LIMNOLOGY OF THE RIVER NILE

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Summary

The Nile basin covers an area of over 3.12 million km^2, and a length of about 6,800 km, being the longest in the world. The basin extends from 4^o S to 31^o N, stretching over different geographical, climatological and topographical regions**.** The hydrographical and hydrological characteristics vary greatly over the basin with abundant rainfall in the headwaters and arid conditions in Sudan and Egypt**.** Fluctuations in both of abiotic and biotic characteristic features of the Nile water are discussed. The river and its lakes are important fisheries resources; navigable waterways; the various dams generate large

amounts of power, and hold irrigation resources for increasing agricultural production. Newly discovered hydrocarbon deposits are under development in at least three zones of the Basin. This may contribute to river pollution. The full utilization of the water resources of the Nile Basin is an essential prerequisite for the development of its agricultural and industrial potential, besides being basic to the survival of human, plant, and animal life.

1. Introduction

Water is an important resource for sustaining life. The uses of water are manifold, and include domestic uses, industrial uses such as the production of hydroelectricity, irrigation and animal husbandry. Lotic (moving) and lentic (stagnant) water such as rivers and lakes serve as reservoirs for waste disposal. Water security around the world continues to be threatened by population explosion and the rising standards of living, confirming that water is finite and cannot withstand all pressures to its quality, quantity and life-giving purposes. The intensified use of the world's water resources in the last 100 years has been hastened by technical developments, expansion of energy capture systems and the subtle and direct consequences of population growth at a scale unprecedented in human history. These developments occur amidst the natural variability in soil types, river drainage networks, and climate change among the world's watersheds. Rivers are characterized by a uni-directional current with a relatively high average flow velocity ranging from 0.1 to 1 m s^{-1}. River flow is highly variable in time, depending on the climatic situation and the drainage pattern.

The Nile basin covers an area of over 3.12 million km^2, and a length of about 6800 km, being the longest in the world. The basin extends from 4^o S to 31^o N, stretching over different geographical, climatological and topographical regions. Besides the two plateaus in Ethiopia and around the equatorial lakes (Victoria, Albert, Kyoga, Edward), the Nile Basin can be considered as a large flat plain, in particular the White Nile sub-basin. The Nile Basin is one of the world's most famous river basins. There is a fascination about the Nile River which has captured human imagination throughout history. Some five thousand years ago a great civilization emerged depending on the river and its annual flooding cycle. Unlike other world rivers, the Nile is marked by the following characteristics. It passes from south to north; The Nile covers more than 35 latitudes stretching between its sources at the Equatorial Lakes and its mouth in the Mediterranean sea; The Nile water flows into a distance of 2700 kilometers between Atbara River and Mediterranean Sea without receiving any tributaries; The River Nile yield fluctuates from one year to another, the lowest recorded yield reached 42 billion cubic meters, while the highest amounted yield reached 150 billion cubic meters. The Niles average annual yield throughout the twentieth century was nearly 84 billion cubic meters at Aswan. In spite of its great length and large drainage basin (3,120,000 km^2, or about 10% of Africa, and affecting 10 nations), it carriers relatively little water. Yearly flows over the past century ranged from a low of 42 km^3 in the drought year of 1984 to a high of 120 km^3 for 1916 (Hulme, 1994). This relatively low flow for such a long river is because no water is added to it north of its confluence with the Atbara River, and much is lost by evaporation. Most other great rivers join with other large streams as they approach the sea, joining their waters into an ever-swelling stream. Instead, the

Nile wanders unaided through the largest and most arid region on earth, the Sahara Desert.

The hydrographical and hydrological characteristics vary greatly over the basin with abundant rainfall in the headwaters and arid conditions in Sudan and Egypt. Therefore, although the watershed is large, the portion contributing to stream flow is almost half of the entire basin (only $1.6x10^6$ km^2) due to the fact that north of 18° N latitude, rainfall is almost zero.

Precipitation increases towards the headwaters to about 1,200 to 1,600 mm yr^{-1} on the Ethiopian Plateau and in the region of the Equatorial lakes: Victoria, Albert, Kyoga, and Edward (Mohamed *et al*., 2005). The seasonal pattern of rainfall follows the Inter-Tropical Convergence Zone (ITCZ), where the dry northeast winds meet the wet southwest winds and are forced upward causing water vapor to condense.

The ITCZ follows the area of most intense solar heating and warmest surface temperature and reaches the northerly position of Ethiopian Plateau by late July. The southward shift of the ITCZ results in the retreat of the rainy season towards the central part of the basin after October. Therefore, the monthly distribution of precipitation over the basin shows one single but long wet season over the Ethiopian Plateau and two rainy seasons over the Equatorial Lakes Plateau (Mohamed *et al*., 2005).

2. Watershed of the Nile River

The Nile River, with an estimated length of over 6800 km, is the longest river flowing from south to north over 35 degrees of latitude (FAO, 1997). It was long thought that Lake Victoria was its ultimate source, the lake itself is fed by rivers that arise further south, the most important of which is the Kagera. Until recently, it was believed that its tributary, the Luvironza that springs in Tanzania at ca 4° S was the Nile's ultimate source.

The Nile is the only permanent river that manages to cross the Sahara, the largest desert in the world, and reach the Mediterranean Sea, yet its early beginnings are in a montane equatorial climate and it traverses a series of several climatic zones before reaching its Delta. Its basin orientation is unique among the major rivers in the world in that it runs almost perfectly from south to north, discharging at 31° N.

Each climate zone that it crosses shows considerable variability in precipitation and run-off (Camberlin, 2009), but over more than half its length it receives less than 150 mm of rain per annum. Its basin is relatively narrow and small (3.12×10^6 km^2) compared to that of most other large rivers of the world (the Congo, ca 4×10^6 km^2 according to Bailey (1986); the Amazon ca 7×10^6 km^2 according to Sioli (1984)).

The Nile basin covers most of Egypt and the Sudan, one third of Ethiopia, the whole of Uganda, and parts of Kenya, Tanzania, Congo, Rwanda and Burundi (Tudorancea & Taylor, 2002). Conventionally, the Nile is divided into a number of sub-basins: the White or Equatorial Nile and its source lakes, the Blue Nile and Lake Tana, and the

Main Nile. The River Atbara is often considered a separate, although small, sub-basin (Fig. 1).

Figure 1. The Nile Basin (Based on MWRI, 2005)
MWRI (Ministry of Water Resources and Irrigation), 2005. National water resources plan for Egypt- 2017, Ministry of Water Resources and Irrigation, Cairo

According to Eltahir (2004) the component parts that make up the Nile River's watershed are:

(1) The Lake Victoria Basin
(2) East African Lakes south of Lake Victoria
(3) The Bahr el Jebel and the Sudd region
(4) The Bahr el Ghazal Basin
(5) The Sobat Basin and the Machar Marshes
(6) The White Nile south of Malakal
(7) The Blue Nile and its Tributaries
(8) The Atbara and Main Nile to Wadi Halfa
(9) The Main Nile in Egypt.

The Lake Victoria Basin has an annual rainfall of 1151 mm/yr contributing to approximately 122 km^3/yr of water to the flow. Its tributaries contribute approximately 276 mm/yr or 22.4 km^3/yr, while evaporation accounts for 1116 mm or 107 km^3/yr. The resulting outflow from this system is 311 mm or 39.8 km^3/yr. This provides a relatively steady base flow for the river. The East African Lakes below Lake Victoria include

Lake Albert, Lake Kyoga, and Lake Edward. Rainfall contributes to about 10.3 km^3/yr, while its tributaries contribute about 10.6 km^3/yr and 16.3 km^3/yr is evaporated. Thus, the total resulting outflow is approximately 45 km^3/yr. The outflow contribution to the Nile in this part is dominated by Lake Victoria. This region historically had also a dramatic variation in flow level.

The Bahr el Jebel and the Sudd receives an annual rainfall of 871 mm while evaporation in the area is much higher at 2150 mm. This part of Nile reaches is the most complex to having many seasonal inflows. The high levels of evaporation and transpiration come from the wide distribution of the river area of the spreading water and from the large amounts of vegetation (e.g. *Papyrus*). The Jonglei Canal was conceived in order to provide a more direct way of the water traveling through this region in order to stem the evaporation losses incurred in this area.

The Bahr el Ghazal Basin outflow to the White Nile is almost negligible with amounts less than 3%. The upper basins have relatively high rainfall, but the river flow spills over into the many flood plain areas, resulting in almost total loss to evaporation. The sediment loads of these rivers are greater than lake-fed Bahr el Jebel and they have a higher potential for alluvial channels.

The Sobat Basin and the Machar Marshes are also a highly complex area. Most of the runoff develops in the mountains and foothills of Ethiopia. Pibor drains a wide area of plains, but only contributes significantly in times of high rainfall. These reaches also provide about half of the flow for the White Nile, and thus have relatively the same outflow as the Sudd.

The White Nile north of Malakal drops 13 m over a distance of 840 km. The tributary inflows are sporadic and small while flood plain storage results in delay of outflow and increased loss to evaporation. The Jebel Aulia dam further raised upstream river levels after June 1937. Irrigation and evaporation have led to increased losses.

The Blue Nile and its tributaries provide the greater part of flow of the Main Nile, approximated at 60%. Its reaches begin in the Ethiopian Plateau at elevations averaging 2000-3000 m, peaking at 4000 m. The terrain consists of very broken and hilly, grassy uplands, swamp valleys, and scattered deciduous forests.

The Blue Nile leaves and travels through a series of cataracts through the Sudanese plains, sloping westward from about 700 m height. The region it passes through in the plains are covered with savannah or thorn scrub. Its major tributaries are the Rahad and the Dinder. Upon its length are the Roseires Dam (2.4 km^2) and Sennar Dam (0.5 km^2). It is the single largest contributor to sediments in the Main Nile, averaging at 140 million tons per year.

The Atbara and Main Nile to Wadi Halfa is the convergence of White Nile and the Blue Nile at Khartoum. The river Atbara is the only major tributary that exists after Khartoum. The river Atbara drains northern Ethiopia (68,800 km^2) and the mountains north of Lake Tana (31,400 km^2). Most of its terrain consists of arid plains dotted with low hills and rocky outcrops.

The Main Nile in Egypt is the last major stretch of the Nile before entering the Mediterranean. There are no more flows generated below the Atbara confluence (Eltahir, 2004). The Eastern Desert wadis in Egypt and northern Sudan used to feed the Nile in the former Pluvial periods, but at present they only provide insignificant torrents once every few years.

3. Climate of the Nile Basin

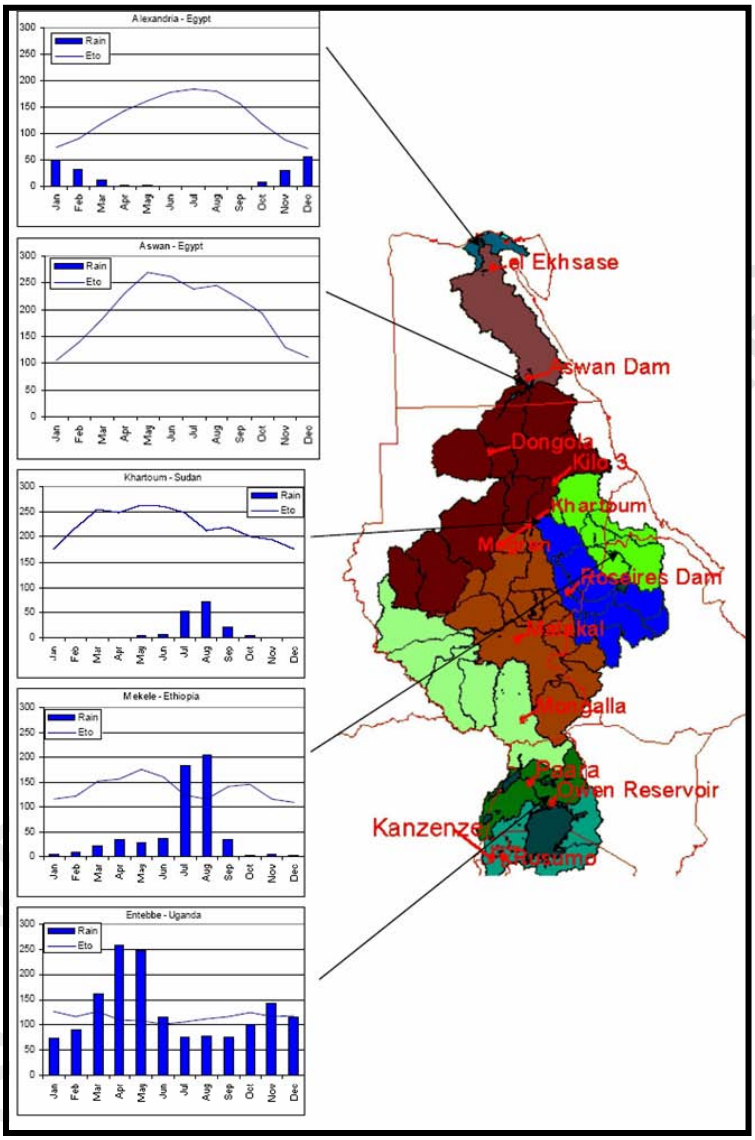

Figure 2: Rainfall and Evaporation for selected towns in the Nile basin. (Source, Olet et al., 2006)
Olet I E, Koen R.., Mansfeld M., Smit R. and Walsum P. (2006). Baseline Assessment Report for the Nile River Basin. Report of the NeWater project. New Approaches to Adaptive Water Management under Uncertainty *www.newater.info.*

Climate characteristics and vegetation cover in the basin are closely correlated with the amount of precipitation (Fig. 2). Precipitation is to a large extent governed by the movement of the Inter-Tropical Convergence Zone (ITCZ) and the land topography. The main climate zones to be distinguished from North to South are: The Mediterranean climate, a narrow strip around the Nile Delta, followed by the very dry Sahara desert climate down to around 16° N, then a narrow strip of the semi desert climate, followed by the wide Savannah climate (deciduous and tropical Savannah) down to the southern border of Sudan. On the extreme south and southwestern boundary of the basin (around Lake Victoria) tropical and rainforest climates are found. In general, precipitation increases southward, and with altitude (note the curvature of the rain isohyets parallel to the Ethiopian Plateau). Precipitation is virtually zero in the Sahara desert, and increases southward to about 1200–1600 mm/yr on the Ethiopian and Equatorial Lakes Plateaus.

Two oceanic sources supply the atmospheric moisture over the Nile basin; the Atlantic and the Indian Oceans. The seasonal pattern of rainfall in the basin follows the movement of the ITCZ. The ITCZ is formed where the dry northeast winds meet the wet southwest winds. As these winds converge, moist air is forced upward, causing water vapor to condense (Mohamed *et al*., 2005). El-Tom (1975) claimed that the highest precipitation falls in a region 300 to 600 km south of the surface position of the ITCZ in association with an upper tropospheric tropical easterly jet stream. The ITCZ moves seasonally, drawn toward the area of most intense solar heating or warmest surface temperatures. Normally by late August/early September, it reaches its most northerly position up to 20° N. Moist air from both the Equatorial Atlantic and the Indian Ocean flows inland and encounters topographic barriers over the Ethiopian Plateau that lead to intense precipitation, responsible for the strongly seasonal discharge pattern of the Blue Nile. The retreat of the rainy season in the central part of the basin from Oct onwards is characterized by a southward shift of the ITCZ (following the migration of the overhead sun), and the disappearance of the tropical easterly jet in the upper troposphere. The Inter-annual variability of the Nile precipitation is determined by several factors, of which the ENSO and the sea surface temperature over both the Indian and Atlantic Oceans are claimed to be the most dominant (Nicholson, 1996). Camberlin (1997) suggested that monsoon activity over India is a major trigger for the July to September rainfall variability in the East African highlands.

4. Hydrology and Limnology of the Nile Basin

The Nile starts from Lake Victoria (in fact from further south at the Kagera River feeding the lake) and travels north, receiving water from numerous streams and lakes on both sides. In the Sudd, Region, where it takes the name of Bahr el Jebel, the river spills its banks, creating huge swamps where more than half of the river inflow is evaporated. The emerging soils after retreat of water are called "toich" lands, good for grazing. At Lake No, east of Malakal, it is joined by the Bahr el Ghazal River, draining the southwestern ridges and plains bordering the Congo Basin watershed. The Bahr el Ghazal is a huge basin subject to high rainfall over the upper catchments, but with negligible contribution to the Nile flows. Almost all its gauged inflow (12 Gm^3) is evaporated in the central Bahr el Ghazal swamps. The Sobat tributary originating from the Ethiopian Plateau and partly from the plains east of the main river, joins Bahr el Jebel at Malakal. Downstream this confluence (where the river is called the White Nile), it travels downstream northwards in a mild slope up to the confluence with the Blue Nile at Khartoum. The Blue Nile originates from Lake Tana located on the Ethiopian

Plateau at 1800 masl, and in a region of high summer rainfall (1500 mm/yr). The last main tributary of the Nile before it ends up at the Mediterranean Sea is the Atbara River, also originating from the Ethiopian Plateau. The flows from the Ethiopian Plateau are quite seasonal and with a more rapid response to climatic variability, compared to the flow of the White Nile coming from the Equatorial lakes. Further details on the Nile hydrology can be found in Shahin (1985), and Sutcliffe & Parks (1999). The relative contribution to the mean annual Nile water at Aswan of 84.1 Gm^3 is approximately 4/7ths from the Blue Nile, 2/7ths from the White Nile (of which 1/7th from the Sobat), and $1/7^{th}$ from the Atbara River. So the Ethiopian catchments (Sobat, Blue Nile and Atbara River) contribute about 6/7ths of the Nile water resources at Aswan. Ten countries share the Nile River Basin: Burundi, Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda*. The percentage area of the Nile catchments within each country is: 0.4, 0.7, 10.5, 0.8, 11.7, 1.5, 0.6, 63.6, 2.7, and 7.4%, respectively. The Nile water is vital to the dry countries downstream (Egypt and Sudan), where historically intensive irrigation development exists, and still continues, imposing increasing demands on the Nile water. The upstream countries are known to rely less on the Nile waters, than on rainwater (Mohamed *et al*., 2005).

5. Temperature

Temperature affects the speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites, and other pathogens interact with aquatic residents. Over most of the Nile a prolonged or seasonal thermal stratification is absent, due to wind- and current-induced mixing in shallow waters. Among the headwater lakes, this is applicable to the relatively shallow L. Tana (Morandini, 1940) and L. George (Viner & Smith, 1973). Though the vertical temperature differences are small; an annual cycle of thermal stratification can be distinguished in Lake Victoria (Fish, 1957). Thermal stratification appears briefly and irregularly in the downstream reservoir at Roseires (Hammerton, 1972 a, b), but is annual and prolonged in Lake Nasser-Nubia (Entz 1976) where it is eliminated by winter cooling and the entry of new flood water. Prolonged stratification is lacking in the shallower reservoirs of Gebel (= Jebel) Aulia and Sennar in the Sudan. The physical and chemical characteristic features of the Nile water are shown in Table (1) below.

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Bibliography

Aboul-Ezz S. M. (1988). Periodicity and distribution of bottom fauna in the hypersaline Bardawil lagoon. *Bulletin of the National Institute of Oceanography and Fisheries of Egypt* 14(1): 159 – 174. [This paper illustrates the standing crop and community composition of the lake bottom fauna].

Ali M.H, (2006). Water properties. In Shaltout and Khalil (eds) *Bardawil lagoon*. EEAA publication, 604 pp. [A multi-author monographs book, covering all aspects of the lagoon, hydrology and biodiversity]

Andreini, M., van de Giesen, N.C., van Edig, A., Fosu, M., and Andah, W. (2000). Volta Basin Water Valance; ZEF-Discussion Papers on Development Policy, Number 21. Bonn, Germany. Center for Development Research. [This paper is a preliminary exploration of some of the Volta River Basin hydrologic data].

Antwi, L. (1990). Limno-chemistry of Volta Lake 25 years after its formation. Technical Report of the Institute of Aquatic Biology, Accra, Ghana: 11 p. [This report presents essential aspects of abiotic variables of the lake in a comprehensive way]

Beaugrand, G. and Reid, P.C. (2003). Long-term changes in phytoplankton, zooplankton and salmon related to climate. *Global Change Biology* 9: 801-817. [This is a complete guide of the effects of climatic changes on aquatic ecosystem]

Bene, C. (2007). Diagnostic study of the Volta Basin fisheries. Part 1 - Overview of the fisheries resources. Volta Basin Focal Project Report No 6. WorldFish Center Regional Offices for Africa and West Asia, Cairo Egypt, and CPWF, Colombo, Sri Lanka, 31 p. [The report presenting a background of the fisheries resources in the Volta Basin essentially from a biological perspective].

Bullock, A., Gilman, K., McCartney, M., Waughray, D., Blyth, K., and Andrews, A. (1998). Hydrological strategy to develop and manage African wetland resources for sustainable agricultural use. Wetland Characterization and Classification for Sustainable Agricultural Development. FAO/SAFR, Rome. www.fao.org. [This is one of a series of key publications which review different aspects of African wetlands at the continental scale, which yield valuable information and data]

Cantrell, M.A. (1988). Effect of lake level fluctuations on the habitats of benthic invertebrates in a shallow tropical lake. *Hydrobiologia* 158: 125-131.[This review the effect of various phases of Chilwa lake on benthic invertebrates and the possible reasons for the record fish catches which coincide with high lake levels]

Chi-Bonnardel, Regine Van (1973*). Atlas of Africa. Institut geographique national (France)*. Paris: Editions Jeune Afrique, pp.335. [An excellent and comprehensive illustrated history of Africa].

Cohen, A.S., Kaufman, L. and Ogutu-Ohwayo, R. (1996). Anthropogenic threats, impacts and conservation strategies in the African Great, Lakes: A review. In: The Limnology, Climatology and Paleoclimatology of the East African Lakes. Johnson, T.C. and Odada, E. (eds). Gordon and Breach, Toronto, pp. 575-624. [This is a widely used textbook dealing with different aspects of ecology of East African Lakes].

Convention on Biological Diversity (CDB). (2005). Inland Waters Biodiversity Introduction. Secretariat of the Convention on Biological Diversity, Montreal. [This report provides an overview of the current information on inland water ecosystems and their dependent species in order to identify information gaps and needs that should be addressed by the CBD programme of work on the biological diversity of inland water ecosystems].

Coulter, G.W. (1991). *Lake Tanganyika and its Life*. 1st edition. Oxford University Press, New York. A very useful compilation of different subjects on Lake Tanganyika .

Coulter, G. (1994). Speciation and fluctuating environments, with reference to ancient East African Lakes, in K. Martens, B. Goddeeris and G. Coulter (eds.), Speciation in Ancient Lakes, *Advances in Limnology* 44:127-137. [This research papers provides a comprehensive coverage of the large lakes of the African Rift System, touching on climate, limnology, palaeoclimatology, sedimentation processes, biodiversity, and management issues of these lakes].

Coulter, G.W. (1994). Lake Tanganyika. In: Speciation in Ancient Lakes. Edited by Martens, K., Goddeeris, B. and Coulter, G. *Archiv fur Hydrobiologie* 44: 13-18. [This research papers provides a comprehensive coverage of the large lakes of the African Rift System, touching on climate, limnology, palaeoclimatology, sedimentation processes, biodiversity, and management issues of these lakes].

Davies, B.R. and Day, J. (1998). *Vanishing Waters*. University of Cape Town Press, Cape Town. 487pp. [This book contains the most up-to-date information on conservation and usage, rivers, dams and wetlands. The book is fully illustrated with line-drawings, maps, tables, graphs and charts].

De Jonge, V. N., Elliot M. and Orive, E. (2002). Causes, historical development, effects and future challenges of a common environmental problem: eutrophication. *Hydrobiologia* 475–476: 1–19. [This presents approaches to assess criteria to reduce eutrophication back to a level acceptable to both humans and nature].

Dudgeon D, Arthington A.H, Gessner M.O, Kawabata Z.I, Knowler D.J, Leveque C, Naiman R.J, Prieur-Richard A.H, Soto D, Stiassny M.L.J and Sullivan CA. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews*, 81: 163–182. [This is a case study discussed a wise principle of co-existence between man and nature, even if it has to be a modified kind of man and a modified kind of nature].

Dugan, P.J. (1992). Wetland management: a critical issue for conservation in Africa. In: Matiza, T., Chabwela, H.N. (Eds.), Wetlands Management: A Critical Issue for Conservation in Africa, Wetlands Conservation Conference for Southern Africa. IUCN, Gland, pp. 1 –8. [This paper illustrates the magnitude of the economic value of global wetlands in addition to their biodiversity, scientific value, climate regulation, potential tourism, socio-cultural and other important wetland values].

ECA, (2000). Transboundary River/Lake Basin Water Development in Africa: Prospects, Problems, and Achievements. United Nations Economic Commission for Africa Addis Ababa, Ethiopia, 75pp. [This programmed study focuses on the prospects, problems, efforts and experiences of transboundary river/lake basins water development in Africa].

Eccles, D.H. (1974). An outline of the physical limnology of Lake Malawi (Lake Nyasa). *Limnol. Oceanogr*. 19: 730-742. [This work presents new results and attempts to correlate all physical limnology variables with earlier work and to derive an outline of the physical processes in the lake as a whole].

Edwards, M. and Richardson, A., (2004). Impact of climate change on marine pelagic phonology and trophic mismatch. *Nature* 430: 881-884. [This paper illustrate that, not only is the marine pelagic community responding to climate changes, but also that the level of response differs throughout the community and the seasonal cycle, leading to a mismatch between trophic levels and functional groups].

El-Bana, M. I.; Ivan N. and Fred K. (2002). Microenvironmental and vegetational heterogeneity induced by phytogenic nebkhas in an arid coastal ecosystem. *Plant and Soil* 247: 283–293. [This paper illustrates the vegetation cover on the Bardawil lagoon islands].

El-Ganainy A.A., Yassien M.H., and Khalil, M.T, (2002). Ecological Survey of Bardawil nature protectorate: Fishes and Fisheries. Conservation of wetland and coastal ecosystem in the Mediterranean Region. Med. Wet. Coast. E.E.A.A. 72pp. [Technical report Provides comprehensive overviews of Bardawil lake fisheries].

El-Shabrawy, G.M. (2006). Ecological study on zooplankton community in Bardawil lagoon, Egypt. *Thalassia Salentina* 29: 3-17. [This paper illustrates the long term changes of the lake zooplankton in the lagoon].

FAO (1997). Irrigation potential in Africa: A basin approach The Nile Basin and The Congo/Zaire River basin. Information Division, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00100 Rome, Italy. [This report describes the data used for the assessment of the irrigation potential, summarizes the assessment of the soil and terrain suitability for irrigation and gives a brief review of the African water resources].

Fouda, M. Wanes, M. and Saleh, M. (1985). Ecology of Bardawil lagoon. A report to the Oil pollution Res. Unit, Pemboke, UK. for BP Petroleum LTD. Egypt. 94 pp. [a preliminary report on fauna and flora of the lagoon].

Fryer, G. (1972a). Conservation of the Great Lakes of East Africa: a lesson and a warning. *Biological Conservation* 4: 256–262. [This presents the importance of these lakes and the methods to conserve its endemic fauna].

Fryer, G. (1972b). Some hazards facing African lakes. *Biological Conservation* 4: 301–302. (A short communication article].

Furse, M.T., Morgan, P.R. and Kalk, M. (1979). The fisheries of Lake Chilwa. In Kalk,M., McLachlan, A.J. and Howard-Williams, C. eds. *Lake Chilwa: studies of change in a tropical ecosystem,* pp. 209-229.

The Hague-Boston-London. Dr. W.Junk Publishers. [This book consists of a series of papers by different authors on Lake Chilwa environmental systems].

Global Environment Facility (GEF) (2002). Reversal of Land and Water Degradation Trends in the Lake Chad Basin Ecosystem, Project Brief. Available at http://www.gefonline.org/project-Details.cfm?projID=767. [This project contribute to the sustainable management of land and water resources in the greater conventional basin of Lake Chad].

Gilabert, J. (2001). Seasonal plankton dynamics in a Mediterranean hypersaline coastal lagoon: the Mar Menor. *Journal of Plankton Research* 23: 207–217. [A classic work on plankton dynamics in a Mediterranean coastal lagoon]

Gougswaard, P.C. and Avoke, S. (1993). Length frequency of processed fish in Yeji weekly market.Field Document of IDAF, UNDO/FAO GHA/88/004, Integrated Development of Artesian Fisheries project. [This text contains introductory aspects to Integrated Development of Artesian Fisheries].

Hails, A.J. (1996). Wetlands, Biodiversity and the Ramsar Convention. Ramsar Convention Bureau, Gland. [A classic introductory report to knowledge of wetland]

Hecky, R.E. and Bugenyi, F.W.B. (1992). Hydrology and chemistry of the African Great Lakes and water quality issues: Problems and solutions. *Mitt. Internat. Verein. Limnol*. 23: 45-54. [A pioneer work on the African Great Lakes].

Herrera-Silveira, J.A. (1994). Spatial heterogeneity and seasonal patterns in a tropical coastal lagoon. *Journal of Coastal Research* 103: 738–746. [This study using multivariate statistical approaches describes the hydrology of a tropical coastal lagoon].

Hinrichsen, D., Robey, B., and Upadhyay, U.D. (1997). Solutions for a Water-Short World. Population Reports, Series M, No. 14. Baltimore: Johns Hopkins School of Public Health, Population Information Program. [A collection of reviews on various aspects of solutions of water short].

Horne, A. J. and Goldman, C. R., (1994). *Limnology*. 2nd ed. McGraw-Hill, Inc., NY. [This book is one of the most rigorous and complete approaches to limnology. Mostly used as a high-level textbook].

Iiecky, R.E., and Fee, E.J. (1981). Primary production and rates of algal growth in Lake Tanganyika. *Limnol. Oceanogr*. 26: 532-547. [Provides a holistic perspective on phytoplankton dynamics and lake fish production].

ILEC International Lake Environment Committee Foundation (2003). World Lake Database. International Lake Environment Committee, United Nations Environment Programme and Environment Agency of Japan, Shiga, Japan. [(ILEC) was established in 1986, collected environmental and socio-economic data of important lakes and reservoirs around the world].

IPCC, (2001). Climate Change. Third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. 881 p. [This report provide essential information and evidence needed for decisions on what constitutes dangerous anthropogenic interference with the climate system].

Irvine, K. (1995). Standing biomasses, production, spatial and temporal distributions of the crustacean zooplankton. The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa. Scientific Report of the UK/SADC Pelagic Fish Resource Assessment Project, pp. 85-108. [This article assists in the understanding of fisheries production and, the nature of ecosystem trophic dynamics in one of the African Great Lake].

Jackson, P.B.N. (1973). The African Great Lakes: food source and world treasure. *Biol. Cons*. 5: 302–304. [Description of the functioning of African Great Lakes in fisheries production and biodiversity].

Johnson T.C., C.A. Scholz C.A., Talbot M.R., Kelts K., Ngobi G., Beuning K., Ssemanda I. and McGill J.A. (1996). Later Pleistocene desiccation of Lake Victoria and rapid evolution of cichlid fishes. *Science* 273:1091-1093. [This study confirmed that the rate of speciation of cichlid fish in this tropical lake has been extremely rapid].

Kabii, T (1996). An overview of African wetlands. http://hdl.handle.net/1834/457 [General distribution, biodiversity, Values, threats and future prospects of African Wetlands are described].

Kalk, M. (1979). Experimental trawling in 1975-76. In Kalk, M., McLachlan, A.J and Howard-Williams, C. eds. *Lake Chilwa studies of change in a tropical ecosystem*, pp. 225-227. The Hague-Boston-London. Dr. W. Junk Publishers. [This Chapter reviews applications of gear net used in Chilwa lake]

Kalk, M., McLachlan, A.J and Howard-Williams, C. (1979). Lake Chilwa studies of change in a tropical ecosystem. *Monographae Biologicae* 35:17-227. [This book consists of a number of articles by different authors on different aspects of Lake Chilwa].

Kassas, M. et al. (2002). Management Plan for Zaranik Protected Area. Med Wet Coast, Global Environment Facility & Egyptian Environment Affairs Agency, Cairo, Egypt. [An excellent report, covering all aspects of Zaranik Protected Area, hydrology and biodiversity]

Kjerfve, B., (1994). Coastal lagoons. In Kjerfve, B. (ed.), *Coastal Lagoon Processes*. Elsevier Science, Amsterdam: 1–8. [This is a chapter of text book covers many of the principles and techniques used for Coastal lagoons].

Lehman, J.T., Mugidde, R., and Lehman, D.A. (1998). Lake Victoria plankton ecology: Mixing depth and climate-driven control of lake condition. In J. T. Lehman (ed.), *Environmental Change and Response in East African Lakes*. Kluwer, Dordrecht, pp. 99–116. This is a chapter of a book consists of a series of papers by different authors on different aspects of East African Lakes].

Mather, J.R. (1978). The climatic water budget in environmental analysis. Lexington Books, Lexington, Massachusetts. [A good and big reference book on physical oceanography].

McCully, P. (1996). Silenced rivers: The ecology and politics of large dams. London: Zed Books. [Excellent textbook dealing with extensive technical, safety, and economic problems associated with large dams].

Mockrin, M. and Thieme, M. (2001). Lake Chad flooded savanna (AT0904). World Wildlife Fund (WWF). Available at www.worldwildlife.org/wildworld/profi les/terrestrial/at/at0904_full.html. [This report describes the boundaries and the main physical and socio-economic characteristics of lake Chad region].

Morgan, A. and Kalk, M. (1970). Seasonal changes in the waters of Lake Chilwa (Malawi) in a drying phase 1966--1968. *Hydrobiologia* 36: 81-103. [This article intended to assist plans to conserve the fishing industry, which in years of high lake level produces almost half the total catch of the country].

Msiska, O.V. (2001). A review of the limnology of Malawi. Pp. 121-189 In, Wetzel, R.G., and B. Gopal (eds.), *Limnology in developing countries* 3. Societas Internationalis Limnologiae. [This four volume book provides a wealth of information on limnology in different countries].

Musa I K et al. (2008). Saving Lake Chad. Proceedings of Sirte Roundtable (LCBC and ICID), 17 December, Libya. [This report is dealing with the challenges facing the people of Lake Chad Basin as a result of the impact of global climate change].

MWH (1998). Ghana water resources management study – International waters ‘‘building block’’ study. Main report (final). Ministry of Works and Housing, Accra, Ghana. [This study is to document the distribution of these water related and water associated diseases in the various river basis in Ghana].

Nami B. (2002). Environmental Degradation of the Lake Chad Basin: Implications for Food Security. [How to saving Lake Chad and deterring further environmental degradation and desert encroachment].

Ngounou Ngatcha, B., (2009). Water Resources Protection in the Lake Chad Basin in the Changing Environment, European Water, Issue 25/26: 3-12. [A good guide on preserving and managing the Chad basin water resources in an integrated and sustainable manner].

Nicholson, S.E. (1998). Fluctuations of rift valley Lakes Malawi and Chilwa during historical times: a synthesis of geological, archaelogical and historical information’’. In Lehman, J.T. ed. *Environmental change and response in East African lakes*, pp. 208. The Netherlands: Kluwer Academic Publishers. [A good chapter in a big reference book on in East African lakes]

Nixon, S.W. (1988). Physical energy inputs and the comparative ecology of Lake and marine ecosystems. *Limnol. Oceanogr.* 33: 1005–1025. [A classic of marine ecosystems and lake ecology and most parts are still available].

Njaya, F.J. (1998). Co-management programmes in Malawi: a comparative case study for Lakes Malombe, Chilwa and Chiuta''. In Eide, A. and Vassdal, T. eds. The Ninth Biennial Conference of the International Institute of Fisheries Economics and Trade. pp. 260-269. Norway: Norwegian College of Fishery Science. [This paper highlights the challenges and potential of fisheries co-management programs in Malawi and proposes a way forward for improvement].

O'Reilly, C.M., Alin, S.R., Plisnier, P.-D., Cohen, A.S. and McKee, B.A. (2003). Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature* 424: 766-768. [This study provides evidence that the impact of regional effects of global climate change on aquatic ecosystem functions and services can be larger than that of local anthropogenic activity or overfishing].

Oguntunde, P.G. (2004). Evapotranspiration and complementarity relations in the water balance of the Volta Basin: field measurements and GIS-based regional estimates Ecology and Development Series, vol. 22. Cuvillier Verlag, Goettingen, p. 169.

Ogutu-Ohwayo, R and Balirwa J.S. (2006). Management challenges of freshwater fisheries in Africa Lakes & Reservoirs: Research and Management 11: 215–226. [Provides a holistic perspective on Africa Lakes].

Oki T and Kanae S. (2006). Global hydrological cycles and world water resources. *Science*, 313: 1068–1072. [This study mentioned that unlike oil, water circulates, forming closed hydrologic cycles. The amount of water will not diminish on shorter than geological time scales and added that water scarcity become a widespread reality within a few decades].

Oliveira AM and Kjerfve B. (1993). Environmental responses of a tropical coastal lagoon system to hydrological variability: Mundau-Manguaba, Brazil. Estuarine, *Coastal and Shelf Science* 37: 575–591. [A work shows that productivity of tropical coastal lagoons are frequently interrupted by both natural and anthropogenic ecological disasters].

Olivry J.C., Chouret A., Vuillaume G., Lemoalle J., and Bricquet J.P. (1996). Hydrologie du Lac Tchad. ORSTOM, Paris, 259 p. [This book covers many ecological features of lake Chad].

Patterson, G. and Kachinjika. O. (1995). Limnology and phytoplankton ecology, p. 1-67. In A. Menz (ed.). The fishery potential and productivity of the pelagic zone of Lake Malawi/Niassa, NRI/ODA. 386 p.

Patterson, G., Wooster. M.J and Sear, C.B. (1995). Real-time monitoring of African aquatic resources using remote sensing: with special reference to Lake Malawi. Chatham, UK: Natural Resources Institute. 21 p. [This publication describes work carried out on Lake Malawi. Daily, remotely sensed maps of lake surface temperature were compared with information collected in situ].

Perez-Ruzafa, A. Carmen-Mompean, M. and Marcos C. (2007). Hydrographic, geomorphologic and fish assemblage relationships in coastal lagoons. *Hydrobiologia* 577: 107–125. [In this study, 40 Atlanto-Mediterranean coastal lagoons were analyzed in order to evaluate the extent to which their ecological characteristics depend on hydrographic, trophic or geomorphologic features].

Plisnier P., Chitamwebwa D., Mwape L., Tshibangu K., Langenberg V. and Coenen E. (1999). Limnological annual cycle inferred from physical-chemical fluctuations at three stations of Lake Tanganyika. *Hydrobiologia*, 407: 45-58.

Plus, M. La Jeunesse, I. Bouraouic, F. Zaldívar, J. Chapelle A. and Lazure P (2006). Modelling water discharges and nitrogen inputs into a Mediterranean lagoon Impact on the primary production Ecological Modelling 193 (1-2): 69-89. [This work provides the lagoon model (LM) with simulated riverine inflows in order to assess their impact on the primary production].

Ratcliffe, C. (1971). The Fishery of the Lower Shire Area Malawi. Fisheries Bulletin No. 3. Government of Malawi, Ministry of Agriculture. Fisheries Department, Zomba. [A precise work on the fisheries of Lake Malawi]

Ribbink, A., Marsh, B. Marsh, A. Ribbink A. and Sharp, B. (1983). A preliminary survey of the cichlids fishes of rocky habitats in Lake Malawi. *Afr. J. Zool*. 18: 149–310. [This gives the role of rocky habitats and the community structure of cichlids fishes].

Saad, M.A. (2006). Phytoplankton and Periphytic Algae In Shaltout K. and Khalil, M (eds) Bardawil lagoon. EEAA publication 604pp. [this is a chapter on phytoplankton biodiversity in a text book, covering all aspects of the lake, hydrology and biodiversity]

Salama W. and Grieve A. (1996). The Zaranik Experience. Sandgrouse 18: 14–17.

Salonen, K., Sarvala, J., Järvinen, M., Langenberg, V., Nuottajärvi, M., Vuoirio, K. and Chitawebwa, D.B.R. (1999). Phytoplankton in Lake Tanganyika: Vertical and horizontal distribution of in vivo fluorescence. *Hydrobiologia*, 407: 89−103.

Sarch M.T. and Birkett C.M. (2000) 'Fishing and Farming at Lake Chad: Responses to Lake Level Fluctuations' *Geographical Journal* 166(2).

Schuyt, K. (2002). Land and Water Use of Wetlands in Africa: Economic values of African wetlands. IIASA Interim Report IR-02-063. International Institute for Applied Systems Analysis,Austria. ttp://www.iiasa.ac.at/Admin/PUB/Documents/IR-02-063.pdf

Schuyt, K. (2005). Economic consequences of wetland degradation for local populations in Africa Ecological Economics 53: 177– 190.

Seehausen, O. (1996). Lake Victoria rock cichlids: taxonomy, ecology, and distribution. Verduyn Cichlids, Zevenhuizen, the Netherlands. [This is the first popular book about Lake Victoria cichlids].

Shaltout, K.H. and Khalil, M.T. (2005).*Lake Borullus (Borullus Protected Area).* Publication of National Biodiversity Unit, No. 13, Egyptian Environmental Affairs Agency, Egypt, 578 pp. [A text book, covering all aspects of the lake, hydrology and biodiversity].

Sikes, S. (2003). *Lake Chad versus the Sahara Desert*. Newbury: Mirage Newbury. [Dr Sylvia Sikes traveled on and around Lake Chad. This book presents an easy-to-read record of her travels, adventures and observations during this time].

Snoeks J., Rüber L., Verheyen E. (1994) The Tanganyika problem: comments on the taxonomy and distribution patterns of its cichlid fauna. In: *Speciation in Ancient Lakes* (eds Martens K, Goddeeris G, Coulter G), pp. 355–372. Schweizerbart, Stuttgart.

Souza M.F.L, Kjerfve B, Knoppers B, Landim de Souza W.F, Damasceno R.N (2003). Nutrient budgets and trophic state in a hypersaline coastal lagoon: Lagoa de Araruama, Brazil. *Estuar Coast Shelf Sci* 57:843–858. [This work describes the nutrient distribution, trophic state, and dominant biogeochemical processes in the tropical and hypersaline Lagoon].

Spigel R.H, Coulter G.W. (1996). Comparison of hydrology and physical limnology of the East African Great Lakes: Tanganyika, Malawi, Victoria, Kivu and Turkana (with reference to some North American Great Lakes). In: Johnson TC, Odada EO (eds) *The Limnology, Climatology and Paleoclimatology of East African Lakes*: Gordon and Breach, Toronto, pp 103–139. [This is a widely used textbook dealing with different aspects of ecology of East African Lakes].

UNEP. (1999). Early Warning of Selected Emerging Environmental Issues in Africa: Change and Correlation from a Geographic Perspective. UNEP/DEWA Environment Information and Assessment Technical Report, TR. 99-2, p. 42.

UNEP. (2006). Africa Environmental Outlook 2: Our Environment, Our Wealth. United Nations Environmental Programme. 542 pp. [This report is useful to all who subscribe to the attainment of sustainable development in Africa for the benefit of present and future generations].

UNEP GEMS/Water Programme. (2008). Water Quality for Ecosystem and Human Health, www.unwater.org/downloads/water_quality_human_health.pdf. [One of the basic reports provides an introduction to a diverse range of global water quality issues, including approaches to their identification, analysis and resolution].

Verschuren, D. (2003). The heat on Lake Tanganyika. *Nature* 424: 731-732.

Wagner, I., Marsalek J. and P. Breil, p. (2007). Aquatic Habitats in SustainableUrban Water Management: *Science*, Policy and Practice Taylor & Francis Group, London, Leiden / New York / Philadelphia / Singapore

Walling, D.E. (1996). Hydrology and rivers. In Adams W, Goudie A, Orme A (eds). *The physical geography of Africa.* Oxford University Press, Oxford pp. 101-121

Wandiga S.O. (2003). Lake Basin Management Problems in Africa: Historical and Future Perspectives.www.worldlakes.org/.../Lake%20Basin%20Problems%20in%20Africa_12.16. 03.pdf

Wikipeda (2005). Africa - Wikipedia. Available at http://en.wikipedia.org/wiki/Africa

Williams, W.D. (1996). What future saline lakes? Environment 38: 12–20, 38–39.

Williams, W.D. (2001). Anthropogenic salinisation of inland waters. *Hydrobiologia* 466: 329–337.

World Commission on Dams (2001). Dam Statistics: Africa and the Middle East Regions. Available at: http://www.dams.org/kbase/consultations/afrme/dam_stats_eng.htm

WWF (2002). The facts on water of Africa Living Waters Conserving the source of life www.panda.org/livingwaters. [One of the basic reports provides an introduction to water management in Africa].

Zahran M. and Willis A.J. (1992*). The Vegetation of Egypt*. Chapman & Hall, London. 424 pp. [Text book in which The vegetation types of the different habitats of Egypt are described].

Zaldivar, J. M., Cattaneo, E. Plus, M. Murray, C.N. Giordani, G. and Viaroli, P. (2003). Long-term simulation of main biogeochemical events in a coastal lagoon: Sacca Di Goro (Northern Adriatic Coast, Italy). *Continental Shelf Research* 23: 1847–1875. [In This study a biogeochemical model for the Sacca di Goro Lagoon has been developed and partially validated with field data from 1989 to 1998].

Zinabu, A. M. (1998). Science in Africa - Emerging water management problems. In: J. SCHONEBOOM (ed.), Human interactions and water quality in the Horn of Africa, pp. 47 -61. A publication of the symposium at the 1998 American Association for the Advancement of Science (AAAS), Annual Meeting, Philadelphia. [This paper intend to evaluate the human activities that are the possible causes of the water quality changes in the Ethiopian lakes, which can related to other countries in the Horn of Africa].

Zaghloul, F.A. (1985). Seasonal variation of plankton in Lake Nasser. Ph.D. Thesis, Faculty of Science, Suez Cannel University. Egypt. 364 pp. [This thesis presents essential aspects on phytoplankton ecology in a comprehensive way]

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