at. l^{-1} (it approximates the annual mean of cadmium). It had a minimum value of 1.1 µg-at. l^{-1} at station 11 (middle sector) and a maximum of 6.3 µg-at. l^{-1} at station 14 in the western sector. Regarding the variation along the east-west axis, the mean value in the east was 4.4 µg-at. l^{-1}, that of the middle was 1.9 µg-at. l^{-1} and that of the west was 4.3 µg-at. l^{-1}. On the other hand, the lead increased from the north (2.5 µg-at. l^{-1}) to the south (4.8 µg-at. l^{-1}). The monthly mean ranged between 1.2 µg-at. l^{-1} during July and 6.2 µg-at. l^{-1} during April.

2.4.5. Zinc (Zn)

Zinc has the highest values of heavy metals in Lake Burullus, with an annual mean of 8.5 ± 5.7 µg-at. l^{-1}. It had a minimum of 3.5 µg-at. l^{-1} at station 15 (western sector) and a maximum of 17.2 µg-at. l^{-1} at station 1 in the eastern sector. Regarding the variation along the east-west axis, the mean value decreased from 12.1 µg-at. l^{-1} in the east to 4.9 µg-at. l^{-1} in the west. On the other hand, it increased from the north (7.1 µg-at. l^{-1}) to the south (9.4 µg-at. l^{-1}). The monthly mean ranged between 4.3 µg-at. l^{-1} during July and 12.7 µg-at. l^{-1} during March.

2.5. CHANGES IN WATER CHEMISTRY

The comparison of the dissolved salts in the water of Lake Burullus in the present treatise (2001), with that of 1987 (Abdel-Moati *et al*. 1988) and 1997 (Radwan *et al*. 1997) indicated an increase of nitrate, nitrite and phosphate from 1987 to 1997, but a decrease in 2001 (Table 2.4). On the other hand, silicate had a decreasing pattern from 66.8 µg-at. l^{-1} in 1987 to 47.3 µg-at. l^{-1} in 1997 and 41.7 µg-at. l^{-1} in 2001. Regarding the variation of heavy metals, there is a continuous increase in Cu, Zn, Pb and Cd contents from 1987 (Abdel Moneim *et al*. 1990) to 1997 (Radwan 1997) and then to 2001 (the present treatise).

***Table 2.4.* Changes in water chemistry in Lake Burullus.**

a- Dissolved salts (μg-at. l^{-1})					
Year	**NO_3**	**NO_2**	**PO_4**	**SiO_2**	**Reference**
1987	4.0	0.8	1.6	66.8	Abdel-Moati *et al*. (1988)
1997	5.7	2.1	2.9	47.3	Radwan *et al*. (1997)
2001	2.8	1.1	1.3	41.7	Present treatise
b- Heavy metals (μg-at. l^{-1})					
Year	**Cu**	**Zn**	**Pb**	**Cd**	**Reference**
1987	2.3	5.5	1.9	1.6	Abdel-Moneim *et al*. (1990)
1997	3.5	6.8	2.7	1.9	Radwan (1997)
2001	5.9	8.5	3.6	3.8	Present treatise

2.6.CORRELATION BETWEEN WATER PROPERTIES

The simple linear correlation analysis of the water properties in Lake Burullus (Table 2.5) indicates that the salinity and chlorosity are positively correlated with each other ($r = 0.99$, $P < 0.001$). In addition, Cd and Zn are positively correlated with each other on one hand ($r = 0.94$, $P < 0.001$), and with the salinity and chlorosity on the other hand ($r = 0.84 – 0.86$, $P < 0.001$). These correlations indicate that a considerable portion of the Cd and Zn in the water of Lake Burullus is due to the sea water (the main source for increasing water salinity in this lake). The pollution by detergents that come mainly from the sea may partially interpret the increase of Zn. No doubt, that the drains which carry the liquid industrial wastes are among the main sources for heavy metal pollution in Lake Burullus (Mahmoud & Beltagy 1988).

Phosphates, nitrates and nitrites, that are used as fertilizers for the agricultural land in the catchment area of Lake Burullus, are positively correlated with each other (they are washed with the agricultural drainage into the lake). In addition Cu, Fe and Pb are positively correlated with each other on one hand, and with the previously mentioned dissolved salts on the other hand. This may indicate that the main source for pollution with these heavy metals are the agricultural drainage. This conclusion is supported by the fact that the levels of these heavy metals are much higher in the south (where all the drains pour their drainage water into the lake) than the north.

Table 2.5. **Matrix of Pearson simple linear correlation coefficients (r) between the water properties of Lake Burullus. *: P < 0.05, **: P < 0.01, ***: P < 0.001.**

Water properties	**Physical and aggregate properties**				**Oxygen properties**			**Dissolved salts**				**Heavy metals**				
	EC	**Cl**	**pH**	**Alk.**	**DO**	**COD**	**BOD**	**PO_4**	**NO_3**	**NO_2**	**SiO_2**	**Cu**	**Fe**	**Cd**	**Pb**	**Zn**
Physical and aggregate properties																
Transparency	-0.15	0.16	0.06	-0.68**	0.58*	-0.33	-0.28	-0.66**	-0.45	-0.21	0.73**	-0.39	-0.50	-0.42	-0.37	-0.46
EC	---	0.99***	0.46	0.03	0.00	-0.08	-0.13	-0.20	-0.36	-0.56*	-0.38	0.26	0.38	0.84***	0.10	0.84**
Cl		---	0.41	0.04	-0.02	-0.07	-0.12	-0.18	-0.33	-0.53*	-0.40	0.28	0.42	0.85***	0.13	0.86***
pH			---	0.00	0.34	-0.17	-0.43	-0.48	-0.65**	-0.74**	-0.32	-0.35	-0.30	0.24	-0.54*	0.22
Alk.				---	-0.06	0.05	-0.02	0.33	0.23	0.12	-0.48	0.01	0.15	0.13	-0.07	0.23
Oxygen properties																
DO					---	-0.20	-0.24	-0.69**	-0.55*	-0.37	0.39	-0.51	-0.60*	-0.32	-0.60*	-0.38
COD						---	0.72**	0.54*	0.37	0.35	-0.10	0.50	0.31	0.21	0.48	0.16
BOD							---	0.63*	0.63*	0.63*	0.08	0.75***	0.50	0.23	0.80***	0.16
Dissolved salts																
PO_4								---	0.88***	0.78***	-0.20	0.73**	0.72**	0.26	0.77***	0.23
NO_3									---	0.93***	-0.04	0.67**	0.71**	0.08	0.76***	0.06
NO_2										---	0.22	0.53*	0.51	-0.14	0.66**	-0.20
SiO_2											---	-0.08	-0.30	-0.41	0.00	-0.55*
Heavy metals																
Cu												---	0.86***	0.63*	0.95***	0.60*
Fe													---	0.71**	0.84***	0.68**
Cg														---	0.48	0.94***
Pb															---	0.44
Zn																---

2.7. SUMMARY

Water properties of Lake Burullus were evaluated based on one year monitoring at monthly intervals (January – December 2001) for 15 stations representing the eastern, middle and western sectors of the lake. The estimated variables were classified into 4 main groups: physical and aggregate properties (air temperature, water temperature, transparency, depth, salinity, chlorosity, acidity and alkalinity), oxygen properties (dissolved oxygen, chemical and biological oxygen demands), dissolved salts (phosphate, nitrate, nitrite and silicate) and heavy metals (cupper, iron, cadmium, lead and zinc). The PCA ordination of the 15 stations based on their water properties indicates a clear separation between the stations of the eastern, middle and western sectors.

The annual mean of air and water temperatures were 22.9 and 22.3 °C, with spatial ranges among stations of 21.3-24.2 and 21.8-23.3 °C, and monthly ranges of 16.7-28.8 and 16.0- 29.4 °C. The annual means of water transparency and water depth were 31.0 and 115.8 cm, with spatial ranges of 22.3-49.6 and 80.8-195.3 cm, and monthly ranges of 25.3-40.0 and 110-133.3 cm. The annual mean of water salinity was 5.4 mS cm^{-1}, with spatial range of 1.6-16.8 mS cm^{-1}, and monthly range of 3.9-6.7 mS cm^{-1}. Chlorosity had the same trend of salinity with an annual mean of 1.9 g l^{-1}, spatial range of 0.6-6.6 g l^{-1} and monthly range of 1.3-2.3 g l^{-1}. Water in Lake Burullus is alkaline throughout the year. The annual mean of pH was 8.6, with a spatial range of 8.4-8.9 and a monthly range 8.0-9.2. On the other hand, the annual mean of alkalinity was 257.8 mg l^{-1}, with a spatial range of 188.0-309.6 mg l^{-1} and monthly range of 213.7-279.6 mg l^{-1}.

The annual mean of dissolved oxygen (DO), chemical (COD) and biological (BOD) oxygen demands were 8.6, 4.6 and 3.6 mg l^{-1}, respectively. The spatial ranges were 6.6-10.4, 3.6-5.4 and 2.7-4.6 mg l^{-1} ; and the monthly ranges of 7.5-10.2, 2.4-6.4 and 1.7-5.4 mg $l^{-1.}$ The concentrations of dissolved had the following sequence: SiO_2 > NO_3 > PO_4 > NO_2, with annual means of 41.7, 2.8, 1.2 and 1.1 µg-at. l^{-1}. The spatial ranges were 29.8-51.9, 0.8-6.5, 0.6-2.7 and 0.3-2.0 µg-at. l^{-1}; and the monthly ranges were 19.5-81.9, 1.6-4.7, 0.6-1.8 and 0.7-1.4 µg-at. l^{-1}, respectively.

The concentrations of heavy metals had the following sequence: Zn > Fe > Cu > Cd > Pb, with annual means of 8.5, 6.2, 5.9, 3.8 and 3.6 µg-at. l^{-1}. Generally, most of the estimated heavy metals of the water near to the southern shore were higher than those near the northern shore. In addition, the trend of variation along east-west axis was as follows: eastern sector > western sector > middle sector for all metals except Zn (east > middle > west). The spatial ranges in µg-at. l^{-1} were 3.5-17.2 (Zn), 1.9-13.7 (Fe), 2.6-8.8 (Cu), 1.6-8.4 (Cd) and 1.1-6.3 (Pb). On the other hand, the period extended from February to May had the peak of heavy metals increase, while the period from June to September had the reverse. The monthly ranges in µg-at. l^{-1} were 4.3-12.7 (Zn), 0.7-13.2 (Fe), 3.6-11.5 (Cu), 1.7-6.6 (Cd) and 1.2-6.2 (Pb).

The comparison of the dissolved salts in the water of Lake Burullus in 2001, with those of 1987 and 1997 indicated an increase of nitrate, nitrite and phosphate from 1987 to 1997, but a decrease in 2001. On the other hand, silicate had a decreasing pattern from 66.8 µg-at. l^{-1} in 1987 to 47.3 µg-at. l^{-1} in 1997 and 41.7 µg-at. l^{-1} in 2001. Regarding the heavy metals, there was a continuous increase in Cu, Zn, Pb and Cd contents from 1987 to 1997 and then to 2001. The correlation between salinity and chlorosity was significant positive. In addition, Cd and Zn had significant positive correlation with each other, on one hand, and with the salinity and chlorosity, on the other hand. This trend indicates that a considerable portion of the Cd and Zn in the water of Lake Burullus is due to the sea water (the main source for increasing water salinity in this lake). Phosphate, nitrate and nitrite, that used as fertilizers for the agricultural land in the catchment area of Lake Burullus, were positively correlated with each other (they are washed with the agricultural drainage into the lake). In addition Cu, Fe and Pb had significant positive correlations with each other on one hand, and with the previously mentioned dissolved salts on the other hand. This may indicate that the main source for pollution with these heavy metals are the agricultural drainage.

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