Chapter 1
General Characteristics

1.1. LOCATION

Burullus Wetland is located along the Mediterranean coast in the north part of Nile Delta. It is bordered from the north by Mediterranean Sea and from south by the agricultural lands of north Nile Delta. Burullus Wetland belongs administratively to Kafr El-Sheikh Governorate. It lies in a central position between the two branches of Nile: Damietta to the east and Rosetta to the west. Its coordinates are 31° 36' N and 30° 33' E in north - west, 31° 36' N and 31° 07' E in the north – east, 31° 22' N and 30° 33' E in the south – east, 31° 22' N and 31° 07' E in the south – east. It has a total area of 460 km^2, which includes the entire area of Lake Burullus with numerous islets insides it, as well as the sand bar separating the lake from the Mediterranean Sea, with a shoreline of about 65 km. (Fig. 1.1).

1.2. GEOLOGY

1.2.1. Formation of Nile Delta

Unlike other major deltas of the world (e. g. Mississippi and Niger), the delta built by River Nile is of relatively recent geological age. A paleo-Nile started to advance across a marine embayment in the Late Pliocene, and developed especially in the Pleistocene through major sea-level changes associated with glacial periods. During low sea-level stands, large quantities of sand and mud were transported and dispersed far into the eastern Mediterranean, forming a large submarine fan (Sestini 1991).

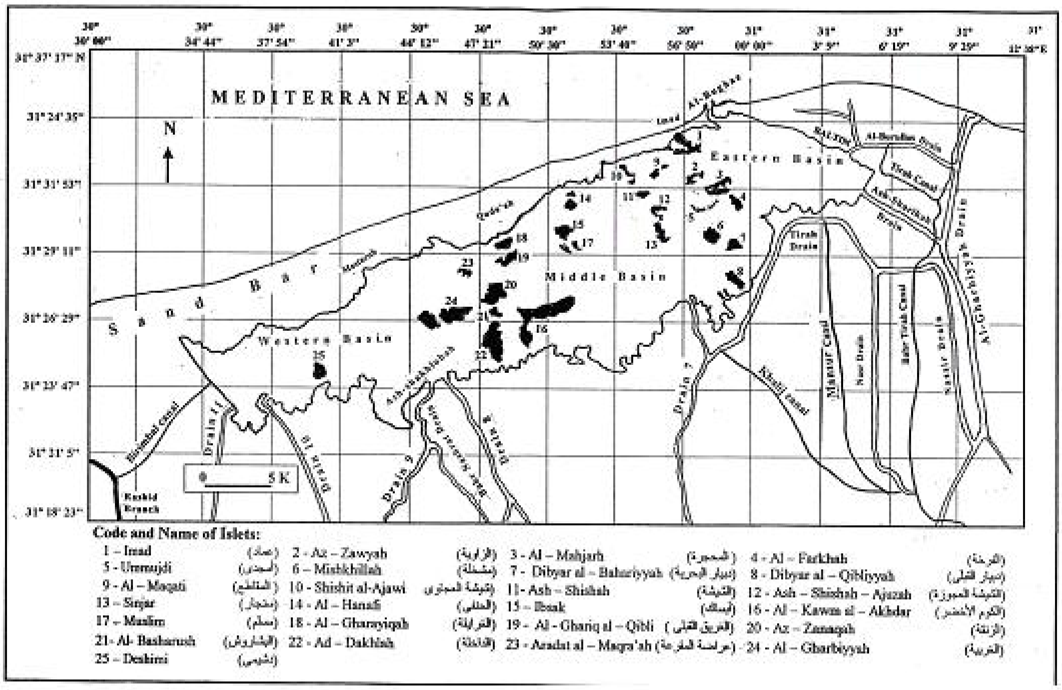

Fig. 1.1. **Sketch map of Burullus Lagoon area (prepared after the Egyptian General Survey Authority, 1992).**

In the period between 8000 to 5000 BP, when sea level began to approach its present situation, the marine transgression had reached its maximum landward extent, as far as 10-20 km inland of the present lagoons. The modern progradation started with the development of small delta lobes (Courtlier & Stanley 1987, Sestini 1989) related to several River Nile distributaries (Fig. 1.2). In the east, the lobes built by the Tanitic, Mendesian and Pelusiac and later the Damietta branches overlapped one another as they evolved. The lobes typically deflected eastward, were probably cuspate subdeltas with a notable asymmetric growth of beach ridges.

Two thousand years ago the main flow was through the western (Canopic) and the central (Sebennytic) Nile branches. The Rosetta and Damietta branches were then no more than canals. The disappearance of the older distributaries occurred mainly in the 2nd –5th centuries AD, the eastern branches (Tanitic, Pelusiac), and perhaps the Sebennytic branch, persisting until the 9th century (Tousson 1934).

Although in late Denastic – Ptloematic times much of the northern Delta was lakes and swamps (as suggested by archeological records), the Burullus and Manzala lagoons were not as extensive as today (Butzer 1976). Smaller lagoons or lakes, possibly represented as interdistributary bays, were closed-in by the longshore growth of spits from the various cuspate subdeltas. They also may have developed out of flood basins, especially during stages of large Nile floods. The lagoon expansion during the last 2000 years has been irregular, mainly due to subsidence behind a stable beach barrier. There is a record of rapid spread of swamp and lagoons since the 5-10th centuries, in coincidence with major earthquakes (Tousson 1934, Ben Menachem 1979).

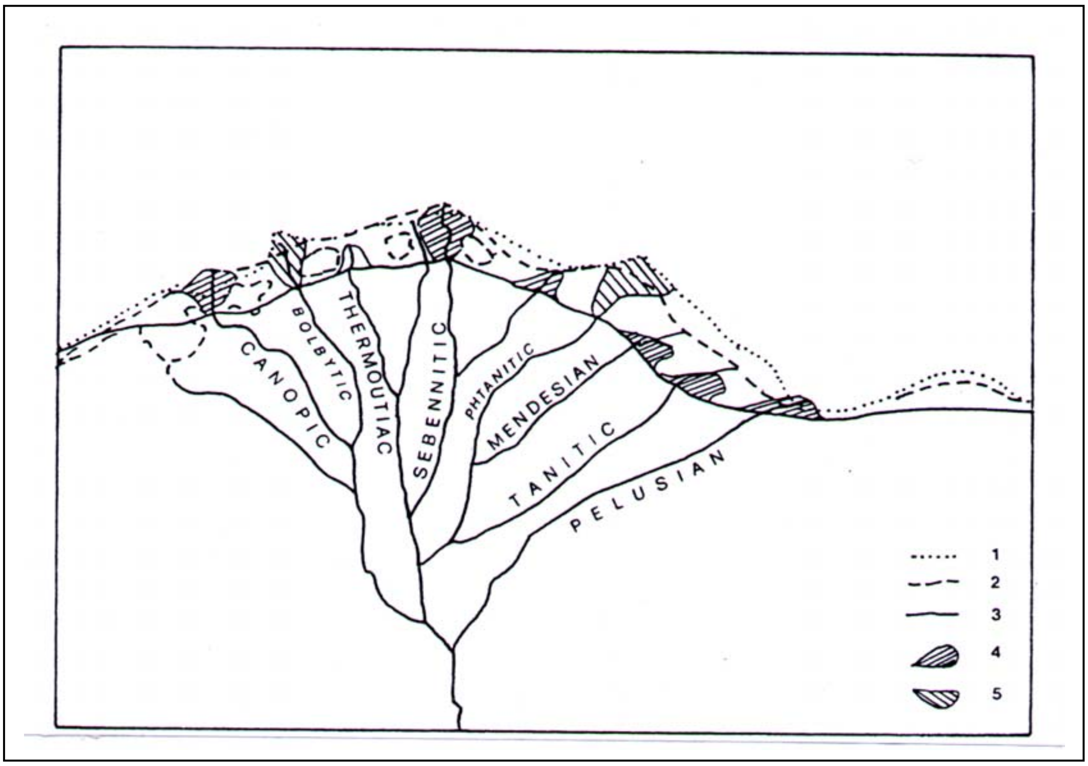

Fig. 1.2. **Nile Delta distributaries and subdeltas in pre-historic times to about 2000 BP. 1: Present coastlines, 2: Coastline 2000 BP, 3: Coastline about 7 – 8000 BP, 4: Ancient subdeltas and 5: Younger delta lobes.**

Coastal changes can be followed from maps since the early 18th century, and with more precision from topographic surveys since early 1800 (UNDP/ UNESCO 1978). Throughout the last century there was a steady advance of the Rosseta and Damietta promontories (Fig. 1.3) respectively, averaging 30 and 10 m/yr, and accretion in all the embayments towards the east. The shores east of Baltim Beach Resort as far as Gamasa, and east of the Port Said protrusion were advancing. The only exception was a slow retreat of the Burullus promontory, from west of El Burg to Baltim Beach (800 m in 100 years), a tendency probably dating back to the disappearance of the Sebennytic mouth, which was located farther north. Stretches of the Manzala barrier were also retreating.

In about 1910, an overall 25% decrease of Nile discharges, due to monsoonal reduced rainfall over eastern Africa, started the present coastal instability and headland recession. From 1910 to1965 the Rosetta promontory receded by 2.5 km (with the destruction of the first lighthouse); the Damietta promontory by about 2 km.

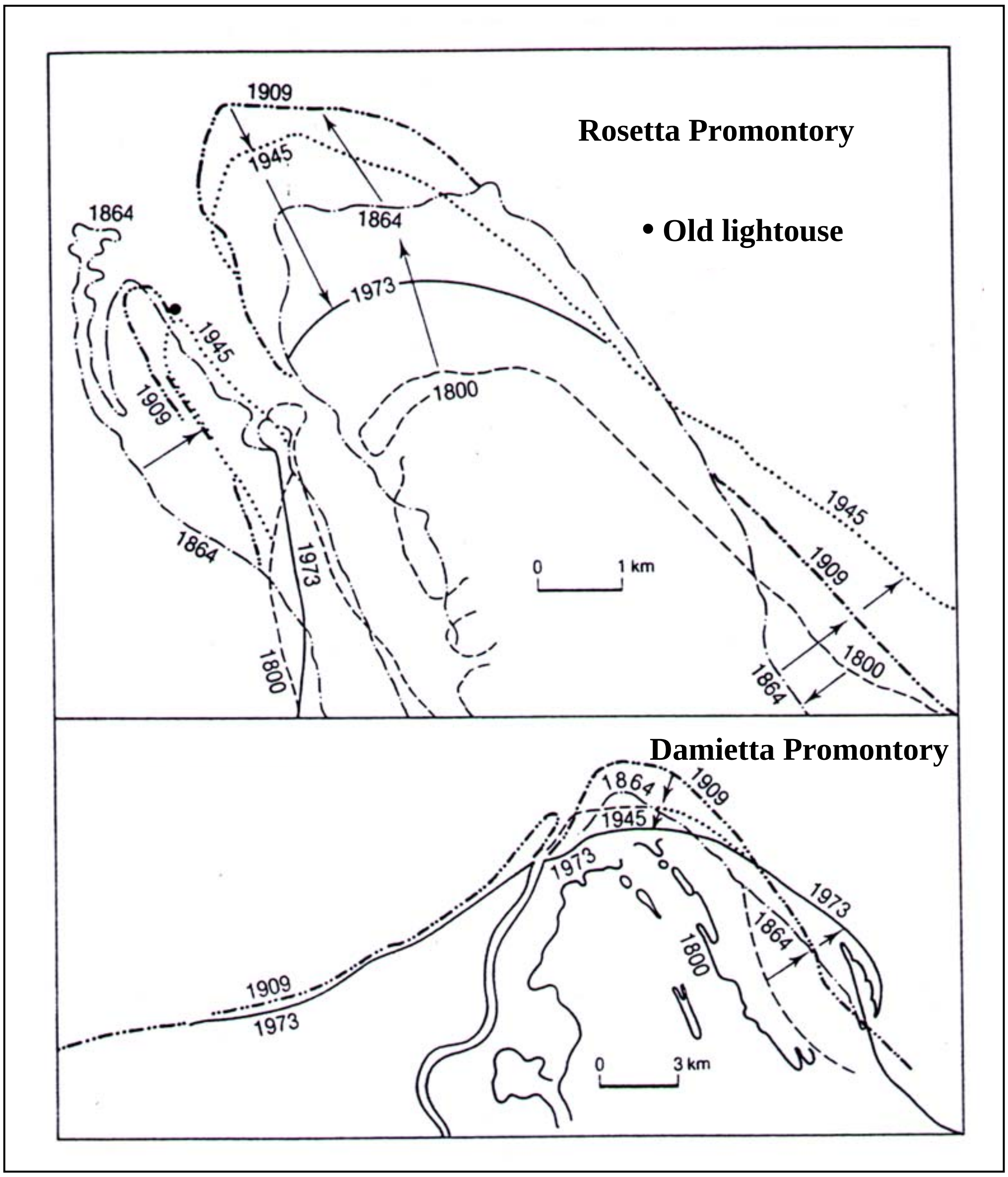

Fig. 1.3. **Coastal changes at the Rosetta and Damietta Nile mouths: 1800 – 1973 (UNDP / UNESCO 1978).**

1.2.2. Subsidence

Considerable long term subsidence of the coastal zone is indicated by the 10-80 m thick layer of post 8000 BP near shore marine, lagoonal and deltaic sediments (Fig. 1.4), with average rates of deposition as much as 5 mm yr^{-1} in the NE part of the Nile Delta, and 4 mm yr^{-1} in the central part (Coutellier & Stanley 1987). Subsidence appears to have been more intense in the lagoonal belt than near the present coast (UNDP/UNESCO 1978). Other evidence for the continued subsidence during the last 2000 years is the presence of many areas 1-3 m below sea level (Emery *et al.* 1988, Stanley 1988).

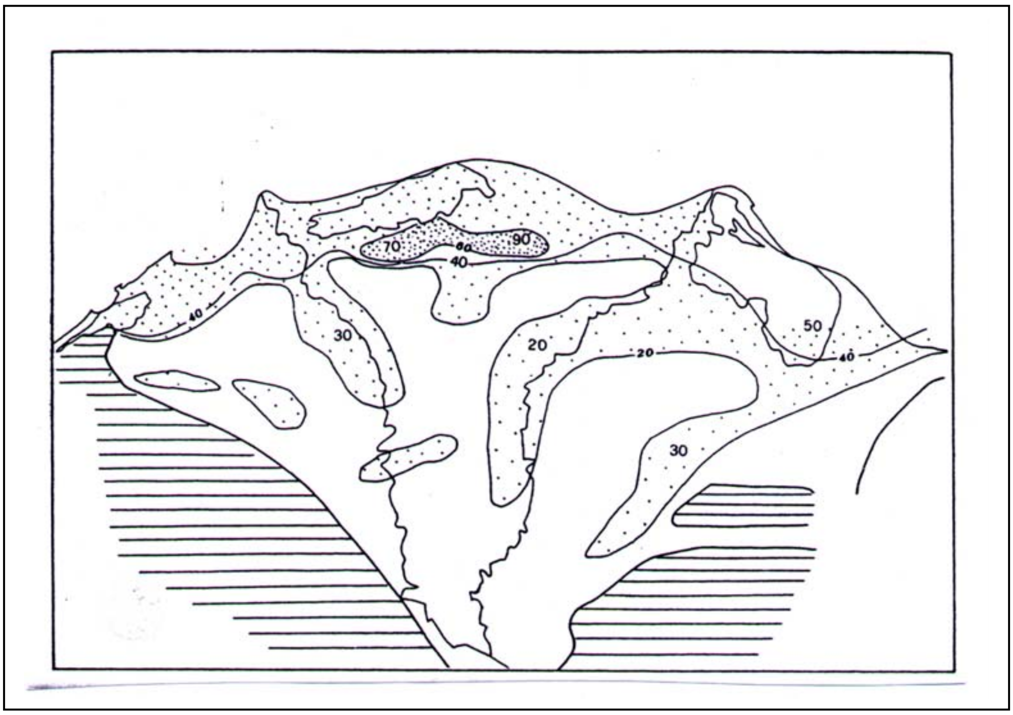

Fig. 1.4. **Thickness (in meters) of late Pleistocene-Holocene silts (post-8000 BP), as an indirect indication of geological subsidence. Horizontal ruling represents the raised Pleistocene deposits (Sestini 1989).**

According to Stanley (1988), mapping of the base of the Holocene deltaic facies, which dated at about 8000-6500 yrs BP, reveals that differential lowering of the northern delta plain is preferentially accentuated toward the northeast. The long-term subsidence rates at or near the coast, averaged for the mid.-to upper Holocene, range from about 0.1 to 0.25 cm yr^{-1} between Alexandria and the north-central delta margins. Rates increase markedly eastward to a maximum of about 0.5 cm yr^{-1} in the Port Said – Manzala lagoon region. This rapid lowering explains the presence of thick marine delta lobe sequences of Holocene age in cores in the northeastern delta (Hussain 1994).

1.2.3. Soils

The soils of Nile delta coastal belt are generally related to the major morphological units of alluvial plain deposition: sand dunes, coastal sand plains, Nile levees and channels (silt to fine sand), Nile flood basins composed of silt, and areas of marshes (Fig. 1.5). Modifications have been introduced by continued agricultural activity (Balba 1981).

The sandy soils of coastal littoral belt are rich in $CaCO_3$. The thickness of the "A" zone is generally 40 cm in the areas between the sand dunes. Deposited in the brackish water of lagoon- lakes and swamps, the clay soils of the fluvio-marine marshlands contain some lime but much salt and gypsum. The exchangeable Na and Mg are high, and the soils are therefore saline sodic. They are all heavy clays, but locally loam subsoils may provide better drainage. The clay soils of former swamps are rich in organic matter.

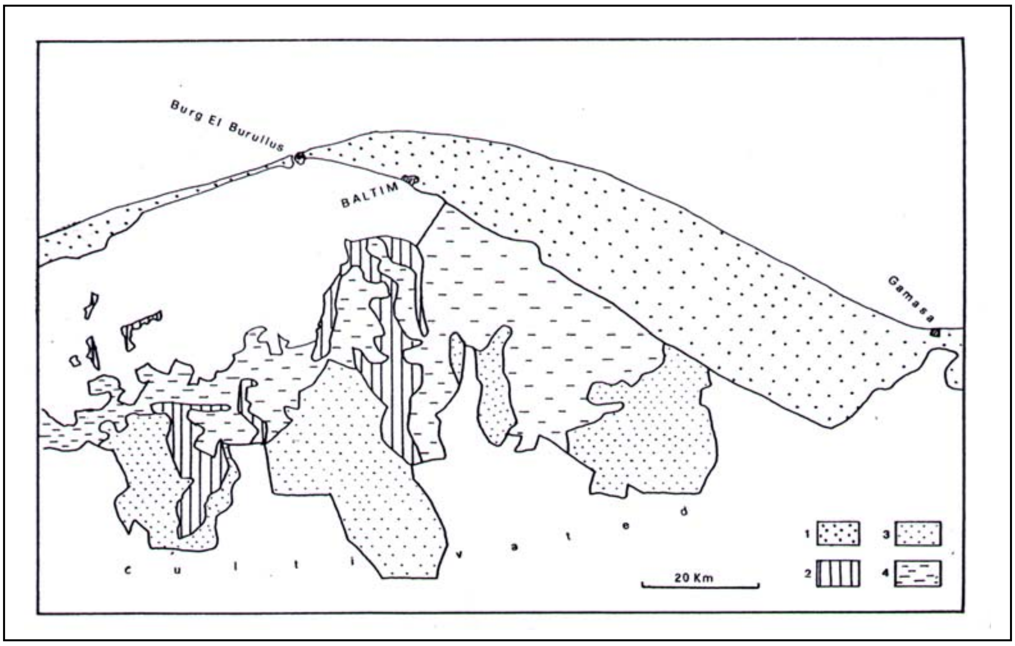

Fig. 1.5. **Principal soil types in the north-central Nile Delta. 1: Calcareous sands, 2: Silts-fine grained sands of fluvial channels, 3: Silts (floodbasins ± salty), 4: Acid soils of former marshes: clays, loams, peats, (Sestini 1989).**

South and between the lakes, recently reclaimed areas have soils generally made of fine-textured clay and silt, normally poorly drained unless mixed with shells. The water table is shallow, about 50-100 cm from the surface. The soils are saline sodic with a high concentration of salts on the surface before reclamation. Vast areas had to be drained and irrigated with Nile water, frequently applied to improve the physical properties of the impermeable clay soils and to decrease their exchangeable sodium content (Balba 1981).

1.2.4. Coastal Processes

In Nile Delta wave energy concentration is particularly high on all north-east trending coastal stretches and promontories (Manohar 1981, Inman & Jenkins 1984). The NE- oriented stretches are attacked more by NE and N waves as a consequence of refraction, than by less frequent NE and NNE waves (Fig. 1.6). The eastward littoral drift drives the beach and the near shore sands of Nile Delta to and beyond north Sinai. Conservative estimates are that one million m^3 sand move yearly by littoral currents, which are quite strong (Fig. 1.7). In addition, large amounts of sand have been and continue to be removed from the offshore winds. Estimates of sand losses are in the order of 200,000 $m^3\ yr^{-1}$ of the Rosseta mouth, and 400,000 $m^3\ yr^{-1}$ in the Burullus – Ras El Bar coast (Manohar 1981, Smith & Abd Elkader 1988).

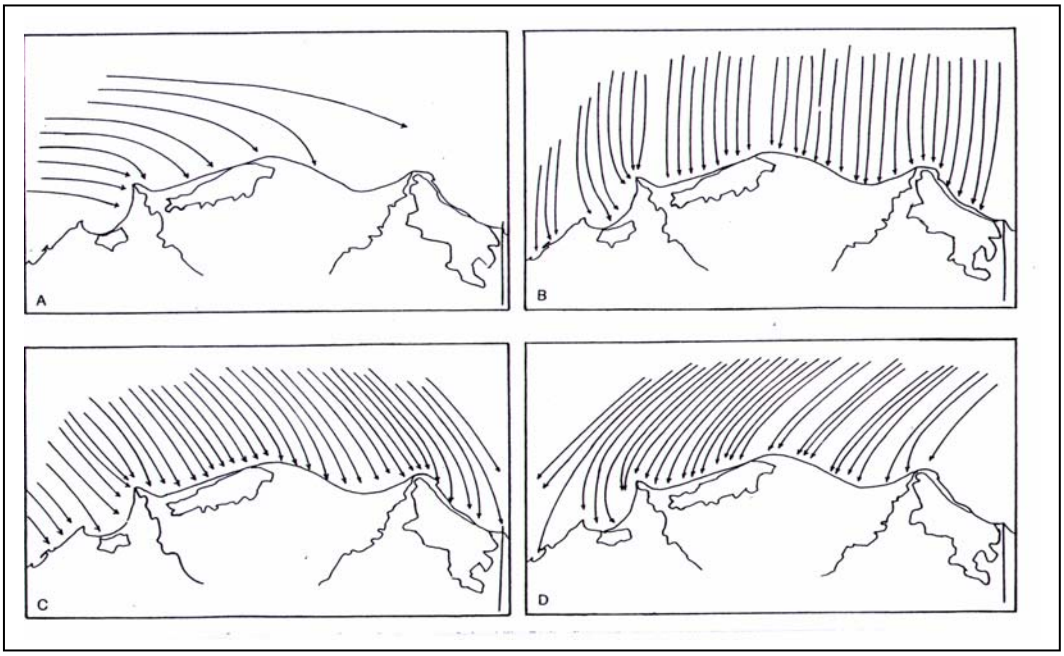

Fig. 1.6. **Main patterns of wave approach to the coast of the Nile Delta. A: Westerly waves, B: Northely waves, C: North-westerly waves, D: North – easterly waves (Tetratech 1986).**

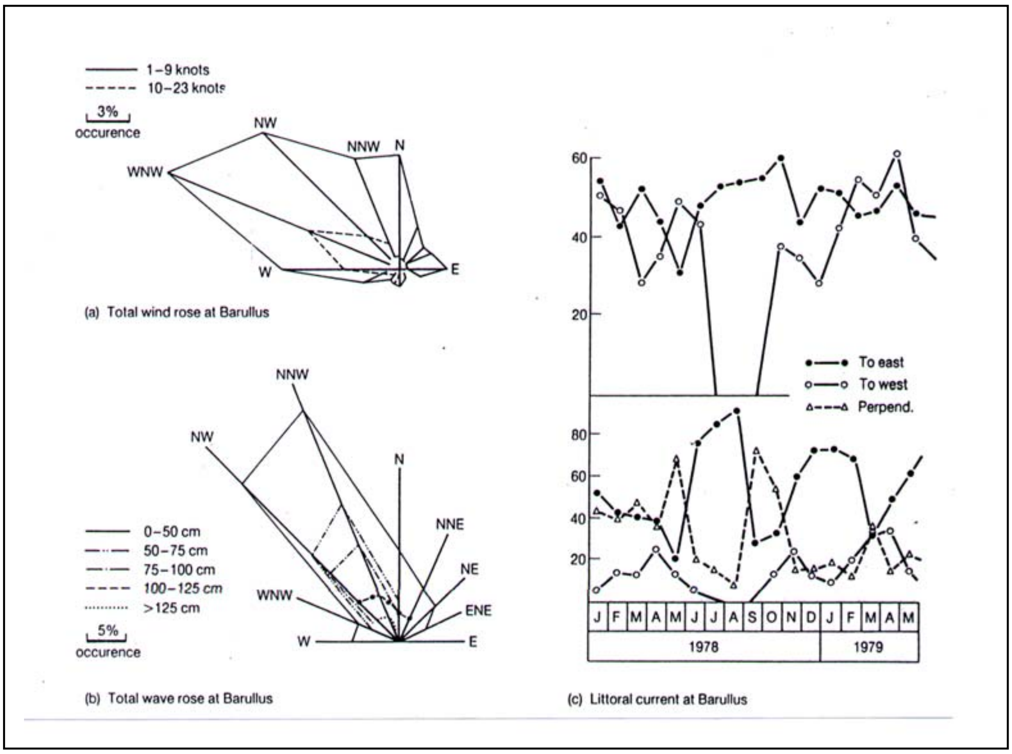

Fig. 1.7. **Waves direction and height, wind and littoral currents directions and speed at Burullus (Manohar 1981).**

Prior to the final 1964 closure of Aswan High Dam, the Nile discharged about 85-90 million tons of sediments into the sea in late summer (65% through the Rosetta, and 35% through the Damietta mouth). One- third was fine-grained sand (0.125- 0.065 mm), which was deposited in the immediate vicinity of the mouths. The other two- thirds of sediments were carried offshore and alongshore in suspension. Because of the pronounced density gradients and regional circulation, a surface plume of suspended clay and silt was carried eastward along the delta front. As shown by satellite images, such turbid plumes are still formed today, (UNDP/UNESCO 1978, Klemas & Abd Elkader 1982). At a few points on the coast (e.g., in the middle of Abu Qir Bay, between Rosetta and Burullus, east of Port Said) there may be sinks, with sands being moved off the coast to the continental shelf (Inman & Jenkins 1984).

During winter storms, the deeper fine–grained bottom sediments (silty and clay) of the Rosetta and Damietta is stirred into suspension and moved, seaward mainly to the east (Summerhayes *et al*. 1978, Frilly *et al*. 1990). The actual movement of these sands, however, is not known. Retreat is continuing on all the most exposed of the coast, and instability has been noted elsewhere (Fig. 1.8). There are a number of stretches where shoreline variability has created problems in relation to existing or planned land uses.

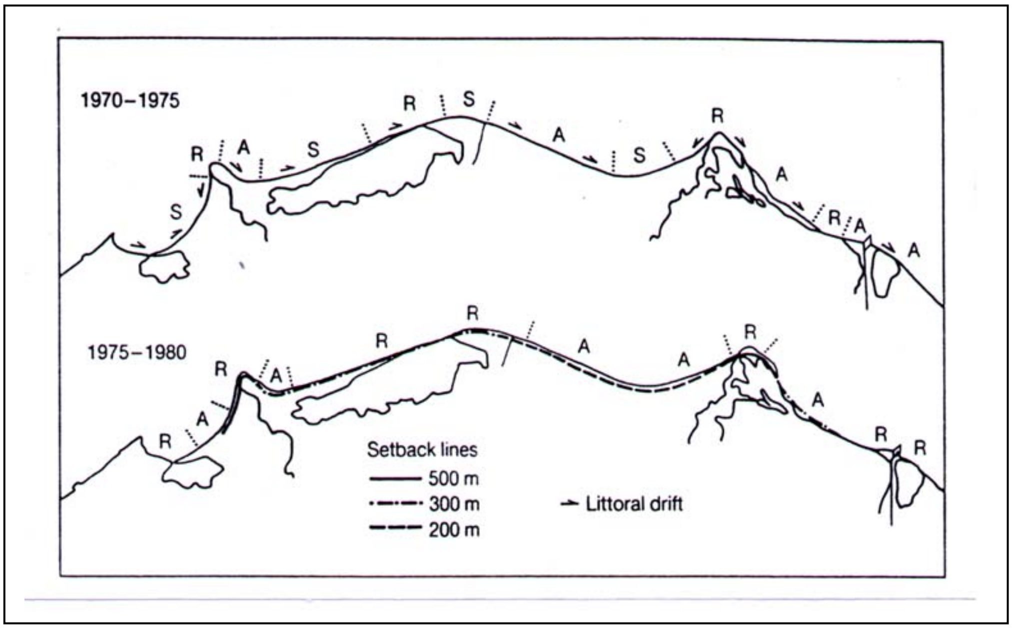

Fig. 1.8. **The state of erosion – accretion of the Nile Delta coastline: 1970 – 1980 (UNDP/UNESCO 1978 and Tetratech 1986).**

Twenty-five years after the cessation of Nile discharge, the following conditions had been noted along the shorefront (UNDP/UNESCO 1978, Tetratech 1986, as quoted by Sestini 1991):

1- At Alexandria as the coast is directly exposed to the north western and north waves, the eastern and western harbours outer sea walls are in constant need of attention due to frequent overtopping by waves. The small beaches of the city are retreating because there is no littoral drift supply of sand. Sediment movement is complicated by the rocky capes, islands and shallow submerged rocks.

2- In the west part of Abu Qir Bay, the Mohammed Ali sea wall may be undermined by scouring. The wall which is subjected to violent action by storm waves > 2 m in height, had to be renovated in 1981-1984 (Tetratech 1986). The Idku outlet has been stabilized by jetties but flooding is common in Maadia town; a tendency of erosion to the west may be increased by the new fishing harbour. The eastern Abu Qir Bay shore is maintained by the erosion of the Rosetta promontory, the seaward sediment transport about 18 km east of Idku outlet has resulted in increased beach steeping.

3- Retreat of the Rosetta headland between 1970-1987 increased to 80-120 m yr^{-1} (Frihy 1988). Erosion of the beach barrier sands has exposed the underlying finer-grained marine sediments to wave action; the submerged delta cone is thus being eroded to 25-30 m depth or more. Intense erosion occurs especially at the river mouth and is already weakening the sea wall. This structure will eventually function as a detached breakwater, following the gradual progress of erosion at its ends; thus, it should slow down the retreat of the promontory.

4- East of the Rosetta promontory, for 30 km shoreline tends to be stable and presumably will continue to be so for another two to three decades. East of Hanafi to 6 km west of the Burullus outlet, however, the shore is narrow and the swash zone has tended to steepen with some retreat, perhaps because of accretion at the outlet western jetty. Burg El Burullus is protected from erosion by a renovated sea wall, but at the east end of the latter, serious erosion of the sand dunes (6 m yr^{-1}) has occurred for the past 30 years. Land, however, has extended towards the lagoon, both east and west of the lake outlet (Fig. 1.9). Further east, the Burullus headland is retreating at an average of 10 m yr^{-1} with erosion of the dunes. At Baltim beach resort, where the shore had been fluctuating periodically, protection includes sand renourishment and offshore breakwaters. Active longshore and seaward sand transport prevails eastwards to Gamasa; the coast is generally stable or accreting.

5- The stretch from Gamasa drain to Ras El Bar is one of moderate longshore activity, but 7 km west of Ras El Bar retreat has occurred headland. The new Damietta harbour jetties have stimulated accretion on both sides, but have probably modified the local wave and current regimes, with silting of the access canal. Dredging is already necessary and artificial sediment by passing may be needed.

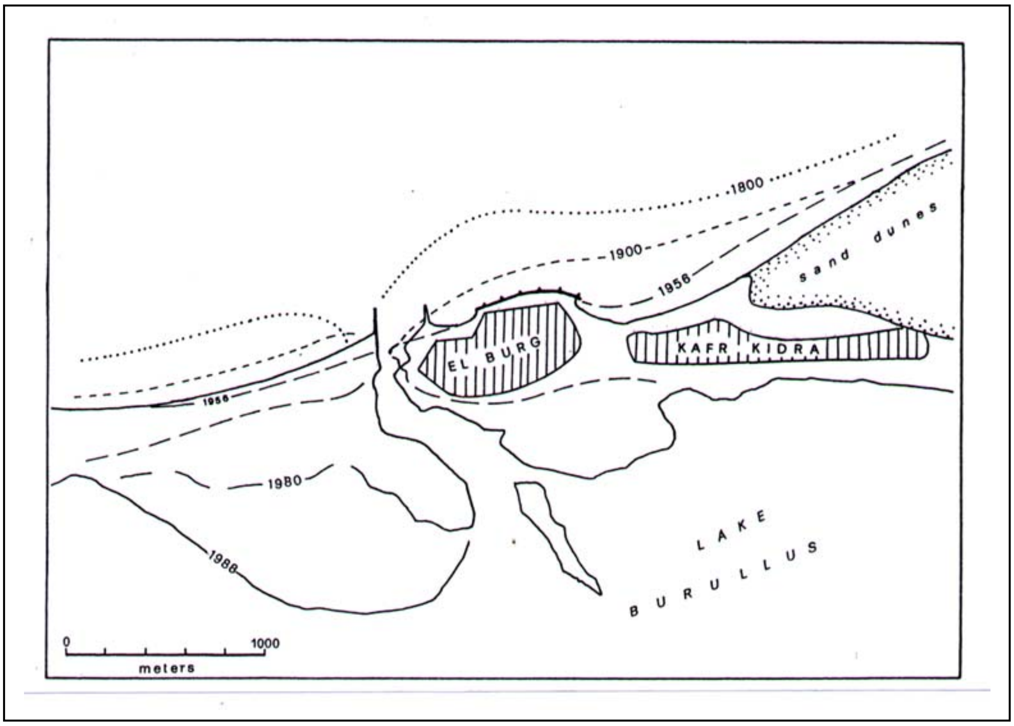

Fig. 1.9. **Topographic changes at Burullus Lake Outlet (UNDP/UNESCO 1978 and Tetratech 1986).**

6- Due to the predominant north-west wave approach, the entire Damietta promontory is under erosion and Ras El Bar protective structures have been only partially or temporarily effective. Circulation in the Nile estuary is presently entirely tidal (there's no river flow from the Farascur Dam) and dredging is required. East of Ras El Bar an earth dike extends as far as the spit (Tetratech 1986); its envisaged revetment into a stronger structure could eventually increase the erosional problems of the Nile mouth area and cause retreat at its eastern end.

7- The whole stretch from Damietta to Port Said is very unstable due to a very active longshore sand migration. The spit has been growing by 90-100 m yr^{-1} and the shoreline for 15 km eastwards is under its dynamic influence with a series of erosion-accretion patterns; the Diba embayment and hump are features that move as much as 100 m yr^{-1}; eventually they, and the spit, might encroach on the new Manzala lagoon outlet.

The section 19 km of Port Said is a unit in itself. It is a weak area except for the 4 km of Port Said western jetty, which has been accreting for over 100 years, though, at slower rate in the last decades. It is characterized by long term retreat, the barrier between the lake and sea was reduced from 1000 to 200 m width between 1810 and 1945, and some retreat has recurred since then (UNDP/UNESCO 1978) and by frequent flooding from the sea.

1.3. GEOMORPHOLOGY AND MORPHOMETRY

1.3.1. Shape and Dimensions

The shoreline of Lake Burullus takes several forms related basically to its formation, origin and evolution. It has an oblong shape extends for a distance of 47 km along NE-SW axis (Fig. 1.1). The width of the lake from north to south varies from site to the other. The western sector has the least width which does not exceed 5 km, then its increases in the middle sector to reach an average of 11 km. As the area of the lake changed with time, its dimensions changed also (Table 1). It is obvious that the lake size had decreased from 502.7 km2 in 1984 to 410 km2 in 1997 (i.e. 18.4% reduction), the maximum length from 56 to 47 km (16.1% reduction) and the maximum width from 15 to 14 km (6.7% reduction).

Table 1.1. **Morphometric dimensions of Lake Burullus in 1984 and 1997 (after El-Bayomi 1999).**

Character	1984	1996	Reduction (%)
Area (km^2)	502.7	410.0	18.4
Circumference (km)	160.0	143.0	10.6
Maximum length (km	56.0	47.0	16.1
Maximum width (km)	15.0	14.0	6.7
Length/width ratio	3.7	3.3	10.8

1.3.1.1. Lake size

It is clear that Lake Burullus had lost about 49% of its size along 112 years from 1801 (1092 km^2) to 1913 (556.5 km^2), and about 62.5% by 1997 (410 km^2) (Table 1.2 and Fig. 1.10).

Table 1.2. **Evolution of the size of Lake Burullus during the period from 1802 to 1997.**

Character	Year						
	1801	1913	1959	1962	1972	1984	1997
Area (km^2)	1092	556.5	546.3	592.9	502.7	440	410
Reduction (%)	-	49.0	50.0	45.7	54.0	59.7	62.5

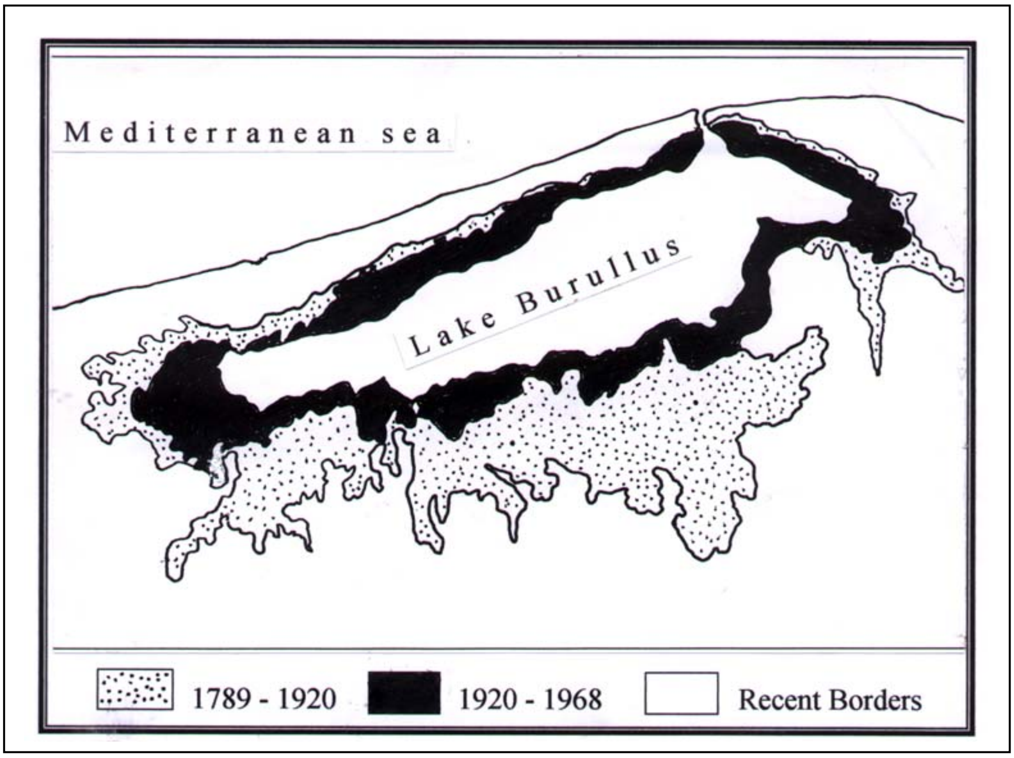

Fig. 1.10. **Size changes of Lake Burullus (1789 – 1997).**

The change in the size of the lake basin in associated with changes in the prevailing natural phenomena. The rate of these changes was assessed using the GIS and remote sensing techniques (Abdel-Rahman & Sadek 1995). As indicated in Fig. 1.11, the human impact was represented by removal of sand dunes in some parts of the marine bar between the Mediterranean sea and the lake, cultivation of some crops in the dried parts of the lake (e.g. grapes and watermelons), increase of the swamps and salt marshes particularly along the south-east and south-west parts and increase of the cultivated lands and human settlements (Table 1.3).

1.3.1.2. Lake depth

Lake Burullus is a shallow lake, its depth varies between 40 cm near the shores and 200 cm near the sea outlet (Boughaz El-Burullus). The remote sensing studies indicated that the deepest parts was in the middle sector of the lake where the depth reached 200 cm, and also the southern parts of the western sector (west of Doshimi islet). The eastern sector is the shallowest where the depth does not exceed 20 cm near the shore, but increases westwards until it reaches about 70 cm (Fig. 1.12).

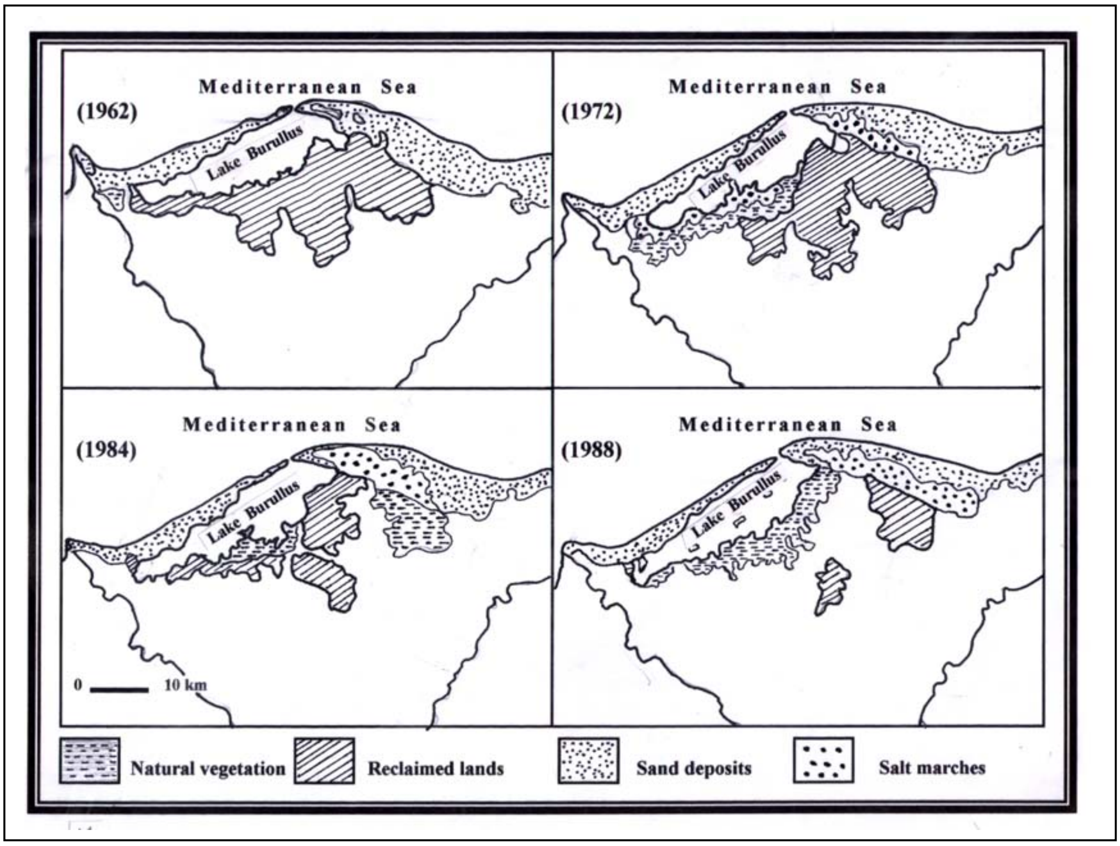

Fig. 1.11. **Morphological change in Lake Burullus (After Abdel Rahman & Sadek 1995).**

Table 1.3. **Changes in the water body, natural and anthropogenic phenomena in Burullus wetland (Abdel-Rahman & Sadek 1995, El-Bayomi 1999).**

Character (km^2)	**Year**			
	1962	**1972**	**1984**	**1997**
Water body	592.9	502.7	440	410
Swamps (under reclamation)	210.7	215.5	315.4	388.5
Sand deposits	866.5	660.8	569.7	266.9
Natural vegetation (under reclamation)	101.6	134.6	190.1	388.6
Reclaimed areas and settlements	-	-	448.1	623.8

Due to the continuous morphological and water budget changes, particularly after constructing many irrigation and drainage projects, and silting of Boughaz El-Burullus, the depth of the lake change from time to time. The changes that happened during the period from 1984 to 1997 was studied using GIS system. The hypsographic analysis (Table 1.4) indicated that the contour line zero (i.e. the shore line of the lake) is about 143.5 km. The area between the shore line and 75 cm depth approximates 58% of the total area of the lake (236.6 km^2 out of 410 km^2). Thus it seems that the lake lives its senility stage particularly with the continuation of drying and silting up processes which lead to the increase of shallow areas; the areas deeper than 130 cm have already decreased to about 20.6 km^2 (5% of the lake size).

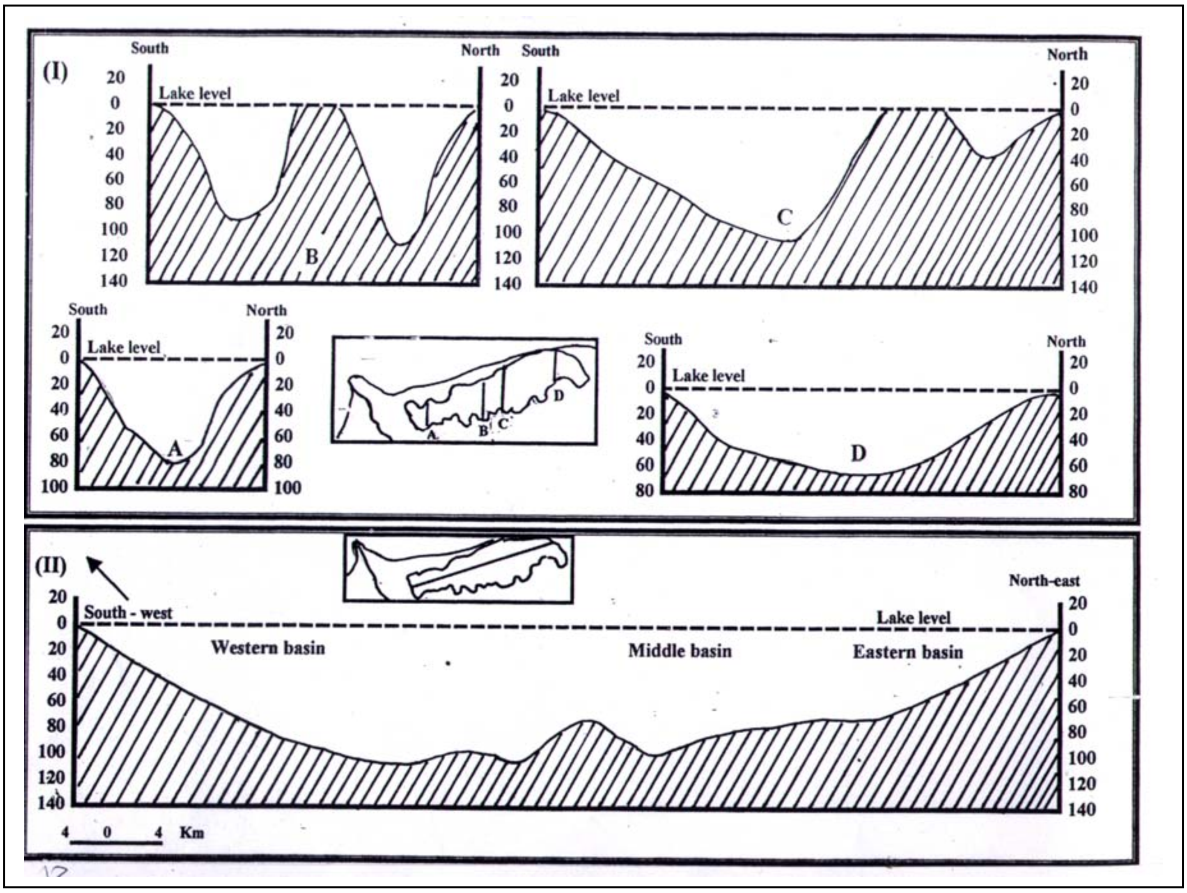

Fig. 1.12. **Transverse (I) and longitudinal sections (II) in the main basin of Lake Burullus indicate the variation in water depth (redrawn from El-Bayoumi 1999).**

Table 1.4. **Hypsographic analysis of Lake Burullus basin (after El-Bayomi 1999).**

Water depth (cm)	Contour line (km)	Size between two contour lines (km^2)	%
Zero	143.5	410.0	-
0 – 50	130.0	122.7	30
50 – 75	95.0	113.9	28
75 – 100	65.0	89.0	22
100 – 130	55.0	63.8	12
> 130	45.0	00.0	5

1.3.2. Morphometric Units Inside the Lake Basin

The main basin of Lake Burullus is classified into three sectors: eastern, middle and western, each one has some sort of homogeneity in the geomorphological, hydrological and biological characteristics. The islets scattered in the lake form physical isolations between these sectors (Fig. 1.11). The dimensions of these sectors and the distribution of islets inside them are presented in Table 1.5.

Table 1.5. **Dimensions of the three sectors of Lake Burullus and the distribution of islets inside them (after El-Bayomi 1999).**

Sector	Area		Islets		Density of islets
	km^2	%	No.	%	($islet/km^2$)
Eastern	117.6	28.7	11	36.7	0.09
Middle	189.0	46.1	15	50.0	0.08
Western	103.4	25.2	4	13.3	0.04
Total	**410.0**	**100**	**30**	**100**	**0.07**

1.3.2.1. The eastern sector

This sector lies at the eastern part of the lake and separated from the middle one by the islets of Mesallam, Absak, Kom Absak, and from the south by Dinar Al-Baharyya, Singar and Baker islets. The sea outlet (i.e. Boughaz El-Burullus) lies at a midway north of this sector. The area of the eastern sector is about 117.6 km2 (28.7% of the total area of the main basin of the lake). Its maximum width is about 14 km and comprises 11 islets (36.7% of the total islets). It is the shallowest sector with depths that vary between 40 and 75 cm, but the area near the sea outlet is among the deepest areas in the lake (it approximates 200 cm). The water in this sector has special characteristics due to the saline water that flows from the sea, and the blowing of the north-western winds.

1.3.2.2. The middle sector

It lies between the eastern and western sectors with an area of 189 km^2 (46.1% of the main basin). It comprises 15 islets (half of the total islets in the main basin). Some of these islets are the biggest in the lake: e.g. Al-Kawm Al-Akhdar (2.8 km2) and El-Dakhala (1.0 km2). The depth of the areas near its northern shore does not exceed 40 cm, but increases towards the center until reach 130 cm, and decreases again towards the southern shore due to high sedimentation rates from the drains that pour in this region (Fig. 1.12). The water in this sector has a medium salinity in relation to the eastern (relatively high salinity) and western (relatively low salinity) sectors.

1.3.2.3. The western sector

Its area approximately 103.4 km^2 (25.2% of the area of the main basin). It has the shortest width (about 4 km) and the lowest number of islets (4 = 13.3 % of the total number of islets). It is separated from the middle sector by the islets of Al-Fakaa, Doshimi, Abu-Amer and bab Al-Askala.. The depth of this sector increases westwards, then decreases gradually towards the western shore of the lake.

1.3.3. Geomorphological Features of the Marine Bar

The marine bar (i.e. sand bar) of Lake Burullus is the zone that separates the Mediterranean coast in the north from the lake shore in the south. It extends between latitudes 31° 23` 26`` to 31° 34` 48`` N and longitudes 31° 2` 48`` to 31° 7` 30`` E and covers an area of about 165 km2 (Fig. 1.1). Although the surface of this bar is relatively flat, but it has different geomorphological features that had been formed upon it as a result of the evolution and development of the geomorphological processes. Some of these features were related to the sedimentation process such as sand flats, sand dunes and sand hillocks; and some others were due to change of sea level like salt marshes and tidal flats.

1.3.3.1. Sand flats

The surface of the marine bar is covered by sand flats particularly along the north western margins of the lake. These flats have a few undulation and sometimes form what is called "sand ripples". The winds are the main effective factor in the formation and direction of the sand ripples, their axes extend from north-east to south-west (i.e. direction of the prevailing winds in this region). The main types and characteristics of sand ripples are (after El-Bayomi 1999):

1- Regular sand ripples. Relatively straight with small slip faces, strongly sloped and perpendicular with the wind direction.
2- Irregular sand ripples. Their irregularity is due to changes in the direction and velocity of wind. They predominate in the relatively elevated and arid area far from the shoreline.

1.3.3.2. Sand dunes

Sand dunes in the marine bar of Lake Burullus represent the principal geomorphological feature affected by the sedimentation processes. Natural factors helped in presence of this geomorphological feature where a closed relation was found between the locations of the sand dunes and the ancient Nile Deltiac branches (Fig. 1.13). The coastal sand dune formations are desertic sands: from the western desert where the predominant western winds helped in their formation after mixing with the Nile deposits of the ancient Nile Deltiac branches and the marine deposits carried by the marine currents, particularly in the north eastern part of the marine bar. In general, the sand dunes along this bar could be classified into:

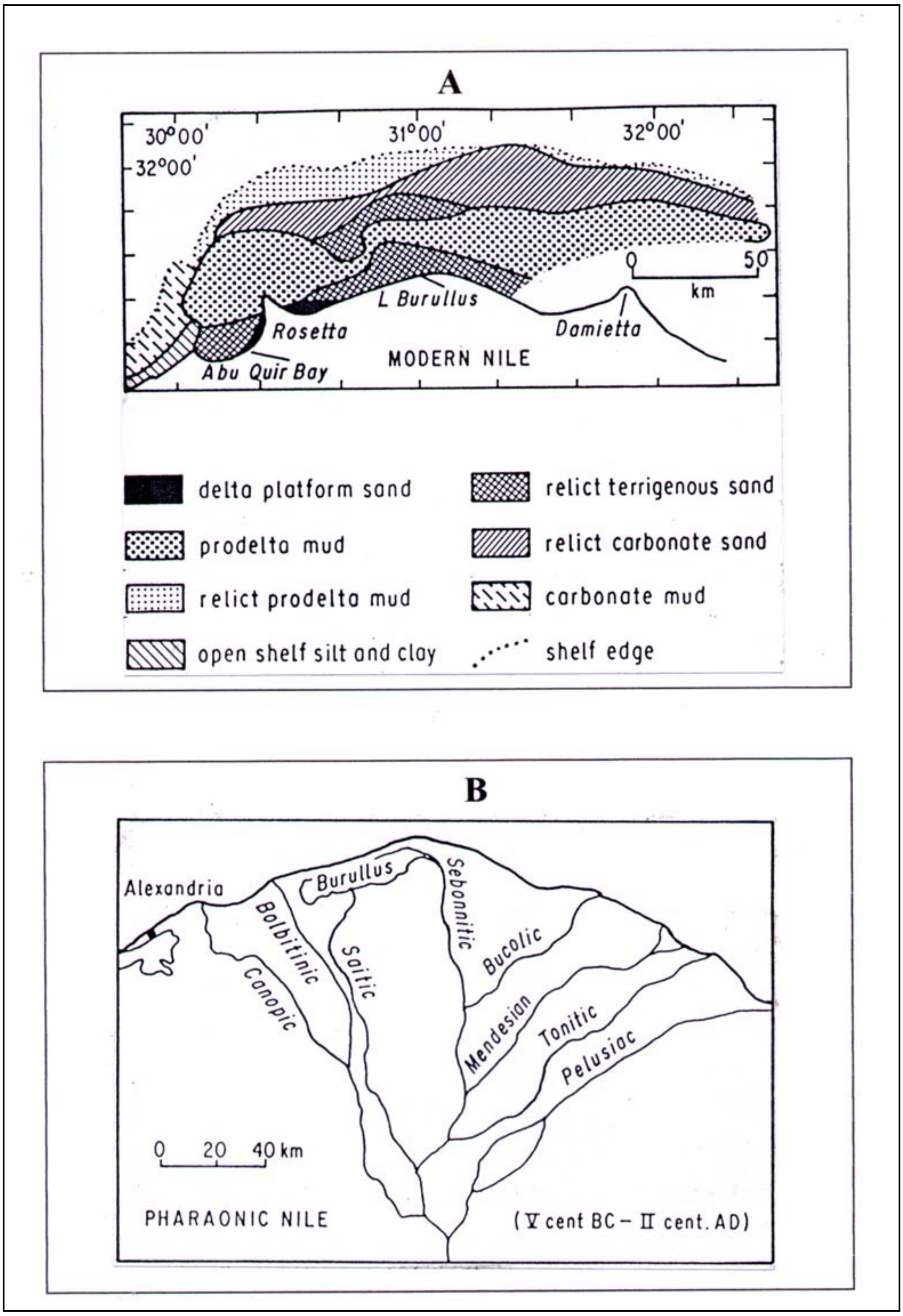

Fig. 1.13. **Maps showing the continental shelf of the Nile Delta (modified from Summerhayes *et al*. 1978). A: simplified faces distribution on the Nile Delta shelf, B: ancient Nile River distribution.**

1- Barchan embryonic sand dunes. They represent the first stage of dune formation, and usually take the crescent shape with heights that do not exceed 3 meters. They predominate in area between Burg El-Burullus and Baltim.
2- Longitudinal sand dunes. They were formed as a result of helicoidal air currents and strong winds that blow frequently in one direction whereof lead to change the crescent shapes of the dunes into longitudinal ones. Their heights approach 4 to 5 m with mean length of 500 m, and mean width of 50 m. This type of dunes is common in the eastern parts of the marine bar. Their axes are parallel to the direction of the prevailing winds in this region.
3- Complex dunes: This type is dominant in Baltim, Sheikh Mubarak and some other zones in the marine bar. They have several apices ad seem to be broad and irregular. Their height approach 13 m above sea level and their axes deviate from the north apparently related to the direction of the prevailing winds.

1.3.3.3. Sand hillocks

Sand hillocks are embryonic dunes with heights that range between a few centimeters and a few meters. They have domal or longitudinal shapes. Their windward sides are covered by some herbs and shrubs (e.g. *Tamarix nilotica*) that help in the fixation of these hillocks. The factors that lead to the formation of these hillocks are the friable sands of different sizes, sparsity of vegetation, relative flatness of the soil surface, absence of the physiographic barriers and the blowing of winds with different velocities and directions. El-Bayomi (1999) has carried out some morphometric measurements on some hillocks distributed in the area between Burg El-Burullus and Baltim in the eastern part of the marine bar, and Arab El-Hefny and Kom Meshal in its western part. It is shown in Table 1.6 that the hillocks length range between 1.5 and 2.9 m, the width between 0.5 and 1.8 and the height between 0.5 and 0.9 m.

Table 1.6. **Morphometric measurements of the dimensions of some hillocks in the marine bar of Lake Burullus.**

Dimension		Range	Mean ± SD
Length	m	1.5 - 2.9	2.6 ± 0.45
Width	m	0.5 - 1.8	1.3 ± 0.46
Height	m	0.5 - 0.9	0.6 ± 0.16
Windward slope degree	o	1.5 - 5.0	2.8 ± 1.03
Leeward slope degree	o	1.6 – 7.0	4.3 ± 1.85

It is well known that the plant species play an important role in determining the size and consistency of the hillocks (i.e. phytogenetic hillocks) to the extent of establishment of a close positive relationship between the height of hillocks and the height of the plants that cover them. *Zygophyllim album*, *Arthrocenmum strobilaceum* and *Tamarix nilotica* are among the species of close association with the hillock formation in this region (i.e. sand binding plants). When the hillocks approach each other, they merge together and form large dunes covered by dense vegetation.

1.3.3.4. Salt marshes

Coastal salt marshes are lowlands near the coasts, covered with water during the tide, have increasing salinity particularly with the increase of evaporation rate, and covered with salt tolerant plants of high capacities for trapping and fixing soil deposits. They extend along the marine bar of Lake Burullus with an area that approximates 40% of the total area of the bar (6% only found in the eastern part, and 34% in the western part due to the relative low level of its surface). Their clay deposits vary between 60 and 80%, which may indicate that the origin of these marshes were associated with the primary stages of the initiation of the whole area. With the flowing of the ancient Nile Deltiac branches, and with the help of wind and marine currents, the sand deposits spread over the area.

Tidal action is considered among the principal factors responsible for the formation and development of salt marshes along the marine bar of Lake Burullus. With the extension of water during tide and retreating during ebb-tide, and with the gentle sloping of the shore, tidal waters extend to cover vast areas that increase with the happening of storm waves. Natural vegetation plays an important role in the development and evolution of salt marshes as it leads to increase evaporation rate and salinity. Moreover, the heavy growth of salt tolerant plants trap the deposits and help in leveling up the beds of the marshes.

1.3.3.5. Tidal flats

These flats extend along the shore between Burg El-Burullus and Baltim in the eastern part of the bar. They are usually submerged by sea water during the tide, while the water retreats during the ebb-tide. The surface of these flats consists of materials with homogeneous sizes and seems to be devoid of plants. With movement of waves over these flats, current wave ripple marks appear, their axes extend parallel to the shore with depths that vary between 4 and 6 cm, and widths between 15 and 20 cm. This phenomenon is a temporary one. The sources of tidal flats are the friable sands transported by the north-western winds, the deposits produced as a result of shore erosion by the effect of waves, and the deposits transported by the tidal and coastal currents.

1.3.3.6. Sea outlet

The outlet that connects the Mediterranean sea with Lake Burullus is called Boughaz El-Burullus. From the original viewpoint, it is a natural water course. Its length approximates 250 m, the width at the narrowest point is about 50 m, and the water depth varies between 50 cm and more than 200 cm. This outlet crosses the marine bar at the narrowest point where the soil surface is flat and devoid from sand dunes. The main factors that affect its morphology are:

1- The shape of the outlet as a protrusion inside the sea where the attack of waves become more strong than the other parts of the bar. This often leads to deepen the area around the outlet.
2- The movement of water into and from the lake during the tides leads to widen the outlet (Table 1.7).

Table 1.7. **Amount of the water exchanged between Lake Burullus and Mediterranean Sea. Coastal Protection Agency 1996 (as quoted by El-Bayomi 1999). Maximum current velocity is 54 m/sec., while mean current velocity is 26 m/sec.**

Character	**m^3 sec^{-1}**	**10^6 m^3 day^{-1}**
Maximum discharge into Sea	98	8.47
Maximum flow from Sea	95	8.21
Mean discharge into Sea	45	3.89
Mean flow from Sea	40	3.46

3- The shore currents that move from the sea into the lake. With the weakness of these currents, displacement or pushing effects of the waves that come towards the lake decrease which leads to silting up and closing of the outlet.
4- The waves that approach parallel to the shoreline move sediments from the sea bottom.
5- Human activities are among the main factors that affect the morphology of the outlet. Man changes the shape and dimension of Boughaz El-Burullus by constructing sand and wave barriers, artificial digging and deepening.

1.3.4. Morphology of the Lake Islets

Many islets with different sizes are distributed in Lake Burullus (Fig. 1.1). Due to the continuing of the effects of the geomorphological processes (e.g. sedimentation, erosion and water flooding), the number, size, dimensions and locations of these islets change from time to time. They move from their locations or merge together when become close to each other.

The number of islets in Lake Burullus has changed along the years. This was associated with differences in the physical factors that affected the whole region such as: 1- change of the lake size, 2-change in hydraulic conditions of the water courses that pour their loads into the lake, 3- full controlling of the irrigation and drainage system, after the building of High Dam, and 4- merging of some islets with the lake shores, particularly in the southern part, due to the drying of some parts of the lake for the agricultural purposes (Table 1.8).

Table 1.8. **Change in the number of islets in Lake Burullus during the period from 1789 to 1997 (after El-Bayomi 1999).**

Sector	**1789**	**1920**	**1952**	**1972**	**1984**	**1997**
Eastern	52	38	34	14	15	1
Middle	81	22	20	17	17	15
Western	25	20	18	17	13	4
Total	**158**	**80**	**72**	**48**	**45**	**30**

The size of islets, as their numbers, has changed with time. The size of some islets has increased due to merging with the nearby islets as a result of increasing rates of sedimentation (Table 1.9). The heavy growth of reed and sedge plants (e.g. *Phragmites ausralis* and *Typha domingensis*) facilitates the merging of these nearby islets. Due to continuing of geomorphological processes and photometric changes, the number and size of Lake Burullus islets will be changed. A new islet appeared in the north of the eastern sector near the sea outlet. Doshimi islet in the western sector approaches to merge with the southern shore, while Shishit Al-Aggari and Makatee Al-Aggari islets in the eastern sector will merge together in the near future.

Table 1.9. **Change in size of islets in Lake Burullus during the period from 1789 to 1997. E, M and W are the eastern, middle and western sectors of the lake, T: total.**

Size	**< 0.5 km^2**				**0.5 – 1.0 km^2**				**> 1 km^2**				**Total**
Sector / Year	**E**	**M**	**W**	**T**	**E**	**M**	**W**	**T**	**E**	**M**	**W**	**T**	
1789	42	66	15	123	5	8	10	23	5	7	-	12	158
1920	26	11	8	46	7	6	12	25	5	5	-	10	80
1925	23	9	9	41	6	5	8	19	5	6	1	12	72
1972	3	7	14	24	6	5	2	13	5	5	1	11	48
1984	4	5	9	18	5	4	2	11	6	8	2	16	45
1997	2	2	1	5	3	2	2	7	6	11	1	18	30

Islets of Lake Burullus could be classified according to their shapes into different groups : longitudinal (e.g. Dibar), circular or oval (e.g. El-Zanka), triangular (e.g. Doshimi), arc (e.g. Shishet Al-Agoza), curved (e.g. El-Zoaya) and irregular (El-Maghara and Absak). Many islets have obvious longitudinal extensions parallel with the directions of the prevailing western winds, their axes usually extend from north to south, and occasionally from north to east. Their surface levels approach 3 meters above water level of the lake, thus they are called hills or piles, where some remains of settlement centers related to Romanian era are still found over some of them (e.g. Singar islet in the eastern sector). The surface levels of some other islets (e.g. El-Zanka, Farash El-Toob and El-Dakhla in the middle sector) approach the water level of the lake, sometimes the water submerged them particularly during the increase of water flow from the sea and drains.

In general the remote sensing study of Guirguis *et al*. (1996) on Lake Burullus indicated that the erosion and accretion were effective factors at different times. Erosion occurred during 1983 and accretion during 1985 (Fig. 1.14). Erosion is still continuing although protection procedures are in effect on the eastern side of the sea outlet during the last few years. Accretion is found only at the western part of the sea outlet. Lake area decreased during the period of study (1983 to 1991) at an average rate of 8.6 km2 yr-1. The rate of increase of reclaimed areas by drying from he lake body was higher during the period 1983 to 1985 (27.5 km^2 yr^{-1}) than during 1985 to 1991 (2. 33 km^2 yr^{-1}).

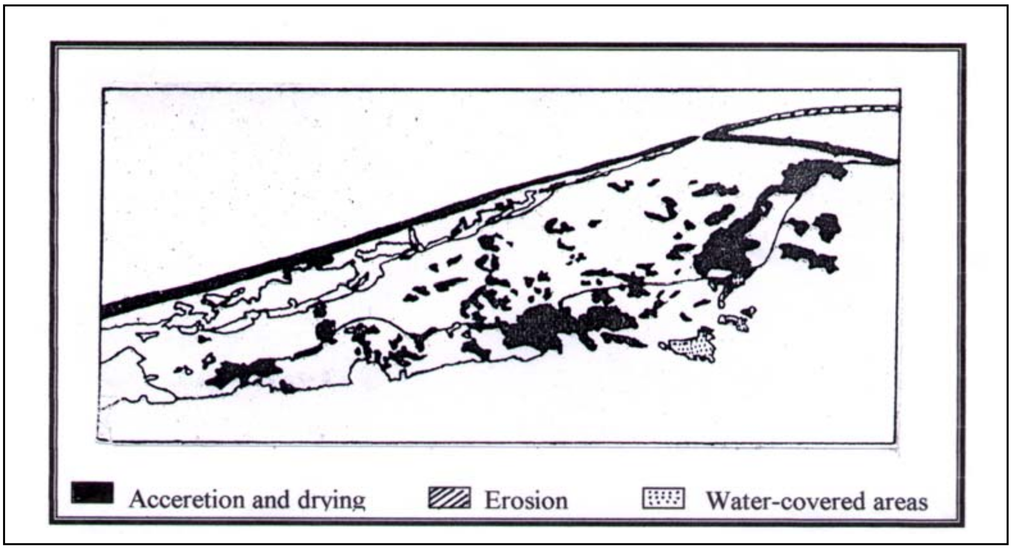

Fig. 1.14. **Map of Lake Burullus depicting major change during 1983 – 1991 (after Guirguis *et al*. 1996).**

1.4. CLIMATOLOGY

According to the map of world distribution of arid regions (UNESCO 1977), the northern part of Nile Delta belongs to the Mediterranean arid region. The climatic conditions are warm summer (20 to 30 °C) and mild winter (10 to 20 °C). The aridity index (P/PET: where P is the annual precipitation and PET is the potential evapo-transpiration) ranges between 0.03 and 0.2 at the north Delta (arid region), and less than 0.03 at the south (hyperarid region). Long-term climatic averages of three meteorological stations distributed within Burullus Wetland were used to draw their climatic diagrams (Fig. 1.15).

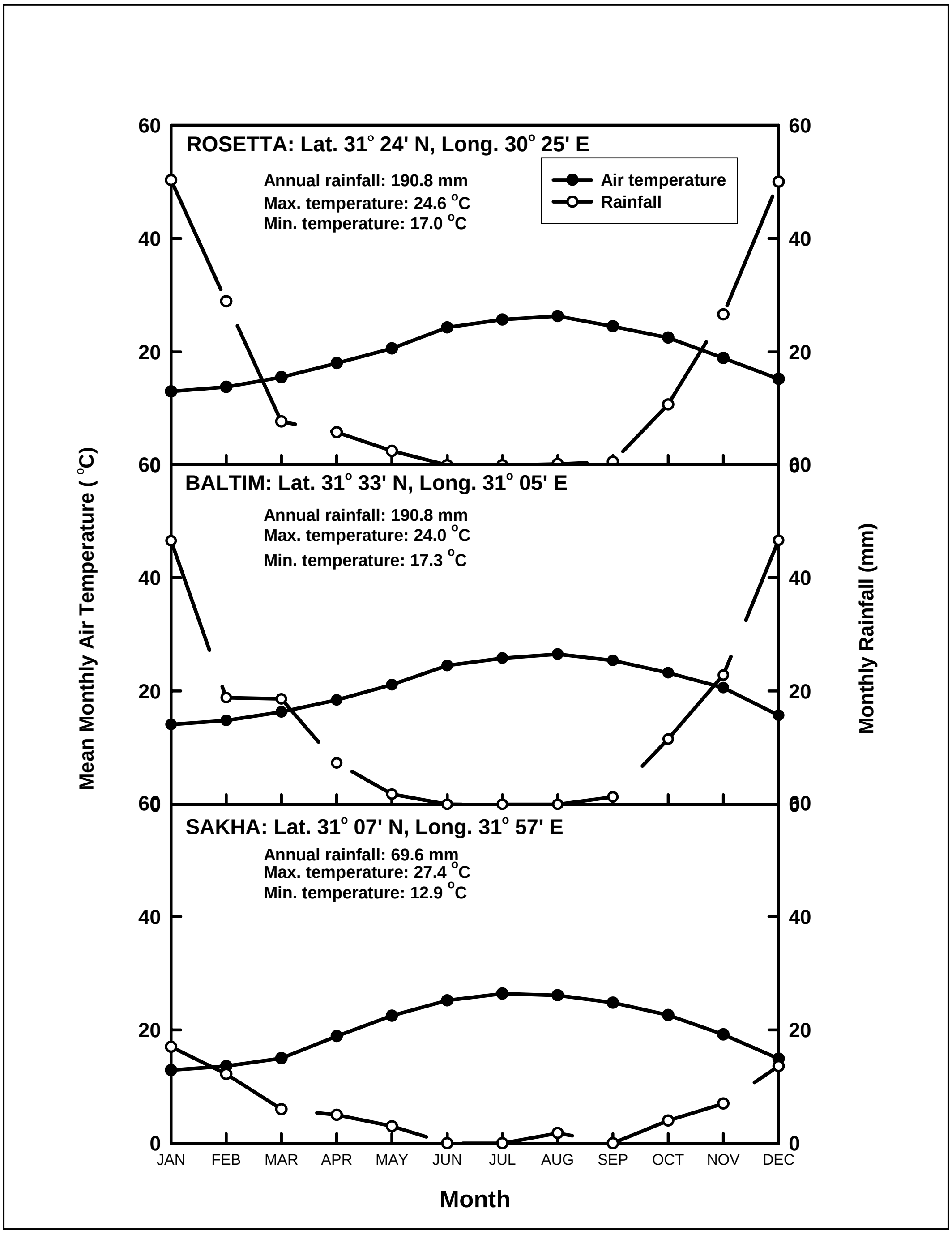

Fig. 1.15. **Climatic diagrams of Rosetta, Baltim and Sakha metereological stations**

In general, January is the coldest month, while July and August are the hottest. The annual mean maximum temperature varies between 24°C at Baltim and 27.4 °C at Sakha, and that of minimum varies between 12.9 °C at Sakha and 17.3 °C at Baltim. (Tables 1.10). The annual mean of wind speed varies between 2.9 knot at Sakha and 6.6 knot at Baltim. The annual mean of relative humidity, evaporation and sky cover exhibit narrow ranges of variation

Table 1.10. **Long-term averages (≥ 20 years) of the climatic records of Burullus Wetland (after the Climatic Normals for the Arab Republic of Egypt up to 1975: Anonymous 1980). *: total annual rainfall in mm.**

Month	Air temperature (°C)			RH	RF	EV (mm	WS	SC
	Max.	Min.	Mean	(%)	(mm month^{-1})	day^{-1})	(knot)	(oktas)
a- Baltim station: Lat. 31° 33' N, Long. 31° 05' E								
January	17.4	11.2	14.1	72	46.5	3.3	7.0	3.3
February	17.9	11.6	14.8	68	18.8	3.9	6.8	2.8
March	19.9	13.1	16.3	65	18.6	4.8	8.1	2.8
April	22.5	14.9	18.4	67	7.3	5.2	7.8	2.4
May	25.5	17.7	21.1	67	1.8	5.2	6.8	1.5
June	28.5	21.2	24.5	69	Tr.	5.6	7.1	0.8
July	29.3	22.9	25.8	73	Tr.	5.4	7.6	0.9
August	29.7	23.6	26.5	72	0.0	5.2	7.0	1.0
September	28.0	22.2	25.4	70	1.3	5.0	5.5	0.9
October	26.8	20.0	23.2	68	11.5	4.5	4.5	1.6
November	23.3	16.9	20.6	70	22.8	3.9	5.1	2.4
December	19.0	12.8	15.7	71	46.6	3.5	6.5	3.1
Mean	24.0	17.3	20.5	69	175.2*	4.6	6.6	2.0
b- Rosetta station: Lat. 31° 24' N, Long. 30° 25' E								
January	18.1	10.8	13.0	69	50.3	3.3	5.4	3.4
February	18.7	10.8	13.8	71	28.9	3.7	5.5	2.9
March	20.4	12.3	15.5	65	7.7	4.1	6.4	2.7
April	23.0	14.4	18.0	66	5.8	4.4	5.9	2.6
May	26.0	17.4	20.6	65	2.5	4.6	5.0	1.9
June	28.4	20.0	24.3	66	Tr.	4.8	5.2	1.0
July	29.6	23.0	25.7	70	0.0	4.8	5.5	1.1
August	30.4	23.4	26.3	71	0.2	4.8	4.5	1.2
September	29.5	22.8	24.5	70	0.6	4.8	4.1	1.4
October	27.5	19.8	22.5	72	10.7	3.6	3.7	1.9
November	23.8	16.4	18.9	72	26.6	3.8	4.0	2.8
December	20.1	12.5	15.2	70	50.0	3.3	5.3	3.2
Mean	24.6	17.0	19.8	69	190.8*	4.2	5.0	2.2
Sakha station: Lat. 31° 07' N, Long. 31° 57' E								
January	19.4	6.4	12.9	74	17.0	2.2	2.8	3.1
February	20.6	6.5	13.6	72	12.2	2.7	3.1	3.0
March	22.0	8.0	15.0	69	6.0	3.5	3.3	2.5
April	27.0	10.8	18.9	64	5.0	5.0	3.3	2.1
May	30.9	14.1	22.5	60	3.0	6.5	3.2	1.9
June	33.1	17.2	25.2	62	Tr.	6.7	3.1	1.2
July	33.7	19.1	26.4	66	0.0	5.7	2.8	1.4
August	33.6	18.6	26.1	69	1.8	5.0	2.6	1.4
September	31.9	17.7	24.8	70	Tr.	4.8	2.5	1.6
October	29.7	15.5	22.6	71	4.0	3.8	2.5	2.2
November	25.7	12.6	19.2	73	7.0	2.8	2.7	2.8
December	21.4	8.4	14.9	75	13.6	2.1	3.0	3.1
Mean	27.4	12.9	20.2	69	69.6*	4.2	2.9	2.2

among stations. The total annual rainfall has a maximum value at Rosetta (190.8 mm yr^{-1}) and a minimum at Sakha (69.6 mm yr^{-1}). The isohytes of the mean annual rainfall in Egypt (Griffiths 1972) indicates that Lake Burullus is between the isohyte 200 mm at its northern border and the isohyte 150 mm at its south (Fig.1.16). In general, the distribution of the mean annual rainfall in this region shows a maximum close to the Mediterranean coast and then decreases rapidly toward the south. More than 80% of the rain falls during winter, and only less than 10% falls during spring.

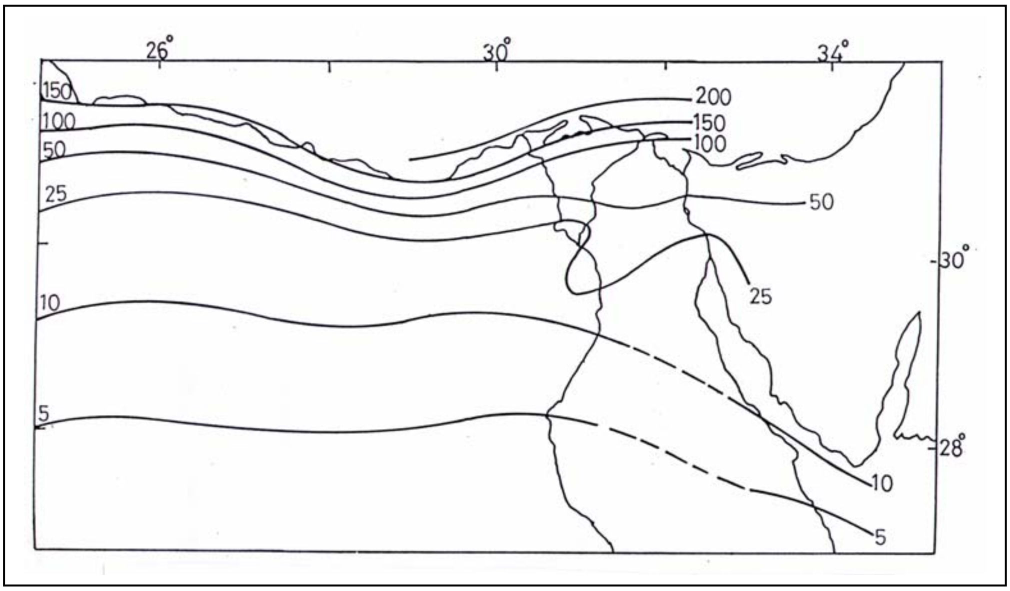

Fig. 1.16. **The isohytes of the mean annual rainfall in Egypt (after Griffiths 1972).**

The pluviothermic index of Emberger (Emberger 1955) has a decreasing trend with a maximum at Rosetta (Q = 21.7), followed by Baltim (Q = 21.5) and Sakha (Q = 11.3) stations.

1.5. HYDROLOGY

1.5.1. Hydrogeology

The Quaternary alluvial deposits in the Nile Delta form the main ground water aquifer (Nile Delta aquifer). The deposits consist of sand and gravel with a relatively high hydraulic conductivity. The Quaternary deposits are underlain by late Tertiary clays, which act as the main aqueduct. In the Nile floodplain, a Holocene clay layer that creates semi-confined conditions covers the aquifer. The ground water in the Quaternary aquifer is not a resource in itself as it is in hydraulic contact with the surface water system (i.e. River Nile, drainage and irrigation canals). Groundwater that is pumped from the aquifer is continuously replenished by surface water or intruding seawater. The aquifer is in fact a large storage reservoir supplied by the Nile water through the net of irrigation system.

The average thickness of the clay cap is less than 20 m. The thickness increases northward where it reaches about 70 m along Mediterranean Sea. The clay cap is followed by silty soft clay or sandy clay layers. The clay cap is an isotropic with permeability in the vertical direction much less than in the horizontal direction. Field measurements and laboratory experiments showed high variations in the values of vertical permeability. A value of 2.5 mm day^{-1} has been adopted estimate of the vertical upward flow through the clay cap. This value is quite low and seems to be very conservative if it is considered for the whole leaky aquifer (El-Shinnawy 2002).

The Quaternary aquifer is highly productive and generally contains good quality water (TDS less than 1000 ppm). In the northern part of Nile Delta, the salinity increases to more 10,000 ppm over a relatively short distance due to seawater intrusion.

1.5.2. Groundwater Movement

The catchment area of Burullus wetland is located between latitude 30° 22' 02" – 31° 36' 16" N and longitude 30° 29' 00" - 31° 21' 19" E. The catchment altitudes vary from zero level at Mediterranean Sea in the north to about 20 m at the most southern edge. The surface slope in the catchment area is northwards with an average slope of 0.0015 m m^{-1}. It covers an area of about 5000 km^2 (El-Shinnawy 2002).

The groundwater pressure is called piezometric head, while the subsoil phereatic surface of clay cap is called shallow water table. Both water heads fluctuate around the year. The groundwater piezometric heads depended mainly in the past on the Nile water levels, while now they depend on the irrigation practices on a regional scale. The shallow water table fluctuates in response to local irrigation practices, seepage from adjacent canals, and field drainage depth. The difference in the levels between the piezometric heads in the aquifer and the water table in the aquitard causes the vertical water movement through the clay cap. The direction of movement is determined by which level is higher compared with a common reference plain. A water table level higher than the piezometric level indicates a downward movement. On the contrary, when the piezometric level is higher, there is a potential for upward movement of the groundwater from the aquifer to the clay cap. Applying this phenomenon to the north of the catchment area where the difference in levels of groundwater head and shallow water table causes upward flow through the clay cap.

The catchment area can be divided on the basis of the above analysis into three zones: 1- the downward movement zone in the south, 2- upward movement zone to the north, and 3- the seawater intrusion zone along the seashore. In the downward movement zone, the aquifer is replenished by deep seepage of surface water to the aquifer. In this zone, salinity of shallow groundwater is higher than that of deep groundwater because the salts are leached by irrigation water. The drainage rate in this zone is low due to the natural drainage component provided by the downward movement. In the upward movement zone, the salinity of groundwater is higher due to the dispersion of the neighboring seawater. The upward flow of the brackish water causes increase of the drainage rates and their salinity in the northern drainage sub-catchments. The drainage system in this area receives simultaneously surface and groundwater flow.

The upward flux was estimated as 97 million m^3 yr^{-1} (based on a permeability coefficient of 4 mm/day), while the upward flow area was about 4200 km^2 (El-Shinnawy 2002). The net downward flux in 1988 was about 667 million m^3 yr^{-1}. This rate of downward flow is a maximum in most southern parts of the catchment area due to the small thickness of the clay cap, increase of soil permeability, and maximum difference between existing heads. The natural drainage diminishes towards the north due to gradual changes in these governing factors.

1.5.3. Groundwater Utilization

Groundwater is mainly abstracted for domestic and agricultural uses. Abstractions for industries probably cover a minor part of the total abstraction. Deep wells usually feed a piped drinking water supply system (serving a municipally or a rural unit) or irrigation canals at the end tails of irrigation system. They generally have depths of up to 70 m with a screened section of 20 – 30 m. Shallow wells operated by hand pumps are still extensively used for domestic purposes, especially in the rural areas of the catchment area. Shallow wells may have depths from 5 to 25 m below ground surface. Hand pump wells are usually drilled until sandy or gravelly sediments are reached, which often coincides with the top of the aquifer. Intercalated sandy layers within the top layer may also be pumped by hand pumps.

1.5.4. Groundwater Quality

The previous studies on groundwater quality in the catchment area, as a part of Nile Delta, dealt with nitrogen, iron, manganese and salinity hazards. Nitrate is almost absent in the groundwater aquifer at the catchment area, probably due to thick covering clay layer and thus long travel times. Iron and manganese have been found at random locations in groundwater aquifer throughout the floodplain. However, relationships could not be assessed between concentrations and distance to pollution sources or with the depth below ground level. On the contrary, these metals are present only in very low concentrations in sandy areas compared to the clayey areas. The irrigation and drainage water generally contain relatively low concentrations of iron and manganese. Therefore, sources of these metals are expected to originate from the lower horizons of the covering clay layers. Moreover there is no inter-relation between iron and manganese concentrations (El-Shinnawy 2002).

The original WHO guidelines for Fe and Mn are 0.3 and 0.1 mg l^{-1}, respectively. On the other hand, the Egyptian guidelines are 1.0 and 0.5 mg l^{-1}, respectively. The salinity of groundwater is reasonably low in the southern parts of the catchment area, where values of salinity are less than 600 ppm. Northwards at the Middle Delta, the salinity increases quickly. The rate of increase is faster near the coastal zone, where salinity as high as 45000 ppm was recorded.

1.5.5. Water Resources

1.5.5.1. Rainfall

The mean annual rainfall over the area is 187.4 mm. This depth of water provides the lake with a mean annual volume of about 77.4 million m^3. Most rainfall takes place during the winter season (October – March), with no rainfall during summer months. The maximum depth of rainfall is received in December and January.

Table 1.11. **Monthly mean rainfall (mm) and rain volume (10^6 m^3) over Lake Burullus (after El-Shinnawy 2002).**

Month	Rainfall (mm)	Rain volume (x 10^6 m^3)
Jan	48.1	19.7
Feb	32.7	13.1
Mar	16.7	6.9
Apr	4.6	1.9
May	1.5	1.6
Jun	0.0	0.0
Jul	0.0	0.0
Aug	0.0	0.0
Sep	0.6	0.3
Oct	7.8	3.2
Nov	28.0	11.5
Dec	48.8	20.0
Annual	**187.4**	**77.4**

1.5.5.2. Drainage discharges

The drainage system provides the lake with about four billion m^3 yr^{-1} of agricultural drainage water. The maximum rate of water discharged to the lake is during rice cultivation season (July – September), while the minimum rate is in January and February (Table 1.12). Drain 9 discharges the maximum amount (about 20 % of the total volume), while Burullus Drain discharges the minimum (about 1.7 % of the total volume).

1.5.5.3. Tidal effect

The tide at Burullus headland was estimated as the difference between the mean high water level of 33 cm and the mean low water level of 18 cm. The 15 cm difference is small and hence the tidal effect would be negligible (Fanos 1992, as quoted by El-Shinnawy 2002). This conclusion works all over the year, but the mean high water level should be considered in the days of winter closure.

Table 1.12. **Monthly inflows of drainage discharges to Lake Burullus (million m^3).**

Month	Terah	Buru-llus	Drain 7	Drain 8	Drain 9	Drain 11	West Burullus	Gharbia	Prempal	Total	%
Jan	32.9	4.9	27.8	29.8	65.0	45.1	7.4	32.2	13.7	258.8	6.6
Feb	36.8	4.6	31.8	28.6	65.0	39.9	7.4	21.4	5.7	241.1	6.2
Mar	40.1	5.7	32.2	29.6	65.0	56.7	10.5	36.4	16.8	293.0	7.5
Apr	41.8	4.9	39.1	28.6	65.0	51.2	9.0	33.1	14.4	287.1	7.4
May	55.6	5.0	36.6	32.7	65.0	65.5	12.7	31.5	16.4	321.0	8.2
Jun	60.6	4.4	44.5	37.3	65.0	78.2	16.6	48.5	15.5	370.6	9.5
Jul	72.6	5.9	51.3	48.5	65.0	85.0	18.2	60.2	17.0	423.6	10.9
Aug	72.3	6.3	52.0	49.6	65.0	77.6	17.4	52.4	18.0	410.6	10.5
Sep	64.1	6.8	48.2	41.9	65.0	71.9	14.1	60.0	23.3	395.4	10.1
Oct	46.7	5.8	39.5	33.1	65.0	56.7	9.8	44.0	19.1	319.7	8.2
Nov	42.9	5.6	36.6	33.2	65.0	53.8	9.9	32.4	20.3	299.5	7.7
Dec	43.1	6.0	36.5	33.0	65.0	41.5	6.8	33.6	18.8	284.3	7.3
Annual	**609.7**	**65.8**	**476.1**	**425.7**	**780.0**	**723.0**	**139.8**	**485.8**	**198.9**	**3904.6**	
%	**15.6**	**1.7**	**12.2**	**10.9**	**20.0**	**18.5**	**3.6**	**12.4**	**5.1**	**100.0**	**100**

1.5.5.4. Human activities

The human activities are represented by outflow/inflow of water from or to the lake by the local inhabitants in the surrounding areas. Social studies revealed that about 185 thousands person live and interact on daily basis with the lake. These inhabitants discharge their domestic effluents directly into the lake. Water consumption for such number of people (based on average rate of 150 l day^{-1} $capita^{-1}$) would be as much as 27750 m^3 day^{-1} (approximately 10 ×

10^6 m^3 yr^{-1}). This water volume would be considered in evaluating the water budget of the lake.

1.5.5.5. Flow of groundwater

To evaluate the groundwater inflow and outflow from Lake Burullus, El-Shinnawy (2002) used a three-dimensional flow model based on the finite element method with triangular element and linear shape function. The model is capable of simulating the interaction between surface water bodies and groundwater aquifer systems. The numerical simulation results indicate that the groundwater inflow into Lake Burullus area is about 88902 m^3 day^{-1} (= 2667060 m^3 $month^{-1}$). The net upward flux to the bottom of the lake is about 63141 m^3 day^{-1}, while the net leakage through the lake boundaries is about 25761 m^3 day^{-1}. The total dissolved solids (TDS) of groundwater reaching the lake from the aquifer are about 16000 ppm.

1.5.5.6. Evaporation

The mean annual evaporation is 1583.3 mm. This value approximates about 646.5 million m^3 of water loss from Lake Burullus. Maximum evaporation takes place during May – September, while the minimum during December – February (Table 1.13).

Table 1.13. **Average daily and monthly evaporation (mm) and monthly volume of water loss (10^6 m^3) at Lake Burullus.**

Month	Daily (mm)	Monthly (mm)	Monthly volume (10^6 m^3)
Jan	3.6	110.7	45.4
Feb	3.9	108.9	44.7
Mar	4.2	131.1	53.5
Apr	4.6	138.6	54.4
May	4.9	151.9	62.3
Jun	4.8	143.1	58.7
Jul	4.8	147.3	60.4
Aug	4.7	144.5	59.2
Sep	4.7	139.8	57.3
Oct	4.3	134.2	55.0
Nov	4.0	118.5	48.6
Dec	3.7	114.7	47.0
Annual	**4.0**	**1583.3**	**646.5**

1.5.5.7. Outflow to the sea

Simulation of the outflow from the lake to the sea was implemented in two different cases (El-Shinnawy 2002). The first case presented the flow from the drainage system over the last four years where the High Dam releases continued without any winter closure. In this case, results indicate that water table was always above mean sea water level (Table 1.14). The elevation of water varied from 28 cm (in February) to 61 cm (in August) above sea level. In this case only, water discharges from the lake to the sea.

The second case presented the usual case of the irrigation system in Egypt that enhances an annual winter closure. In this case, simulation was made by allowing no discharges from the drainage system to the lake during winter closure (in January). Results indicate that water level goes below sea water level by about 26 cm. This case allowed a volume of 110.7 million m^3 of sea water to move into the lake as a result of the winter closure (Table 1.14).

***Table 1.14*. Results of flood routing in Lake Burullus. dH: change in water head.**

Month	**Without winter closure**			**With winter closure**		
	dH (cm)	**Cum.dH (cm)**	**Total Storage (10^6 m^3)**	**dH (cm)**	**Cum.dH (cm)**	**Total Storage (10^6 m^3)**
Feb	28	28	113.5	28	28	113.5
Mar	3	31	127.3	3	31	127.3
Apr	3	34	137.8	3	34	137.8
May	2	36	147.2	2	36	147.2
Jun	9	45	184.9	9	45	184.9
Jul	10	56	228.0	10	56	228.0
Aug	6	61	251.8	6	61	251.8
Sep	- 5	56	229.4	- 5	56	229.4
Oct	- 8	48	196.4	- 8	48	196.4
Nov	- 5	43	174.7	- 5	43	174.7
Dec	- 5	38	155.5	- 5	38	155.5
Jan	- 8	30	124.3	- 36	2	6.0
Feb				- 28	- 26	- 110.7

1.5.5. Water Balance

A water balance is often used to estimate the magnitudes of unknown hydrologic components such as outflow and change in storage within the wetland. To evaluate the change in storage for Lake Burullus, the water budget was estimated as follows: dS/dt = Inflow- outflow, where dS/dt = change of storage within the wetland over a specified time interval, inflow represents water bodies contribution to the lake, and outflow represents water losses and water interaction with the sea.

Results of the annual water balance indicate that the drainage water contributes about 97 %, while the contribution of rainfall is less than 2% and groundwater is less than 1% of the total water resources in the lake ecosystem (Table 1.15, Fig. 1.17). On the other hand, evaporation losses represent about 16% of the total water resources in the system, while the drainage system discharge about 3.2 billion m^3 to the sea through the lake (it represents, in addition to the change of storage in the reservoir, about 84% of the total water resources in the system).

Table 1.15. **Results of the water balance in Lake Burullus). EV: evaporation, GW: groundwater, dS: change in storage, and H: water head.**

Month	Water gain (10^6 m^3)			Water loss (10^6 m^3)			dS (10^6 m^3)	Total H (cm)
	Drainage	Rainfall	Human	EV	Outflow	GW		
Jan	258.8	19.7	0.83	45.4	111.5	2.67	116.3	27
Feb	241.1	13.4	0.83	44.7	217.7	2.67	21.6	30
Mar	293.0	6.9	0.83	53.8	233.3	2.67	13.4	33
Apr	287.1	1.9	0.83	54.4	241.1	2.67	14.0	35
May	321.0	0.6	0.83	62.3	251.4	2.67	36.2	44
Jun	370.6	0.0	0.83	58.7	298.1	2.67	43.9	55
Jul	423.6	0.0	0.83	60.4	337.0	2.67	23.2	61
Aug	410.6	0.0	0.83	59.2	370.7	2.67	-23.4	55
Sep	395.4	0.3	0.83	57.3	339.6	2.67	-35.6	47
Oct	319.7	3.2	0.83	55.0	290.3	2.67	-29.1	42
Nov	299.5	11.5	0.83	48.6	282.5	2.67	.24.3	37
Dec	284.3	20.0	0.83	47.0	248.8	2.67	-0.8	37
Annual	3904.6	77.4	9.99	646.7	3221.9	32.0	155.4	
%	97.0	1.9	0.25	16.1	80.1	0.8	3.9	

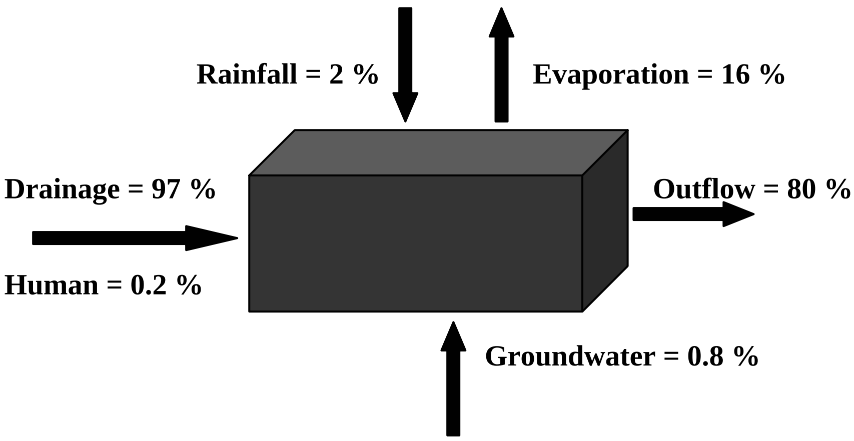

Fig. 1.17. Water balance in Lake Burullus

In order to re-establish the equilibrium status of salt balance in the lake, 84% of the water resources should be discharged outside the lake. This represents about 3.4 billion m^3 annually. This volume of excess water resources within the system makes water level in the lake during the whole year above the mean sea level. Accordingly, the salt balance in Lake Burullus has been deteriorated. In order to make use of this huge amount of drainage water, it is recommended to convert this water to the areas of development projects at the east of the lake and to make use of Al-Moheet Drain to discharge water outside the lake.

Volumes of outflow and change of storage (dS) represent monthly excess water to be used in developing plans. The negative sign in the dS column in Table 1.15 does not represent low levels below the mean sea levels, but it means that outflow is greater than the net inflow in a specific time interval. Due to the winter closure in January, water level in the lake becomes below the sea level with about 26 cm. This case allows sea water to move into the lake with a volume of about 110 million m^3.

1.6. HABITAT TYPES

Six major types of habitat are recognized in Burullus Wetland: the salt marshes, sand formations, lake cuts, drains, lake proper and islets of the lake (Fig. 1.18). The following statements are a brief description of these habitats including the physical and chemical features of their soils.

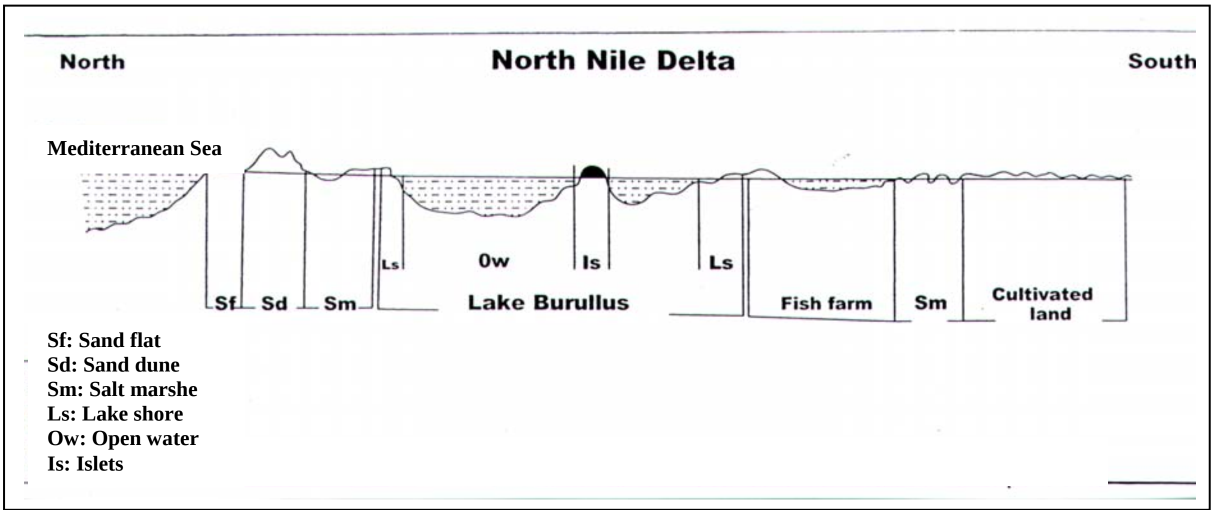

Fig. 1.18. Major types of habitat in Burullus Wetland (after Ahmed 2003).

1.6.1. Salt Marshes

Coastal salt marshes are lowlands near the coasts, covered with water during high tide, have increasing salinity particularly with the increase of evaporation rate, and covered with salt tolerant plants of high capacities for trapping and fixing soil deposits. They extend along the marine bar of Lake Burullus with an area approximates 40% of the total area of the bar (6% in the eastern part, and 34% in the western part). Tidal action is considered among the principal factors responsible for the formation and development of salt marshes along the marine bar of Lake Burullus. With the extension of water during high tide and retreating during ebb-tide, and with the gentle sloping of the shore, tidal waters extend to cover vast areas that increase with the happening of storm waves. Natural vegetation plays an important role in the development and evolution of salt marshes as it leads to increase evaporation rate and salinity. Moreover, the heavy growth of salt tolerant plants traps the deposits and help in leveling up the beds of the marshes (e.g. *Halocnemum strobilaceum*).

1.6.2. Sand Formations

Three types of sand formations cover the surface of the marine bar of lake Burullus: sand sheets (or flats), hillocks and dunes. The sand sheets cover vast area of the marine bar particularly along the north-western margins of the lake. These sheets have a few undulations and sometimes form the so called "sand ripples". Sand hillocks are embryonic dunes with height range between a few centimeters and a few meters. They have domal or longitudinal shapes. Their windward sides are covered by some herbs and shrubs (e.g. *Tamarix nilotica*) that help in the fixation of these hillocks. When the hillocks approach each other, they merge together to form large dunes covered by dense vegetation. Sand dunes in the marine bar of Lake Burullus represent the principal geomorphological feature affected by the sedimentation processes. Natural factors helped in presence of this geomorphological feature where a close relation was found between the locations of the sand dunes and the ancient Nile Deltaic branches. The coastal sand dune formations are desertic sands that come from the western desert where the predominant western winds helped in their formation after mixing with the Nile deposits of the ancient Nile Deltaic branches and the marine deposits carried by the marine currents, particularly in the north eastern part of the marine bar (El-Bayomi 1999).

1.6.3. Lake Cuts

This habitat represents the recent lands resulted after the drying process that took place along the shores of Lake Burullus, particularly the outermost western and eastern fringes, during the period of 1984 to 1997. Some of these lands were used in construction of human settlements (e.g. Sidi Ibrahim El-Disouky and Sidi Ahmed Al-Badawey villages west of Mastaruh) and some others were reclaimed for cultivation: field crops, grapes and watermelons or as fish farms. Some other dried parts are still fallow and were subjected to secondary plant succession.

1.6.4. Drains

Most of cultivated lands in Egypt are irrigated by the Nile through a net of irrigation canals, and drained by a similar net of drainage canals. Land drainage has played an important role in agriculture developing in Nile Delta. Typically, the soil needed to be drained because of high water table, poor surface drainage, slow movement of water through the soil profiles and the need to minimize the salt level of the soil. Six drains pour their water into the Lake

Burullus mainly at its southern border. These are: Al-Gharbiyyah drain (connected with the lake through Al-Burullus and Ash-Sharikah drains in the eastern part), drain 7 (connected with Nassir, Nasr and Tirah drains), drain 8, drain 9 (connected with Bahr Nashart Drain), drains 10 and 11 in the south-western part. These drains discharge their water into the lake through water pump stations. The drains, as a major habitat, were classified into four microhabitats (i.e. zones): terraces, slopes, water-edge and open water (Fig. 1.19).

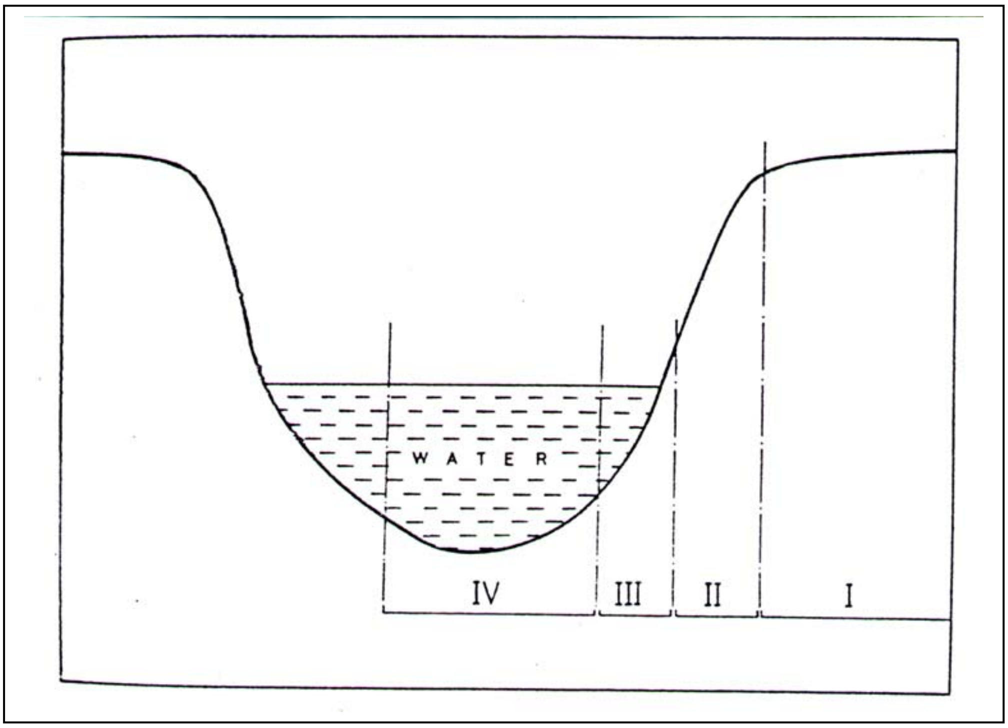

Fig. 1.19. The four zones of the drains. I: terrace, II: slope, III: water edge, IV: open water.

1.6.5. Lake Proper

Lake Burullus has an oblong shape, it extends for a distance of 47 km along NE-SW axis. The lake proper is classified into two habitats: lake shore and open water. The shoreline takes several forms related basically to its formation, origin and evolution The width of the open water of the lake from north to south varies from site to the other. The western sector has the least width which does not exceed 5 km, then it increases in the middle sector to reach an average of 11 km. As the area of the lake changed with time, its dimensions changed also. Vast areas of the water surface are covered with the emergent common reed (*Phragmites australis*), and the submerged sago pondweed (*Potamogeton pectinatus*).

1.6.6. Islets

Many islets with different sizes are distributed in Lake Burullus. Due to the continuing of the effects of the geomorphological processes (e.g. sedimentation, erosion and water flooding), the number, size, dimensions and locations of these islets change from time to time. They move from their locations or merge together when become close to each other. The heavy growth of reeds and sedges (e.g. *Phragmites ausralis* and *Typha domingensis*) facilitates the merging of the nearby islets. They could be classified according to their shapes into different groups : longitudinal (e.g. Dibar), circular or oval (e.g. El-Zanka), triangular (e.g. Doshimi), arc (e.g. shishet Al-Agoza), curved (e.g. El-Zoaya) and irregular (El-Maghara and Absak). Many islets have obvious longitudinal extensions parallel with the directions of the prevailing western winds, their axes usually extend from north to south, and occasionally from north to east. The surface levels of some islets approach 3 meters above water level, thus they are called hills or piles where some remains of settlement centers related to Romanian era are still found over some of them (e.g. Singar islet in the eastern sector). The surface levels of some other islets (e.g. El-Zanka, Farash El-Toob and El-Dakhla in the middle sector) approach the water level of the lake, sometimes the water submerges them particularly during the increase of water flow from the sea and drains.

1.6.7. Soil Characteristics

Physical and chemical characteristics of the habitats indicate that the soil of sand formations is characterized by high values of phosphorus (43.0 mg $100g^{-1}$) and low values of silt (0.5%), organic matter (0.3%), calcium carbonate (2.1%), pH (7.5), nitrogen (16.4 mg $100g^{-1}$), sodium (142 mg $100g^{-1}$), potassium (22.8 mg $100g^{-1}$) and magnesium (157 mg $100g^{-1}$) (Table 1.16). Soil of the drain slopes is characterized by the highest values of clay (16.2%) and calcium carbonates (10.9%), but the lowest of iron (6.8 mg $100g^{-1}$), and that of water edges is characterized by high values of electric conductivity (11.0 mS cm^{-1}), nitrogen, sodium and calcium (93.9, 794 and 1618 mg $100g^{-1}$, respectively), and low of sand (60.9%). Soil underneath the open water zone of the drains has the highest values of silt (29.8%), organic matter (5.4%), pH (8.1) and potassium (309 mg $100g^{-1}$) and low of phosphorus (13.1 mg $100g^{-1}$). On the other hand, soil underneath the open water zone of the lake has high value of pH (8.1) and low of electrical conductivity (1.5 mS cm^{-1}), phosphorus (4.9 mg $100g^{-1}$) and calcium (355 mg $100g^{-1}$). Soil of lake shore is characterized by high values of sand (87.6%), magnesium and iron (339 and 20.6 mg $100g^{-1}$), and that of salt marshes is characterized by high values of phosphorus (43.1 mg $100g^{-1}$).

Table 1.16. **Means (first line) and standard deviations (second line) of some soil characters collected from represented stands of the main habitats of Lake Burullus area. The habitats are: SM: salt marshes, SS: sand formations, LG: lake cuts, TD: terraces, SD: slopes, ED: water edges and OD: open water zones of the drains, LS: lake shores and LO: open water of the lake.**

Soil variables		Habitats									Mean
		SM	SS	LG	TD	SD	ED	OD	LS	LO	
Clay	%	13.0	12.2	13.4	10.4	16.2	13.0	9.1	9.2	9.3	12.3
		2.7	2.5	4.1	4.8	24.5	7.2	7.2	3.8	3.3	10.6
Silt	%	5.2	0.5	1.0	15.3	17.1	26.1	29.8	2.7	4.6	13.6
		9.7	0.6	1.4	15.6	14.3	15.5	16.0	3.8	5.6	15.7
Sand	%	82.0	87.4	85.5	74.3	71.7	60.9	61.1	87.6	86.1	74.9
		10.1	2.4	4.5	13.8	14.5	16.0	17.7	7.3	8.1	15.8
O.M.	%	1.1	0.3	0.9	3.1	3.1	4.3	5.4	1.1	1.4	2.4
		1.3	0.1	0.6	3.4	2.8	2.5	5.7	0.7	0.4	3.1
CaCO3		2.3	2.1	2.5	3.1	10.9	2.5	3.7	4.1	4.3	4.1
		0.3	0.3	0.5	4.8	40.8	1.4	2.1	6.6	2.0	15.7
EC (mS cm^{-1})		4.6	2.8	2.7	2.9	5.9	11.0	2.9	3.5	1.5	5.0
		2.6	0.9	1.9	2.0	5.6	10.5	2.7	1.7	0.6	5.8
pH		7.7	7.5	7.7	7.9	7.9	7.8	8.1	8.0	8.1	7.8
		0.3	0.2	0.2	0.3	0.2	0.3	0.4	0.3	0.4	0.3
N		25.2	16.4	27.4	56.0	34.9	93.9	75.8	39.7	67.9	51.0
		21.1	9.2	18.5	64.9	44.4	67.5	72.4	24.8	32.0	55.4
P	mg $100g^{-1}$	43.1	43.0	25.7	38.3	30.9	27.6	13.1	42.6	4.9	33.3
		16.7	15.1	9.2	16.7	13.2	16.8	7.2	4.6	2.6	18.1
Na	mg $100g^{-1}$	383	142	213	678	438	794	718	469	480	531
		479	91.9	124	620	199	308	287	253	182	434
K	mg $100g^{-1}$	58.2	22.8	28.3	183	161	197	309	98.3	184	143
		86.1	7.7	6.8	182	129	105	80.8	67.3	65.4	136
Ca	mg $100g^{-1}$	1396	750	1498	1402	1536	1618	517	1081	355	1277
		905	115	691	1271	919	1156	385	699	105	981
Mg	mg $100g^{-1}$	236	157	182	251	274	284	285	339	166	254
		155	43.3	55.0	97.4	58.0	155	94.2	167	63.9	124
Fe		13.0	10.9	14.8	7.8	6.8	14.9	10.9	20.6	10.4	11.9
		11.1	3.3	8.4	5.1	5.0	17.4	18.3	24.2	1.5	13.1

1.7. BIOTIC COMMUNITY

Based on ecosystem approach (Fig. 1.20), the biotic community in Lake Burullus is classified into three major groups: producers, consumers and saprotrophs. The producers are classified into vascular plants and phytoplankton (i.e. algae). The consumers are classified into three trophic levels: primary consumers (i.e. herbivores), secondary consumers (i.e. primary carnivores) and tertiary consumers (secondary carnivores). Zooplankton and zoobenthos are mainly primary consumers, but the other animal groups (invertebrates, fishes, reptiles, amphibians, birds and mammals) have members that belong to the three levels of consumers. The saprotrophs are mainly the bacteria and fungi of decay.

1.7.1. Producers

A total of 197 species of vascular plants have been recorded from Burullus Wetland (100 annuals and 97 perennials) including 11 hydrophytes (the most common is *Potamogeton pectinatus*) and one fern (*Azolla ficliculoides*). The most common of all these species is the common reed *Phragmites australis*. With 35 species (i.e. 18 % of the total species), the grasses are the predominant component of the species composition (Shaltout & Al-Sodany 2000). The phytoplankton community includes some 226 algal species: 125 Bacillariophytes (Diatoms), 56 Chlorophytes, 39 Cyanophytes, 2 Euglenophytes, 2 Dinophytes, one Cryptophyte and one Rhodophyte. The first three major groups are arranged according to their biomass as follows Bacillariophytes (69 %), Chlorophytes (16.2 %) and Cyanophytes (14.8%); and according to their numbers as follows: Chlorophytes (58.9%), Bacilliriophyes (31%) and Cyanophytes (8.8%). The other groups had a minor contribution (El-Sherif 1993). The common submergent *Potamogeton pectinatus* is a host for some 45 epiphytic algal species, most of them are limnetic forms and can survive in both planktonic and attached situations (Samman *et al*. 1988).

1.7.2. Consumers

The zooplankton community in Lake Burullus includes 54 species of: Rotifera (35 species), Copepoda (9 species) and Cladocera (10 species). All of these species are of freshwater origin. The zooplankton community is dominated by 8 species, while the rest are either rare or very rare (El-Shabrawy 2002). In a previous study by Aboel Ezz (1995) the zooplankton community of the lake was estimated as 90 species: 26 species of Copepoda, 7 of Cladocera, 26 of Rotifera, and 10 of Protozoa; they constitute collectively about 85% of the total zooplankton. Other infrequent forms (21 species: 15%) were also recorded, beside ciripede larvae, larval stages of decapods, insect larvae, polychaete larvae, veligers of molluscs and free living nematodes.

The study of terrestrial invertebrates in Burullus Wetland is still at a preliminary stage. Specimens of 23 species representing 4 orders of spiders, scorpions and their allies (Araneida, Pseudoscorpionida, Scorpionida, Solpugida) have been collected (El-Hennawy 2000). In addition 94 insect species were recoded so far in this region, however it is believed that this number will be increased substantially on more thorough investigation (Metwally 2000).

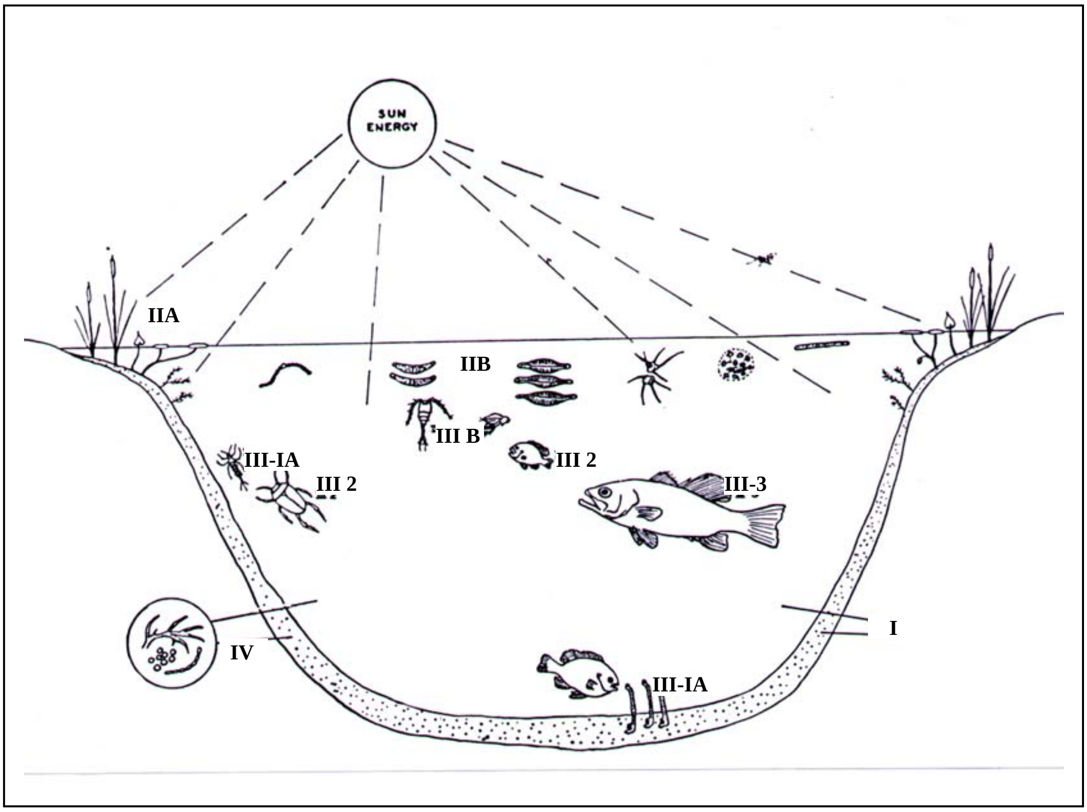

Fig. 1.20. **Diagram of Lake Ecosystem. Basic units are as follows: I: abiotic substances-basic inorganic and organic compounds, IIA: producers-rooted vegetation, IIB: producers-phytoplankton, III-IA: primary consumers (herbivores)-bottom zoobenthos, III-B: primary consumers (herbivores)-zooplankton, III-2: secondary consumers (primary carnivores), III-3: tertiary consumers (secondary carnivores), IV: saprotrophs-bacteria and fungi of decay. The metabolism of the system runs on sun energy, while the rate of metabolism and relative stability of the lake depend on the rate of inflow of materials from rain and from the drainage basin in which the lake is located (modified from Odum 1971).**

The present fish population in Lake Burullus includes of 25 species, 15 of which live in fresh or brackish water. Of the remaining 10 species, four (*Sparus aurata, Johnius hololepidotus, Solea solea* and *Liza saliens*) are of purely marine origin which invade the lake for some time. The remaining six species (*Aphanus fasciatus*, *Atherina mochon*, *Anguilla anguilla*, *Mugil cephalus*, *Liza ramada* and *Gambusia affinis*) belong to a separate group of obligatory migrants which spend their adult life in the brackish water of the lake and migrate to the sea for spawning (Khalil & El-Dawy 2002).

There are 22 species of reptiles and amphibians in Burullus Wetland. The recently described Nile Valley Toad *Bufo kassasii* is endemic to Egypt with localized distribution in Nile Valley, but it is found in dense populations in suitable freshwater swamps along the southern margins of Lake Burullus (Anonymous 2002). The isolated population of Audouin's Shink *Sphenops sepsoides* is widespread Saharan inhabitant of sandy biotopes and common elsewhere in Egypt, it is under threat as a result of the destruction of sand dunes. The relict population of Javelin Sand Boa *Eryx jaculus* is under a similar threat. There are 2 globally endangered reptile species occurring in Burullus Wetland: Loggerhead Turtle *Caretta caretta* and Green Turtle *Chelonia mydas*.

One hundred and twelve species of birds were recoded in Burullus Wetland. Burullus is home to six bird subspecies endemic to Egypt, none is considered threatened: Little Green Bee-eater *Merops orientalis cleopatra*, Laughing Dove *Streptopelia sengalensis aegyptiaca*, Senegal Coucal *Centropus sengalensis aegyptius*, Egyptian Swallow *Hirunda rustica savignii*, Crested Lark *Galerida cristata nigricans* and Egyptian Yellow Wagtail *Motacilla flava pygmaea*. The Egyptian forms of the Laughing Dove and The Swallow are two of the most abundant birds in Egypt. The Egyptian Yellow Wagtail breeds in or at the edge of wetlands and therefore has rather narrow habitat requirements – which are met at Burullus. Five rare species and subspecies occur at Lake Burullus (Goodman *et al.* (1989): Montagu's Harrier *Circus pygargus*, Cuckoo *Cuculus canorus canorus*, Bar-tailed Godwit *Limosa lapponica lapponica*, Pied Avocet *Recurvirostra avosetta* and Jack Snipe *Lymnocryptes minimus*.Two of the bird species occurring in Burullus Wetland are globally threatened: Lesser Kestrel *Falco naumanni naumanni* and Ferruginous Duck *Aythya nyroca*.

A total of 15 mammal species have been recorded from Burullus Wetland. Of these, only one species (Flower's shrew, *Crocidura floweri*) is rare and endemic to Egypt. According to the status categories set out by IUCN, two species (*Canis aureus* and *Felis chaus nilotica*) are cosidered vulnerable (Basuony 2000).

1.7.3. Saprotrophs

The aquatic bacteria and fungi are distributed throughout the rivers, ponds and lakes, but they are especially abundant in the mud-water interface along the bottom where bodies of plants and animals accumulate (Odum 1971). The available data on both biotic groups in Lake Burullus are too limited; only 3 papers were recently published in 2002 and 2004. The first paper deals with the zoosporic fungi recovered from 3 northern lakes (Edku, Burullus and Manzala) and lake Qaron (Mohmoud & Abou Zeid 2002). The second one was published by El-Hissy *et al.* (2004) on the diversity of zoosporic fungi recovered from the surface water of four lakes including Burullus and Manzala in the north, Qaron in the Mid and Nasser in the south. The third deals with the distribution of some actinomycetes groups in Lake Burullus (Abou-Elela *et al*. 2004). No doubt that this gap of information should be filled taking into account the important biological role of the saprotrophic organisms in the dynamics of aquatic ecosystems.

1.8. BIOTIC RESPONSES TO RECENT ENVIRONMENTAL CHANGES

Birks *et al*. (2001) studied the biotic responses of Lake Burullus to recent environmental changes using short sediment core of one meter depth, which usually represents the last hundred years. This core was classified into three zones. In zone 1 (36 – 66 cm), salt marsh is indicated by abundant Chenopodiaceae pollen (Peglar *et al*. 2001) and *Salicornia europaea* seeds. The water level may have been low before 1900, encouraging the outward spread of reed- and salt marsh. Macrophytes were few and *Azolla nilotica* floated on the surface. Animal remains suggest fresh or brackish water with only periodic marine incursions. The zooplankton and diatom assemblages in this zone also indicate fresh or slightly brackish water (Ramdani *et al*. 2001, Flower *et al*. 2001).

In zone 2 (16 – 36 cm), there is a marked local decrease of reed marsh and salt marsh macrofossil taxa and freshwater animals. However, the pollen record suggests a regional increase in salt marsh vegetation (Peglar *et al*. 2001). *Ruppia* expanded, accompanied by other macrophytes tolerant of brackish water, *Myriophyllum spicatum, Potamogeton pectinatus* and *Najas armata*. Lagoon molluscs, ostracods, and forams showed a major expansion. The abundance of shells in the sediments is reflected in the rise of carbonate from 5% to 20% at the top of zone 2 (Birks *et al*. 2000). The gastropod *Hydrobia musaensis* is characteristic of fresh and brackish water in Lower Egypt (Brown 1994). It is possible that a marine incursion around 1900 raised the water level, resulting in a major ecosystem change.

The brackish water community declined, probably after 1920. Around 1940 (zone 3a: 8 – 16 cm) freshwater influence is indicated by the expansion of freshwater molluscs and animals such as *Plumatella*. Lagoon molluscs and other brackish water animals, particularly ostracods and forams, remained abundant, however, reflecting continued, probably seasonal, marine influence. *Ruppia* and *Typha* may have been encouraged by eutrophication, and greater productivity is also suggested by the increases in fish remains and nereid jaws. Nereids were important members of the recorded benthic fauna in all the Delta lakes (Samaan *et al*. 1989) at least up to 1980. *Corbicula* was reported as the most abundant benthic mollusc in Lake Burullus but *Theodoxus niloticus* was confined to the north central area in 1978 – 1979 (Samaan *et al*. 1989). The gastropod *Melanoides tuberculata*, characteristic of bottom mud in disturbed fresh and brackish lakes (Brown 1994), was frequently recorded living in the core site area in 1978 – 1979 (Samaan *et al*. 1989). *Biomphalaria alexandrina* and *Valvata nilotica* snails are rather intolerant of salinity (Brown 1994) and were present but rare. *Azolla nilotica* became extinct after 1960.

In zone 3b (0 – 8 cm), starting in 1963 (Appleby *et al*. 2001), freshwater influence increased. This coincides with the completion of Aswan High Dam. *Ruppia* was replaced by *Potamogeton pectinatus* is very abundant today. *Typha* marsh continued to expand near the coring site and freshwater animals increased, while brackish taxa declined. The large numbers of freshwater molluscs in the surface sediment reflect their living occurrence in the lake today. The spread of *Biomphalaria* in the Delta after 1965 is documented as it is a major carrier of bilharzia (Brown 1994). Lake Burullus was still brackish as shown by the occurrence of many lagoon mollusca in the surface sediments (Fathi *et al*. 2001). However, pollution and eutrophication have increased since 1965. Pb levels have risen in the top sediment (Birks *et al*. 2000). Increased nutrients are suggested by the occurrence of *Ceratophyllum* and the luxuriant growth of *Potamogeton pectinatus* and *Najas armata*. The diatom assemblage indicates brackish water with relatively stable salinity levels, suggesting that periodic marine influence was reduced (Flower *et al*. 2001). In conclusion, recent changes in Lake Burullus have been smaller than in the other Delta lakes, as a degree of salinity has been maintained. Previous changes in water level and marine influence have caused much larger changes in the lake ecosystem. However, declining water quality possibly threatens the fishing industry on the lake (Birks *et al*. 2000).

1.9. SUMMARY

Burullus Wetland (i.e. Burullus Protectorate Area) is located along the Mediterranean coast in the northern part of Nile Delta. It is bordered from the north by Mediterranean Sea and from south by the agricultural lands of northern Nile Delta. Burullus Wetland belongs administratively to Kafr El-Sheikh Governorate. It lies in a central position between the two branches of Nile: Damietta Branch to the east and Rosetta Branch to the west. The Protectorate includes the entire area of Lake Burullus with numerous islets insides it, as well as the sand bar that separates the lake from the Mediterranean Sea, with a shoreline of about 65 km. The total area of this Protectorate is 460 km^2.

The shoreline of Lake Burullus takes several forms related basically to its formation, origin and evolution. It has an oblong shape extends for a distance of 47 km along NE-SW axis. The width of the lake from north to south varies from site to the other. The western sector has the least width which does not exceed 5 km, then its increases in the middle sector to reach an average of 11 km. Lake Burullus had lost about 49% of its size along 112 years (from 1092 km^2 in 1801 to 556 km^2 in 1913), and about 62.5% by 1997 (410 km^2).

Lake Burullus is a shallow lake with a depth varies between 40 cm near the shores and 200 cm near the sea outlet (Boughaz El-Burullus). The field studies using remote sensing indicated that the deepest parts lay in the middle sector of the lake where the depth reaches 200 cm, and also the southern parts of the western sector (west of Doshimi islet). The eastern sector is the shallowest, where the depth does not exceed 20 cm near the shore, but increases westwards until it reaches about 70 cm.

The main basin of Lake Burullus is classified into three sectors: eastern, middle and western, each one of them has some sort of homogeneity in the geomorphological, hydrological and biological characteristics. The islets scattered in the lake form physical isolations between these sectors.

The marine bar (i.e. sand bar) of Lake Burullus is the zone that separates the Mediterranean coast in the north from the lake shore in the south. It covers an area of about 165 km^2. Although the surface of this bar is relatively flat, but it has different geomorphological features that had been formed upon it as a result of the evolution and development of the geomorphological processes (sand flats, sand dunes, sand hillocks, salt marshes, tidal flats and sea outlet). Some of these features were related to the sedimentation process such as sand flats, sand dunes and sand hillocks; and some others were due to change of sea level like salt marshes and tidal flats.

Many islets with different sizes are distributed in Lake Burullus. Due to the continuing the effects of the geomorphological processes (e.g. sedimentation, erosion and water flooding), the number, size, dimensions and locations of these islets change from time to time. They move from their locations or merge together when become close to each other. The recent number is 30 islets that take different shapes such as longitudinal (e.g. Dibar), circular or oval (e.g. El-Zanka), triangular (e.g. Doshimi), arc shape (e.g. Shishet Al-Agoza), curved (e.g. El-Zoaya) and irregular (e.g. Absak).

The northern part of Nile Delta belongs to the Mediterranean arid region. The climatic conditions are warm summer (20 to 30 °C) and mild winter (10 to 20 °C). The aridity index (P/PET: where P is the annual precipitation and PET is the potential evapo-transpiration) ranges between 0.03 and 0.2 at the north Delta (arid region), and less than 0.03 at the south (hyperarid region). In general, the distribution of the mean annual rainfall in this region shows a maximum close to the Mediterranean coast (190.8 mm/year at Rosetta) and then decreases rapidly toward the south. Most of the rain falls during winter (≥ 80%), and only less 10% falls during spring.

Results of the annual water balance indicate that the drainage water contributes about 97 % (3.9 billion m^3), while rainfall contributes less than 2% (77.4 million m^3) and groundwater less than 1% of the total water resources in the lake ecosystem. On the other hand, evaporation losses represent about 16% of the total water resources in the lake (646.7 million m^3), while the drainage system discharges, about 3.2 billion m^3 to the sea through the lake (it represents, in addition to the change of storage in the reservoir, about 84% of the total water resources in this system).

Six major habitats are recognized in Burullus Wetland: salt marshes, sand formations, lake cuts, drains, the lake and islets. Salt marshes extend along the marine bar of Lake Burullus with an area approximates 40% of the total area of the bar (6% in the eastern part, and 34% in the western part). Three types of sand formations cover the surface of the marine bar of lake Burullus: sheets (or flats), hillocks and dunes. Lake cuts represent the recent lands that resulted after the drying process that took place along the shores of Lake Burullus, particularly the outermost western and eastern fringes. The drains, as a major habitat, were classified into four microhabitats (i.e. zones): terraces, slopes, water-edge and open water. The lake proper is classified into two habitats: lake shore and open water.

A total of 197 species of vascular plants have been recorded from Burullus Wetland (100 annuals and 97 perennials) including 11 hydrophytes (the most common is *Potamogeton pectinatus*) and one fern (*Azolla ficliculoides*). The most common of all these species is the common reed *Phragmites australis*. Some 226 algal species were recorded: 125 Bacillariophytes (Diatoms), 56 Chlorophytes, 39 Cyanophytes, 2 Euglenophytes, 2 Dinophytes, one cryptophyte, and one Rhodophyte. The zooplankton community of the lake was estimated as 90 species distributed as follows: 26 species of Copepoda, 7 of Cladocera, 26 of Rotifera, and 10 of Protozoa constitute collectively about 85% of the total zooplankton. The biotic community includes also 127 species of the terrestrial invertebrates, 25 species of fishes, 22 of reptiles, 112 of birds and 15 of mammals.

1.10. REFERENCES

Abdel Rahman, S.I. & Sadek, S.A. 1995. The application of multispectral remote sensing to the assessment of North Nile Delta, Egypt. Academy of Scientific Research and Technology, Cairo.

Aboel Ezz, S.M. 1995. Zooplankton of Lake Burullus (Egypt)). Bull. Nat. Inst. of Ocean. & Fish., 21(1) 233-261.

Abou-Elela, G., Ghanem, N. & Okbah, M. 2004. Distribution of some actinomycetes groups in Burullus Lake. Bull. Fac. Sci., Assiut Univ., In Press.

Ahmed, D.D. 2003. Current situation of the flora and vegetation of Nile Delta region. M. Sc. Thesis, Faculty of Science, Tanta University, 321 pp.

Anonymous 1980. Climatic Normals for the Arab Republic of Egypt up to 1975. Ministry of Civil Aviation: Meteorological Authority. General Organization for Governmental Printing Offices, Cairo, 433 pp.

Anonymous 2002. Site diagnosis for Burullus Protected Area: Concise Report. EEAA, MedWetCoast, Cairo, 41 pp.

Appleby, P.; Birks, H.; Flower, R.; Rose, N.; Peglar, S.; Ramdani, M.; Kraiem, M. & Fathi, A. 2001. Radiometrically determined dates and sedimentation rates for recent sediments in nine North African wetland lakes (the CASSARINA Project). Aquat. Ecol., 35: 347-367.

Balba, A.M. 1981. Sources and protection of soil and water of the Mediterranean Coast of Egypt. Advances in Soil and Water Research, Alexandria, 6, 73 pp.

Basuony, M.I. 2000. Ecological Survey of Burullus Nature Protectorate: Mammals. EEAA, MedWetCoast, Cairo,

Ben Menachem, A. 1979. Earthquake catalogue for the Middle East (92 BC-1980 AD). Boll. Geofisica Teor. Applicata, 21: 245-313.

Birks, H.; Peglar, S. & Bjune, A. 2000. Lithostratigraphy and biostratigraphy (pollen, macrofossiles, molluscs, ostracods) of the secondary sediment cores from the CASSARINA sites, and heavy metal stratigraphy of the primary cores. CASSARINA Project, Final Report of the Bergen Partner (unpublished).

Birks, H.; Peglar, S.; Boomer, I.; Flower, R.; Ramdani, M.; Appleby, P.; Bjune, A.; Patrick, S.; Kraiem, M.; Fathi, A. & Abdelzaher, H. 2001. Palaeolimnological responses of nine North African lakes in the CASSARINA Project to recent environmental changes and human impact detected by plant macrofosil, pollen, and faunal analyses. Aquat. Ecol., 35: 405-430.

Brown, D.S. 1994. Freshwater snails of Africa and their medicinal importance, 2nd edition. Taylor & Francis, London.

Butzer, K.W. 1976. Early hydraulic civilization in Egypt, a study in cultural ecology. The University of Chicago Press, Chicago, 139 pp.

Coutellier, V. & Stanley, D.J. 1987. Late Quaternary stratigraphy and paleogeography of the eastern Nile Delta, Egypt. Marine Geology, 27: 257-275.

El-Bayomi, G.M. 1999. Lake Burullus: a geomorphological study. Ph.D. Thesis, Fac. Arts, Helwan Univ. (In Arabic), 328 pp.

El-Hennawy, H.K. 2000. El-Burullus Protectorate: Archnida (Spiders & Scorpions). EEAA, MedWetCoast, Cairo, 9 pp.

El-Hissy, F., Ali, E. & Abdel-Raheem, A. 2004. Diversity of zoosporic fungi recovered from the surface water of four Egyptian lakes. Ecohydrology & Hydrobiology, 4 (1): 77-84.

El-Shabrawy, G.M. 2002. Ecological survey of Burullus Nature Protectorate: Zooplankton. EEAA, MedWetCoast, Cairo, 50 pp.

El-Sherif, Z.M. 1993. Phytoplankton standing crop, diversity and statistical multispecies analysis in Lake Burollus (Egypt). Bull. Nat Inst. Oceanogr. Fish., 19: 213-233.

El-Shinnawy, I. 2002. Al-Burullus Wetland's hydrological study. MedWetCoast, Global Environmental Facility (GEF) & Egyptian Environmental Affairs Agency (EEAA), Cairo.

Emberger, L. 1955. Une classification biogéographique des climats. Faculté de Science, Université de Montpellier, 7: 3-43.

Emery, K.O.; Aubrey, D.G. & Goldsmith, V. 1988. Coastal neo-tectonics of the Mediterranean from tide-gauge levels. Marine Geology, 81: 41-52.

Fathi, A.; Abdelzaher, H.; Flower, R.; Ramdani, M.; & Kraiem, M. 2001. Phytoplankton communities of North wetland lakes: the CASSARINA Project. Aquat. Ecol., 35: 303-318.

Flower, R.; Dobinson, S.; Ramdani, M.; Kraiem, M.; Ben Hamza, C.; Fathi, A.; Abdelzaher, H.; Birks, H.; Appleby, P.; Less, J.; Shilland, E. & Parick, S.T. 2001. Recent environmental change in North African wetland lakes: diatom and other stratigraphic evidence from nine CASSARINA sites. Aquat. Ecol., 35: 369-388.

Frihy, O., 1988. Nile Delta shoreline changes: aerial photographic study of a 28-year period. J. Coastal Research, 4: 597-606.

Frihy, O.; Khafagy, A.; El Fishawy, N. & Fanos, A.M. 1990. Nile Delta coast identification and evaluation of offshore sand sources for beach nourishment. In: Quelennec, R.E., Eroulani, E. and Michon, G. (eds), Littoral 1990, Eurocoast, Marseille, 724-728.

Goodman, S. M.; Meininger, P. L.; Baha El-Din, S. M.; Hobbs, J. J. & Mullie, W. C. 1989. The Birds of Egypt. Oxford University Press, Oxford, 548 pp.

Griffiths, J.F. 1972. Climate of Africa. In "World Survey of Climatology" Vol. 10, The Netherlands.

Guirguis, S.K.; Hassan, H.M.; El-Raey, M.E. & Hussain, M.M.A. 1996. Multi-temporal change of Lake Burullus, Egypt, from 1983 to 1991. Int. J. Remote Sensing, 17: 2915 - 2921.

Hussain, M.M. 1994. Remote sensing of some environmental conditions at Lake Burullus. M. Sc. Thesis, Institute of Graduate Studies and Research, University of Alexandria, 208 pp.

Inman, D.L. & Jenkins, S.A. 1984. The Nile littoral cell and man's impact on the coastal littoral zone in the SE Mediterranean. Proc. 17th Int. Coastal Eng. Conf., ASCE/Sydney, 1600-1617.

Khalil, M.T. & El-Dawy, F.A. 2002. Ecological survey of Burullus Nature Protectorate: fishes and fisheries. EEAA, MedWetCoast, Cairo.

Klemas, V. & Abdel Kader, A.M. 1982. Remote sensing of coastal processes with emphasis on the Nile Delta. Proc. Int. Symp. On Remote Sensing of Envir., Cairo, 27 pp.

Mahmoud, Y.A. & Abou Zeid, A.M. 2002. Zoosporic fungi isolated from four lakes and the uptake of radioactive waste. Mycology, 30(2): 76-81.

Manohar, M.I. 1981. Coastal processes at the Nile Delta coast. Shore and Beaches, 49: 8-15.

Metwally, S.M. 2000. Burullus Lake: surveying of invertebrates. EEAA, MedWetCoast, Cairo, 15 pp.

Odum, E. 1971. Fundamentals of Ecology. W.B. Saunders Company, Philadephia, 574 pp.

Peglar, S.; Birks, H.H.; Briks, H.J.; Appleby, P.; Fathi, A.; Flower, R.; Kraiem, M.; Patrick, S.; & Ramdani, M. 2001. Terrestrial pollen record of recent land-use changes around nine North African lakes in the CASSARINA Project. Aqut. Ecol., 35: 281-302.

Ramdani, M.; Elkhiati, N.; Flower, R.; Birks, H.; Kraiem, M.; Fathi, A. & Patrick, S. 2001. Open water zooplankton communities in North African wetland lakes: the CASSARINA Project. Aquat. Ecol., 35: 319-333.

Samaan, A.A.; El-Ayouty, E.Y. & El-Sherif, Z.M. 1988. Epiphytes growing on *Potamogeton pectinatus* L. in Lake Burullus (Egypt). Bull. Inst. Ocean. Fish., 14: 133-139.

Samaan, A.; Ghobashy, A. & Abul-Ezz, S. 1989. The benthic fauna of Lake Burullus. II: distribution and periodicity of different species. Bull. Nat. Inst. Oceanogr. & Fish., 15: 19-29.

Sestini, G. 1989. Nile Delta depositional environments and geological history. In: " Sites and Traps for Fossil Fuels" Whateley, K.G. & Pikering, K.T. (eds.), Deltas. Geol. Society Spec. Publs., 41: 99-127, Blackwell Scientific Publication, Oxford.

Sestini, G. 1991. Implications of climatic changes for the Nile Delta. In: " Climatic Change and the Mediterranean" Jeftic, L., Milliman, J.D. & Sestini, G. (eds.): pp. 535-601, E. Arnold, London.

Shaltout, K.H. & Al-Sodany, Y. M. 2000. Phytoecology of Lake Burullus Site. MedWetCoast, Global Environmental Facility (GEF) & Egyptian Environmental Affairs Agency (EEAA), Cairo.

Smith, S.E. & Abdel Kader, A. 1988. Coastal erosion along the Egyptian Delta. J. Coastal Research, 4: 245-255.

Stanley, D.I. 1988. Subsidence in the northeastern Nile Delta: rapid rates, possible causes and consequences. Science, 240: 497-500.

Summerhayes, C.; Sestini G.; Misdrop, R. & Marks, N. 1978. Nile Delta: nature and evaluation of continental shelf sediment system. Marine Geology, 24: 37-47.

Tetratech, 1986. Shore protection masterplan for the Nile Delta. Report to Shore Protection Authority, Ministry of Irrigation, Cairo.

Tousson, O. 1934. Memoire sur les ancienne branches du Nil. Mem de la Soc. Geogr. d´Egypte, Cairo, 4, 144 pp.

UNDP/UNESCO 1978. Arab Republic of Egypt: coastal protection studies. UNDP/EGY/73/063 Final Report, FNR/SC/OSP/78/230.

UNESCO 1977. Map of the World distribution of arid regions. MAB Technical Notes 7.