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 6800 km, making it 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 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 are generating large amounts of power, irrigation source for increasing agricultural production, underdeveloped hydrocarbon deposits, and seats of ancient and modern civilizations in at least three zones of the Basin. This contributes 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 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. Flowing and stagnant water in water bodies 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 support. 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 among the world's watersheds. Rivers are characterized by unidirectional current flow with a relatively high, average flow velocity ranging from 0.1 to 1 m s^{-1}. The 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, 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, Kayoga, 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 year to another, the lowest recorded yield reached 42 billion cubic meters, while the highest amount of yield reached 150 billion cubic meters. The Niles average annual yield throughout twentieth century is 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 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 1.6×10^6 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, Kayoga, 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

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 Montana equatorial climate and it traverses a series of 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 which 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 the whole of Egypt and the Sudan, one third of Ethiopia, the whole of Uganda, and part 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).

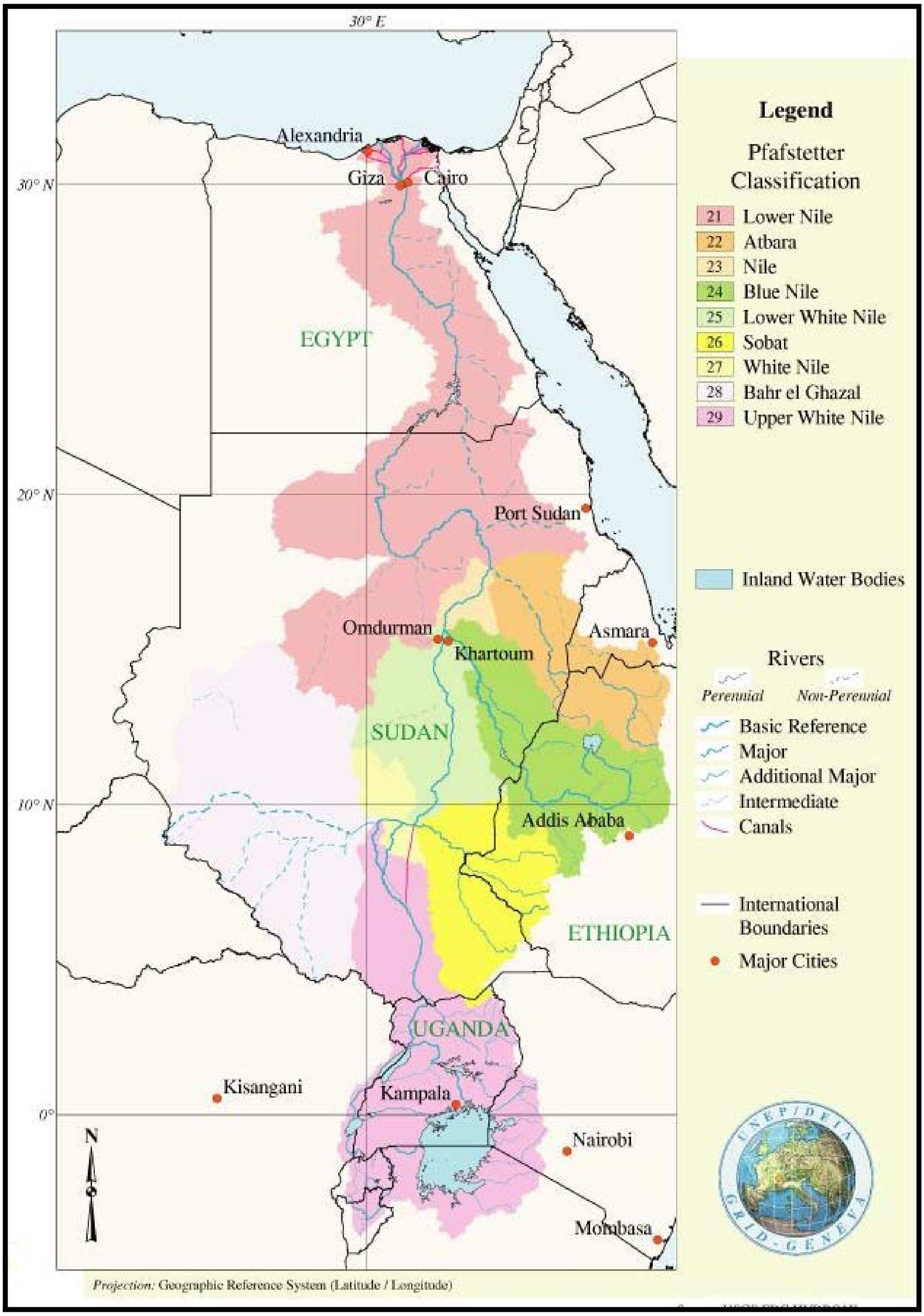

Figure 1. The Nile Basin (Source: UNEP/DEWA/GRID-Geneva 1998-09 with copyright permission)

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 below Lake Victoria
(3) The Bahr el Jebel and the Sudd
(4) The Bahr el Ghazal Basin
(5) The Sobat Basin and the Machar Marshes
(6) The White Nile below 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 contributing approximately 122 km^3/yr to the flow. Its tributaries contribute approximately 276 mm 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 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 Nile is dominated by Lake Victoria. This region has also had a dramatic variation in flow level historically.

The Bahr el Jebel and the Sudd receive an annual rainfall of 871 mm while evaporation in the area is much higher at 2150 mm. This area which Nile reaches is the most complex having many seasonal inflows. The high levels of evaporation and transpiration come from the wide distribution of the river area of the water and from the large amounts of vegetation (i.e. *papyrus*). The Jonglei Canal was created 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 Ghazl Basin outflow to the White Nile is almost negligible which amounts to 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 all lost to evaporation. The sediment load of these rivers is 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 below Malakal drops 13 m over 840 km. The tributary inflows are sporadic and small while flood plain storage results in delay of outflow and increased loss by 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 a greater part of flow of the Main Nile approximated at 60%. Limited information is known about this area's hydrology, especially in its upper basin within Ethiopia. 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 trees.

The Blue Nile leaves and travels through series of cataracts through the Sudanese's Plains sloping westward from about 700 m. The region it passses through in the plains are covered with Savannah or thorn shrub. Its major tributaries are the Rahad and the Dinder. Along 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 type consists of arid plains dotted with low hills and rock outcrops.

The Main Nile in Egypt is the last major stretch of the Nile before entering the Mediterranean. There are no flows generated below the Atbara confluence (Eltahir, 2004).

3. Climate of the Nile Basin

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^o N, then a narrow strip of semi desert climate, followed by a wide Savannah climate (poor 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 isoheights 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 lake 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 Sepember it reaches its most northerly position up to 20^o 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 October 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.

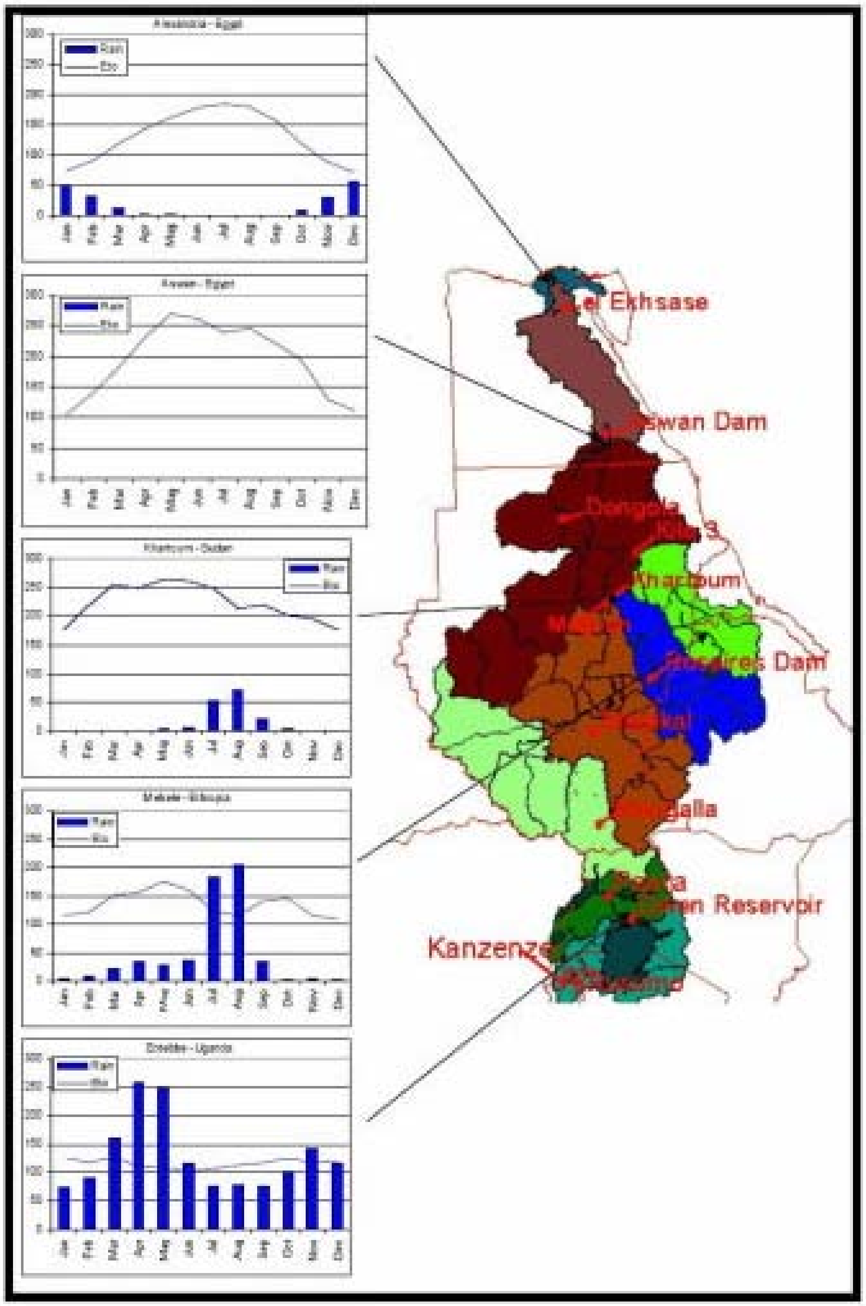

Figure 2. Rainfall and Evaporation for selected towns in the Nile basin

4. Hydrology and Limnology of the Nile basin

The Nile starts from Lake Victoria (in fact from farther south at the Kagera River feeding the lake) and travels north, receiving water from numerous streams and lakes on both sides. In the Sudd, 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. At Lake No, east of Malakal it is joined by the Bahr el Ghazal River draining the southwestern plains bordering the Congo Basin. 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 ($12Gm^3$) 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 it is called the White Nile), it travels downstream 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 1800m above MSL, and in a region of high summer rainfall (1500 mm/yr). The only 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 originated from the Ethiopian Plateau are quite seasonal and with a more rapid response 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), Sutcliffe & Parks (1999). The relative contribution to the mean annual Nile water at Aswan of 84.1 Gm^3 is approximately 4/7 from the Blue Nile, 2/7 from the White Nile (of which 1/7 from the Sobat), and 1/7 from the Atbara River. So the Ethiopian catchments (Sobat, Blue Nile and Atbara River) contribute to about 6/7 of the Nile water resources at Aswan. Ten countries share the Nile River: 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 rely less on the Nile waters, (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, in Lake Victoria, an annual cycle of thermal stratification can be distinguished (Fish, 1957). Thermal stratification appears briefly and irregularly in the downstream reservoir at Roseires (Hammerton, 1972a, b), but is annual and prolonged in Lake Nasser-Nubia (Entz, 1976) where it is eliminated by winter cooling and the entry of 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).

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