Nile River Biography and its Journey from Origin to End

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Abstract The Nile Basin covers an area of 3.18 million km^2, nearly 10 % of the African continent, and is shared by 11 countries. The Nile Basin can be divided into two subbasins: The first is the Eastern Nile subbasin or Ethiopian Highland which is considered as the main resource of the Nile water, sharing 85 % of the total Nile water. It is characterized by seasonal steady flow during the summer and autumn months (June–November). The second subbasin is the Great Equatorial lakes which shares only 15 % but with steady flow over the year. From Jinja in Uganda, the White Nile emerges from Lake Victoria and is thusly named the "Victoria Upper Nile." It travels northward toward Lake Kyoga and then through the Victoria Lower Nile to reach the lake of Albert. The river reemerges from Lake Albert as the Albert Nile and journeys northward to the Nimule; the first city in the South Sudan to carry a new name of Bahr el Jebel flows over the Fula rapids, and then the Nile losses and diapers in the biggest swamp in the world "Sudd" (means a "wall or block" in Arabic language) because of the very small gradient in this area. From Lake "No" at the north end of the Sudd swamp, the river turns eastward and at this point is named the "White Nile"; after a short distance, it receives the stream of Sobat River coming for southwest Ethiopia in their east bank and then continues its northward descent to meet with the Blue Nile at Khartoum, Sudan capital. The Blue Nile originates in Lake Tana in Ethiopia; it is joined by a number of tributaries, the main ones being the Rahad and Dinder, both originating in the border of Ethiopia. From Khartoum the combined rivers of the Nile flow northward and are joined by the Atbara (330 km north of Khartoum, originating in northeast Ethiopian Highlands). The Main Nile continues traveling northward and flows into Lake Nasser/Nubia, a major man-made reservoir on the border between Sudan and Egypt that provides interannual regulation for Egypt. The Nile Basin has several lakes such as Victoria,

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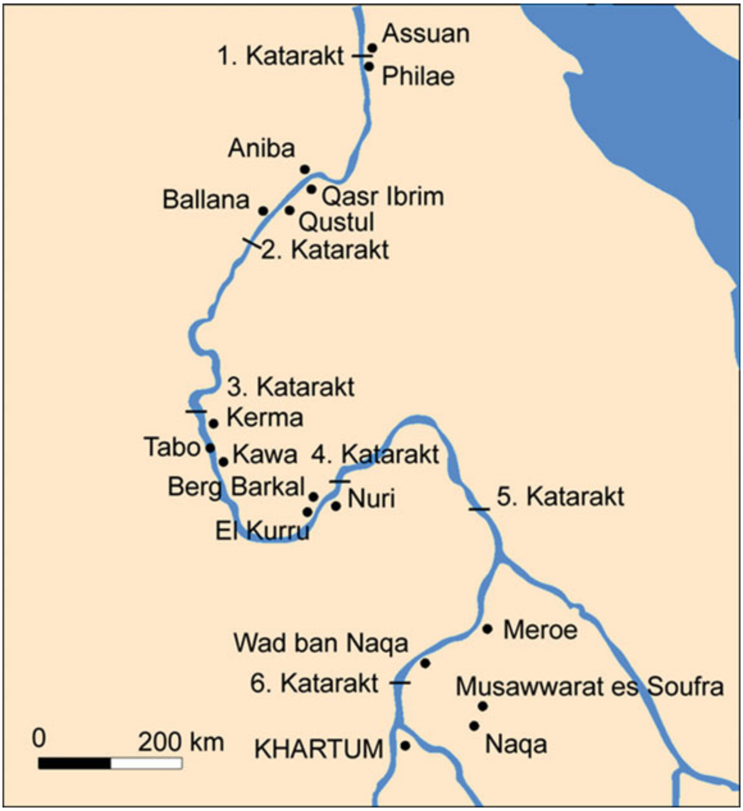
Kyoga, Albert, George, Edward, and Tana in addition to six cataracts. Six cataracts and Nine dams are distributed through the river. These dams are: Owen, Kiira, Jebal al-Aulia, Khashm el-Girba, Sinnar, Roseires, Grand Ethiopian Renaissance, Tekeze, and the Aswan High Dam. The cataracts were count from Egypt (1) to Sudan (6).

Dams through the Nile River (the reference below the map)



The Nile Basin is characterized by high climatic diversity and variability, a low percentage of rainfall reaching the main river, and an uneven distribution of its water resources. Climate changes are expected to affect the upper stream Nile by reducing the precipitation by 70 %.

Keywords Climate change, Dams, Lakes, Nile River Basin, Precipitation, Subbasin, Water resources

Contents

1 Introduction

Africa has only about 9 % of global freshwater resources for 15 % of the global population. Africa is the world's second-driest continent, after Australia, with annual per capita water availability of 4,008 m^3 in 2009 which is well below other world regions except Asia, the world's most populous continent [1].

The Nile River is the longest river in the Africa and even in the world, with a total length of 6,695 km, but has a little amount of water (does not exceed 84 BCM a year), making it out of the list of the tenth biggest river water sources in the world [2]. Figure 1 shows the biggest water discharge rivers in the world.

Its basin covers an area of 3.18 million km^2 – some of 10 % of the African continent – and is shared by 11 countries. The Nile River Basin encompasses a broad range of ecosystems that include mountains, tropical forests, high- and low-attitude wetlands, equatorial lakes, woodlands, and savannas. These ecosystems include flora and fauna unique to East Africa. However, most, if not all of these, are threatened by environmental degradation resulting from the region's

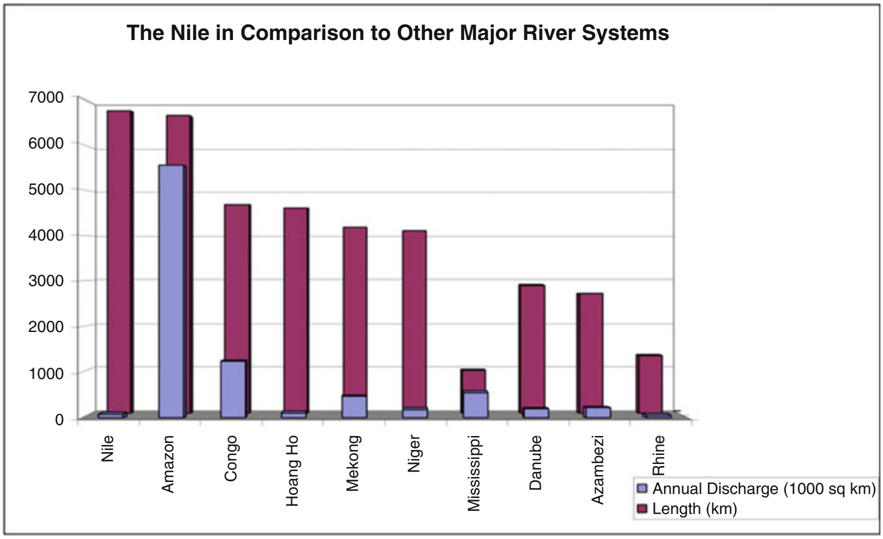


Fig. 1 Nile water in comparison with some well-known international rivers [3]

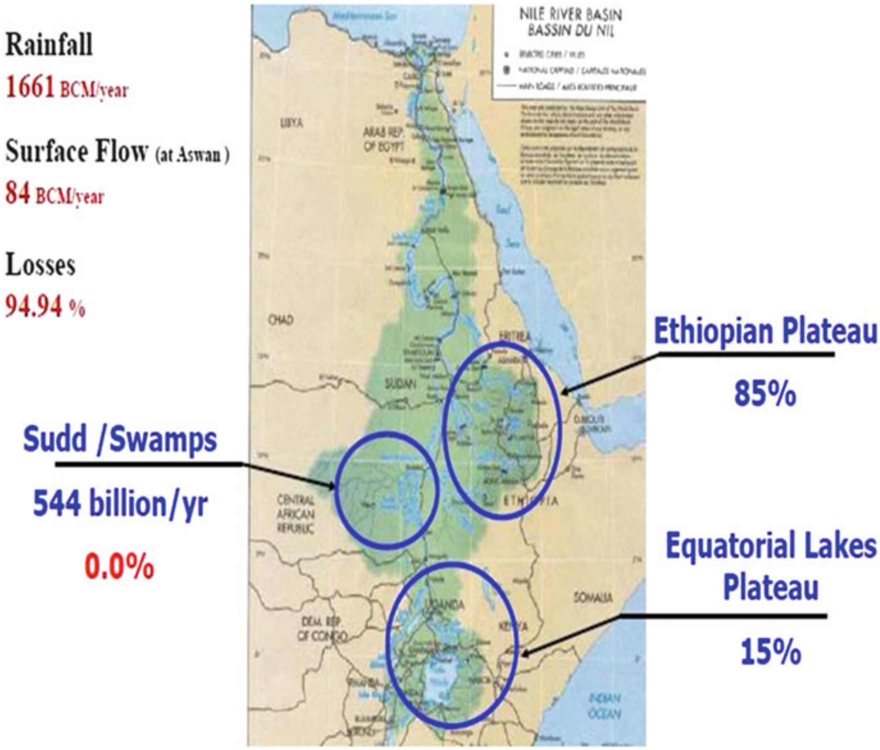


Fig. 2 Water sources in the Nile River [2, 4]

growing population, ongoing development pressure, and woefully inadequate infrastructure. The Nile Basin is characterized by high climatic diversity and variability, a low percentage of rainfall reaching the main river, and an uneven distribution of its water resources. Potential evaporation rates in the Nile region are high, making the basin particularly vulnerable to drought. The Nile Basin is divided into two main subbasins: the first is the Nile equatorial lakes, the source of the White Nile, and the second is the Eastern Nile subbasin, the source of the Blue Nile, Atbara, and Sobat. The White Nile flows only contribute up to 15 % of the annual Nile discharge but are fairly stable throughout the year. The Eastern Nile region supplies up to 85 % of annual Nile flows, but its contribution is highly seasonal [2]. Figures 2 and 3 showed the Nile Basin subbasins and the Nile Basin countries.

Many of the basin's countries are already in a state of water stress or water scarcity, which is defined as less than 1,700 and 1,000 m^3/person/year, respectively, of available freshwater, based on long-term average runoff and pollution. The pressures exerted by the growing population lead to increasing demands for resources leading to loss of forests and wetlands, land degradation, and desertification (Table 1).

Fig. 3 Nile Basin countries and water courses [5, 6]

Table 1 Water discharge of the biggest international rivers [3]

River name	Length	Annual discharge BCM/year	Time of Nile
Nile	6,850	84	–
Amazon	6,700	5,518	66
Yangtze	5,463	525	6.25
Mississippi	5,279	562	6.7
Congo	4,700	1,284	15
Mekong	4,183	264	3.1
Danube	2,888	205	2.5
Niger	2,590	177	2.1

2 Key Facts of the Nile

The basic facts of the Nile River are as follows [1, 2, 4]:

a. Length: 6,695 km
b. Navigable length: 4,149
c. Basin area: 3,176,543 km^2
d. Location: -4S to 31N and 24E to 40E
e. Riparian countries: Burundi, Democratic Republic of the Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda
f. Mean of annual flow (measured at downstream country, Aswan; Egypt): 84 billion m^3/year
g. The main tributaries and Lakes (from upper to downstream): Victoria Lake – Upper Victoria Nile – Lake Kyoga – Lower Victoria Nile – Albert Lake – Albert Nile – Bahr el Jebal + Sudd Swamp + Bahr el Ghazal and Bahr Arab – Lake “No” – White Nile. Then they meet with Eastern Nile sub-basin: Tana Lake – Baro-Pibor-Sobat, Blue Nile (Abay) + Atbara (Tekeze), Main Nile, and Lake Nasser or the man-made lake of Aswan High Dam
h. Runoff coefficients of main subbasins: 1–16 %
i. Runoff coefficient for the whole basin: 4 %
j. Major lakes in the basin: (equatorial) Victoria, Kyoga, Albert, Edward, George, and (East) Tana
k. Highest point: 5,110 m (Mount Stanley, Rwenzori Mountain, Uganda, and Burundi and Rwanda)
l. Lowest point: −133 m (Qattara Depression, Egypt)
m. Precipitation: mean max, 2,093 mm/year (Gore, Ethiopia); mean min, 0 mm/year (Lake Nasser, Egypt); and mean for the entire basin, 1,046 mm/year
n. Total population of the Nile countries: 437 million (2012)
o. Population within the basin: 238 million (54 % of population of basin countries, 2012)

p. Land use (2009): shrublands and woodlands, 37.3 %; bare soils, 30.8 %; agricultural lands, 11.6 %; grasslands, 10.3 %; forest, 6.9 %; water bodies, 3.0 %; and cities and built-up areas, 0.1 %
q. Main consumptive water use sector: agriculture
r. Population consumed by agriculture: 78 % at the peak flow at Aswan (Egypt)
s. Major dams: Owen Falls two dams (Bugala "Naluaale" and Kiira), Jebel Aulia, Roseires, Sennar, Khashm el-Girba, Merowe, Aswan High Dam, Grand Ethiopian Renaissance Dam, and Tekeze Dam

2.1 Key Problems

The key problems of the Nile River include [4, 7, 8]:

1. High population growth.
2. Drought and dryness.
3. Strong socioeconomic dependency on water.
4. Strong wrong belief on water as a power of wealth.
5. Absence of basin-wide management.
6. Complex hydrology.
7. Environmental hazards.
8. Livelihood issue.
9. Conflict and inequality.
10. Power imbalance and mistrust.
11. Uncertainty and lack of transparency.
12. Weak economic with spread of poverty and hunger.
13. Strong belief in financing water for the upper stream countries and belief in should Egypt pay for water! [7].
14. The Nile Basin countries believe that Nile water is only the water stream running between the two banks of the river, but the rain- or groundwater should not be considered [7].
15. Strong false belief in Egypt is the main reason of their problems, and it should aid the progress and economic development in the upper stream countries [7].
16. Some countries such as Ethiopia are looking forward to be the leadership and the power of East Africa.

3 Geography and Voyage of the Nile River and Its Basins

Worldwide, there are 263 transboundary river basins, which can be defined as basins shared by two or more riparian states. Approximately 60 % of the world's population depends on these international water systems [9, 10]. Transboundary river basins are also important because of the complex natural ecosystems they support. The potential increase in conflicts over shared water resources and the effects of climate change present significant social, economic, and environmental threats. In addition, there is a growing danger to human health from inadequate or unsafe water supplies [10]. Africa's 63 international transboundary river basins cover about 64 % of the continent's land area and contain 93 % of its total surface water resources.

The term "basin" refers to the geographical area drained by a river or lake. The Nile Basin refers not only to the physical drainage area of the Nile with its associated biophysical and ecological elements but also to the people living within the basin and features of their social, cultural, and economic development [9, 10].

Nile Basin can be divided into two subbasins: The first is the Eastern Nile subbasin (Ethiopian Highland) which is considered the main resource of the Nile water and is shared with 85 % of the total Nile water and has seasonal steady flow during the summer and autumn months (June–October). The second subbasin is the Equatorial Nile subbasin (Great Equatorial lakes) and shares only 15 % of the total water but in steady flow over the year or months.

Ethiopia, through the Blue Nile and rivers Atbara and Sobat, contributes about 85 % of the annual natural flow, while the White Nile contributes the balance. The White Nile and the Blue Nile are the two hydrological systems that feed the Main Nile. The former originates in the Equatorial Lakes Plateau (Burundi, Rwanda, the United Republic of Tanzania, Kenya, Democratic Republic of the Congo, and Uganda) and is fed by substantial flow from the Baro-Akobo-Sobat river system that originates in the foothills of southwest Ethiopia.

The Blue Nile stems from Lake Tana in the middle of Ethiopian Highlands. The Tekeze-Setit-Atbara river system stems from the northeast of Ethiopia and contributes to the flow further downstream of Khartoum. The region is also blessed with underground water resources that are already being used to supplement the surface water resources, as shown in Figs. 4 and 5.

The basin extends over five climatic zones – Mediterranean, arid, semiarid, subtropical, and tropical [2, 8, 11]. Its landscapes range from mountains, grasslands, forests and woodlands, wetlands, lakes, and deserts to a wave-dominated delta. This combination results in an array of ecosystems that are home to a rich biodiversity that provide a multitude of benefits to the population through cultural and ecological services, trade, tourism, food, medicines, and other products. The Congo-Nile Divide in Rwanda, the Fayoum lakes in the Egyptian desert, the Sudd wetlands in Sudan, and the Albertine Rift on the border of the DRC with Uganda are some of the areas with a unique or rich biodiversity. There are challenges facing the environment of the region. Population is the main driver behind the ever-increasing demand for water and the chief factor responsible for land degradation and environmental pollution. The pressures exerted by the growing population lead to increasing demands for resources leading to loss of forests and wetlands, degraded lands, desertification, alien invasive species, overfishing, and water pollution [2]. Many of the basin's countries are already in a state of water stress or water scarcity, which is defined as less than 1,700 and 1,000 m^3/person/year, respectively, of available water, based on long-term average runoff:

Fig. 4 The Nile course and its subbasins [1, 11]

Fig. 5 Eastern Nile subbasin [6]

Extensive regional aquifer systems holding substantial quantities of groundwater underlie the Nile region. Some of the aquifers hold fossil water, but others are recharged from precipitation over the Basin, or from irrigation areas and the base flow of the Nile. Groundwater is the dominant source of domestic water supply in rural communities across the Basin. The quality of the Nile waters has generally deteriorated because of population growth, intensification of agriculture, and industrial development. Across the Basin, environmental sanitation is poor, resulting in bacteriological contamination and nutrient enrichment of the Nile waters. While the quality of large parts of the Nile system – in particular in the sparsely populated areas – remains acceptable, localized high pollution is experienced mainly around urban centers. Groundwater in isolated locations also has naturally occurring high levels of dissolved minerals.

3.1 The Course of the Nile

The most distant source of the Nile is the Ruvyironza River, which flows into Lake Victoria through the Ruvubu and Kagera rivers [7]. Other rivers converging into Lake Victoria – the largest of the Nile equatorial lakes – include the Simiyu-Duma, Grumati-Rwana, Mara, Gucha-Migori, Sondu, Yala, Nzoia, Sio, Katonga, and Rusizi. From Jinja in Uganda, the White Nile emerges from Lake Victoria as the Victoria Upper Nile and travels northward, passing through two other equatorial lakes – Kyoga and then through the Victoria Lower Nile to reach the lake of Albert. Through these two lakes, the Nile captures runoff from two mountainous and high-rainfall areas (Mts Rwenzori and Elgon) on the southwestern and southeastern peripheries of the basin.

The river reemerges from Lake Albert as the Albert Nile and journeys northward to Nimule near the South Sudan-Uganda border. From this point, the river, now known as the Bahr el Jebel (meaning river of the mountains), flows over the Fula rapids and through the Sudd before meeting the Bahr el Ghazal (meaning river of the gazelles) at Lake “No.” The Bahr el Ghazal drains high-rainfall areas of western South Sudan. From Lake No, the river turns eastward to join with the Sobat River, which carries high, seasonally variable, flows originating in the Ethiopian Highlands. The combined Bahr el Jebel and Sobat rivers form the White Nile, which continues its northward descent and meets with the Blue Nile at Khartoum, Sudan [7].

The Blue Nile (also known as the Abay) originates in Lake Tana in Ethiopia and is the second principal stream of the Nile. Before meeting the White Nile, the Blue Nile is joined by a number of rivers, the main ones being the Rahad and Dinder, both originating in the Ethiopian southwest border with Sudan. From Khartoum, the combined rivers of the Nile flow northward and are joined by the Atbara (Tekeze) (330 km north of Khartoum), also originating in the northeast of Ethiopian Highlands. The Main Nile continues traveling northward and flows into Lake Nasser/Nubia, a major man-made reservoir on the border between Sudan and Egypt that provides interannual regulation for Egypt. The Nile eventually discharges into the Mediterranean Sea via its delta [7].

3.2 Catchment Areas, Dams, and Lakes

The catchments of most of the inflowing rivers have dense rural populations where much of the land is used for subsistence agriculture. Outflow is controlled by the Nalubaale and Kiira dams at Owen Falls, 8 km downstream from the Victoria shoreline. After leaving the lake, the river flows through Lake Kyoga, a shallow wetland complex that is an important fishery for Uganda, and then east to Lake Albert, which also collects inflow from the Semliki River. Flowing north across the Uganda-Sudan border, the river splits into two channels – the Bahr el-Jabal and the Bahr az-Zaraf. Flowing across broad flat plains, the rivers expand into a vast wetland, the Sudd swamp. Covering around 8,000 km^2 during the dry season, the swamp seasonally overflows, flooding an area many times this size [12]. The vast surface area, heavy vegetation, and high temperatures of the Sudd have led to the loss of roughly half the total White Nile's inflow through evaporation and transpiration [13]. The remaining outflow moves north where it meets the Blue Nile, 500 km downstream at Khartoum. The Blue Nile originates at Lake Tana, 1,800 m above sea level in the Ethiopian Highlands, where average annual rainfall is high and evaporation and transpiration are relatively low. It gathers more than 20 tributaries between lakes Tana and Khartoum, including the Rahad, Didessa, Dabus, and Dinder rivers [13]. By the time it reaches the Roseires Dam 80 km into Sudan, it begins to lose more water to evaporation and transpiration than what it receives in rainfall; nevertheless, it has collected enough water to provide between 59 and 64 % of the Nile's flow at Khartoum where it joins the White Nile. Additional inflow from the Ethiopian Highlands comes through the Atbara River, which enters the Nile 300 km downstream. From this point on, the combined effect of large and small irrigation schemes, increased temperatures, and diminishing rainfall cause the river to lose more water than what it receives. In northern Sudan, the Merowe Dam forms an artificial lake that is 174 km long when full [14, 15]. The Nile in Egypt begins with Lake Nasser, a reservoir created by the Aswan High Dam. One of the largest pumps in the world forces water from Lake Nasser into a channel that transports it onto the Western Desert where Egypt has begun a large irrigation and resettlement project. As the Nile flows on from Aswan toward the Mediterranean Sea, it is lined with irrigation canals. Almost all of Egypt's population of 90 million people live along the river and depend heavily on its resources. By the time the river reaches the sea, much of its water has been diverted for irrigation. Along with the water, sediments that have not already been trapped behind the river's many dams are diverted as well. As a consequence, erosion at the delta's margins and subsidence or compaction of the delta's soil is outpacing new deposition, leading the delta to sink and erode [15].

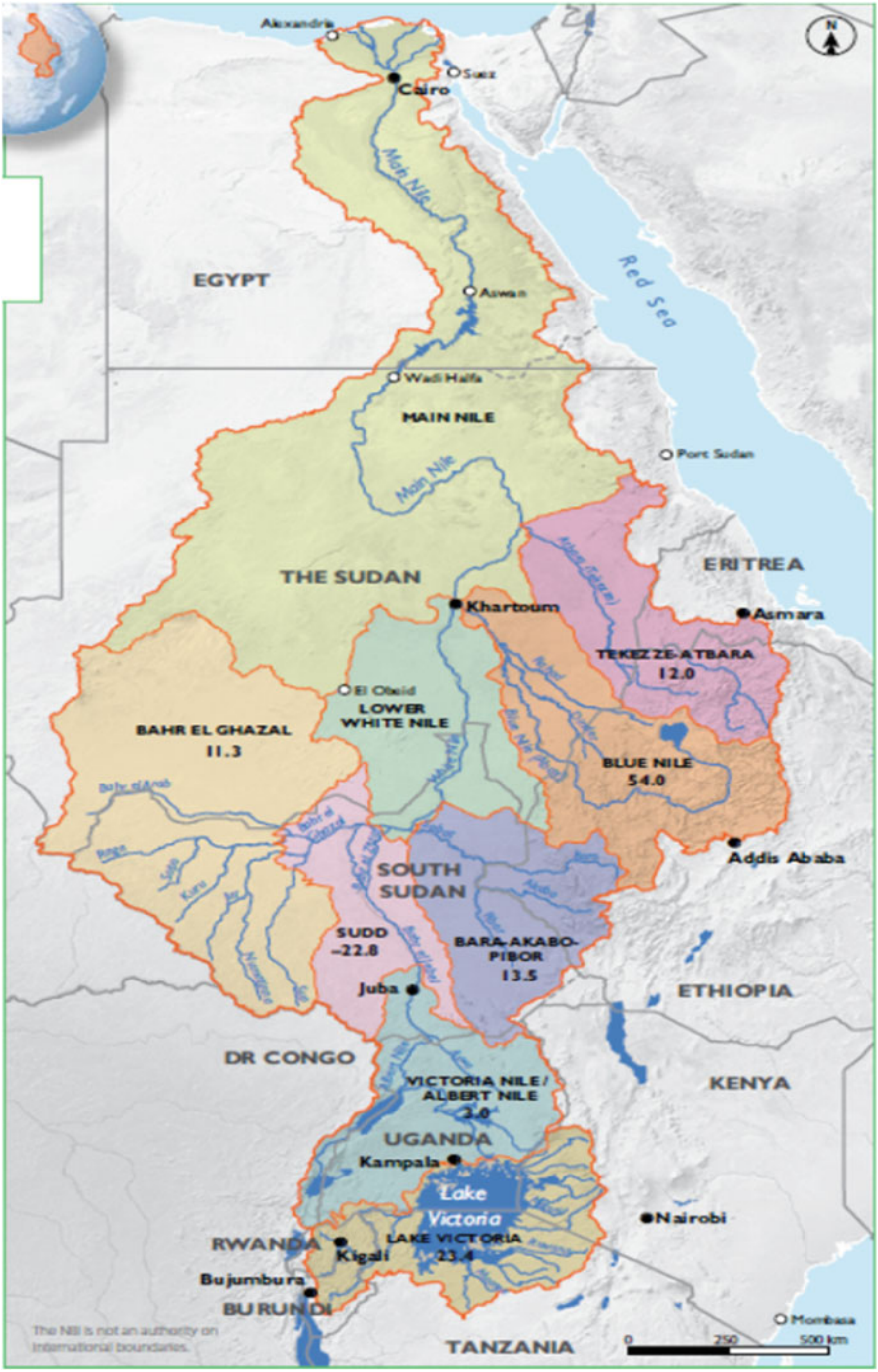


Fig. 6 The main subbasins and their contribution to the Nile (BCM/year) [2]

3.3 The Sudd Swamp and Jonglei Canal

The Sudd is a vast wetland in southern Sudan where the Nile River wanders for nearly 644 km, losing much of its flow to evaporation [16]. During the dry season, the wetlands contract to approximately 8,300 km^2 of permanent swamp [16]. During the wet season from April to October, the Sudd overflows into the surrounding area to cover 80,000 km^2. This annual pattern of flooding is an integral part of the ecosystem and is crucial to the local flora and fauna and to the local Nilotic people's way of life [16, 17].

The Jonglei Canal project is designed to reroute a portion of the Nile's flow around the wetland, thus reducing evaporative loss and increasing the water available downstream for irrigation. The project has been at a standstill since November 1983 when military conflict in the area stopped construction [17]. This conflict has now ended and there are plans to resume construction. According to [18, 19], The Equatorial Nile Project and its Effects on the Anglo-Egyptian Sudan identified many concerns with the Jonglei Canal that are still a source of controversy today. It concluded that a canal diverting 55 million m^3 of the White Nile's water per day would mean the loss of 36 % of pasture and 20,000 metric tons of fish. It would also significantly reduce agricultural production [19]. The pastoralists who depend on the area's seasonal flooding will lose the grasses for their cattle and access to drinking water; in addition, the canals will impede their seasonal migration. Several studies support these concerns, and a little-studied second phase of the project will almost certainly further affect the area. Environmentalists have voiced concern that the project could have drastic effects on the ecosystem, potentially affecting the climate, groundwater recharge, water quality, fisheries, and the local people [18]. The proponents of the canal claim that its benefits will outweigh impacts on the wetlands. In addition to enhancing of downstream irrigation, supporters say that travel from Khartoum to Juba, the main city in the south, will be reduced by 300 km. The impacts of this project are difficult to predict, and further study is needed to ensure that decisions are based on sound up-to-date science (Fig. 6).

4 Climate and Rain

4.1 Rainfall

Annual rainfall distribution over the basin is characterized by highly uneven seasonal and spatial distribution. Most of the basin experiences only one rainy season – typically in the summer months. Only the equatorial zone has two distinct rainy periods. The reliability and volume of precipitation generally decline moving northward, with the arid regions in Egypt and the northern region of Sudan receiving insignificant annual rainfall. The spatial variability of rainfall is clearly illustrated by the pattern of vegetation and distribution of surface water bodies in the basin. Large parts of the Nile watershed do not generate runoff. In fact, the main runoff-producing areas are limited to the Ethiopian Highlands and the Equatorial Lakes Plateau, with some contribution from southwestern Sudan. The relatively small size of the runoff-producing area is central to explaining the very low runoff coefficient of the Nile (3.9 %). Total Nile discharge represents a depth of less than 30 mm if spread over the entire watershed.

4.2 Seasonal Rainfall Distribution [1, 2]

The high temporal variability of rainfall in the basin is demonstrated by the monthly rain records. Broadly speaking, there are three patterns of seasonal rainfall variation:

(1) A single rain peak June–October, with little or no rainfall in other months. Found in subbasins of Eastern Nile and Main Nile.
(2) A fairly evenly distributed rainfall, with a single peak from April to October. Found in northern Uganda and South Sudan. As seen in Fig. 7.
(3) A twin-peaked distribution, peaking in March–May and September–November with considerable but lower rain during other months. This is mostly seen in the Nile Equatorial Lakes Plateau. See histograms from Kijura to Mwanza.

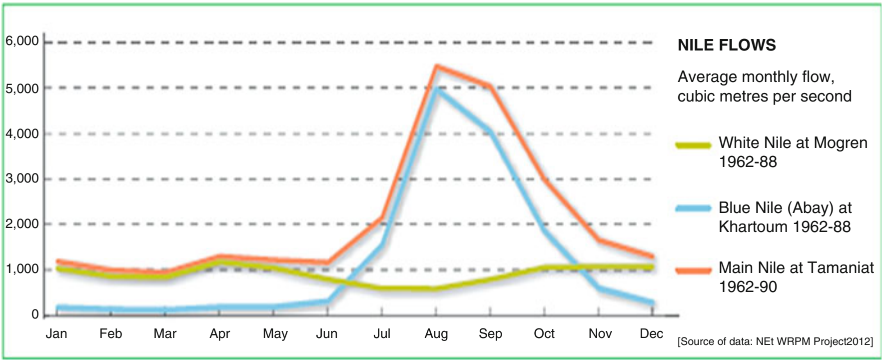


Fig. 7 Nile flow distribution [2]

4.3 Evapotranspiration

4.3.1 Water Loss from the Earth's Surface

Evapotranspiration (ET), which is the sum of evaporation and plant transpiration, is an important element of the water cycle. Evaporation accounts for the movement of water from sources such as soil, canopy interception, and open water bodies to the air, while transpiration accounts for the movement of water within a plant and its subsequent loss to the atmosphere through the plant stomata. Evapotranspiration represents a significant loss of water from drainage basins. Another important term with regard to water loss from the earth's surface is potential evapotranspiration (PET). This is a measure of the amount of water that would be evaporated and transpired if there were sufficient water available. PET is calculated indirectly from other climatic parameters and incorporates the energy available for evaporation as well as the ability of the lower atmosphere to transport evaporated moisture away from the land surface. Actual evapotranspiration (ET) is said to equal potential evapotranspiration (PET) when there is ample water. Actual evapotranspiration in the Nile Basin is generally high compared to other river/lake basins around the world.

4.3.2 Spatial and Temporal Evapotranspiration Trends

Potential evapotranspiration varies considerably across geographical regions and over time. PET is higher in locations and during periods when there are higher levels of solar radiation and higher temperatures (and hence where there is greater energy for evaporation). Accordingly, PET is higher in hot deserts, low-lying lands, and areas near the equator. PET is also higher on less cloudy days and during the dry season (or summer). PET is higher on windy days because evaporated moisture can be quickly transported away from the ground or plant surface, allowing more evaporation to fill its place. Potential evapotranspiration further depends on relative humidity, the surface type (such as open water), percentage soil cover, the soil type (for bare land), and the vegetation type. Across the Nile region, actual and potential evapotranspiration vary markedly. The arid lands in Sudan and Egypt have higher potential evapotranspiration rates than the humid headwater regions of the Nile. However, both have much lower actual evapotranspiration rates because there is little available water and vegetation to cause evapotranspiration. Total annual evapotranspiration is highest in the Lake Victoria subbasin, estimated at about 307 BCM, followed by the Blue Nile subbasin, estimated at 264 BCM and then by the Sudd subbasin estimated at 260 BCM. The Main Nile subbasin downstream of Khartoum has the lowest evapotranspiration rates, estimated at 7 BCM per year. In terms of components of evapotranspiration, the Blue Nile (Abay) subbasin has the highest ET losses over land; Lake Victoria subbasin has the highest evaporation losses over open water; and the Sudd subbasin has the highest ET losses over wetlands. Seasonal/monthly variability of evapotranspiration is a function of temperature, wind speed, relative humidity, solar radiation, and biomass production. No significant month-to-month or year-to-year variation is noted in the upper reaches of the Nile as the areas lie in the tropics that are characterized by all-year sunshine and humid conditions.

4.3.3 A Diverse and Highly Variable Climate

The within-year and between-years variability in rainfall over the Nile Basin is high, making overreliance on rainfed supply or production systems risky. The high potential evaporation values in the Nile region – ranging from some 3,000 mm/year in northern Sudan to 1,400 mm/year in the Ethiopian Highlands and around 1,100 mm/year in the hills in Rwanda and Burundi – make the basin particularly vulnerable to drought events. Drought risks are further amplified by the high variability of the rainfall between seasons and years. This is manifested by uncertainty in the onset of rains, occasional cessation of rainfall during the growing season, and consecutive years of below-average rainfall. This has a marked adverse impact on the productivity of rainfed agriculture and represents a serious constraint to rural development. The impact of the climatic variability on agricultural production is further aggravated by widespread soil degradation that has led to a reduction in the capacity of soils to hold moisture. Rain deficits, therefore, quickly translate into crop failure.

5 Lakes of the Nile Basin

5.1 Great Equatorial Lakes Nile [20–22]

5.1.1 Lake Victoria [14]

Lake Victoria, the second largest freshwater body in the world (area 68,800 km^2), is generally shallow with a maximum depth of 80–90 m and an average depth of 40 m and has a volume of 2,760 lm^3. It is shared by Kenya, Uganda, and Tanzania; Kenya has the smallest portion of the lake by 6 %, Uganda has 45 %, and Tanzania has the largest portion by 49 %. The Lake Victoria basin has an area of 210,000 km^2, with the largest areas in Tanzania by 44 %, Kenya 21.5 %, Uganda 15.9 %, Rwanda 11.4 %, and Burundi 7.2 %.

Lake Victoria has an irregular shoreline of about 3,440 km in length. Its catchments are constituted by five countries (Kenya, Tanzania, Uganda, Burundi, and Rwanda) and drained by a number of large rivers plus many small rivers and streams. The Nile River is the single outlet and 82 % of the water input in the lake comes directly from rainfall.

Kagera River is the largest and longest contributor water in the equatorial lake sub-basin. It originates from Burundi and forms the border between each of; Rwanda-Tanzania and Tanzania-Uganda. The satellite images of 1987 and 2008 show high reflectance of water from the Kagera River due to silt. Silt and suspended solids impact water bodies by loading nutrients into the lake. Nutrients stimulate algae growth which reduces oxygen leading to oxygen depletion that can cause fish kills.

5.1.2 Lake Kyoga

Lake Kyoga occupies a shallow dendritic valley system, part of which is permanently flooded to form a series of shallow lakes, which have a combined maximum open water surface of 341,600 ha and 218,400 ha of permanent swamps. The system is a tributary to the Victoria Nile which flows through the southwestern end of Lake Kyoga and then receives the discharge of Lake Kwania 32 km downstream. The system owes its existence to the upwarping of the western edge of the Lake Victoria basin, which has reduced the gradient and rate of flow in rivers flowing west, causing "ponding" and turning them into sluggish swampy tracts. Lake Kyoga (1°13′-1°47′N/32°33′-33°29′E) is the largest lake in the system. At high water, its surface is 1,034 m asl and covers 263,600 ha. The maximum depth is then 10.7 m and the mean depth about 3 m; the surface level fluctuates by as much as 3.8 m during a year. The lake discharges at the western end into the Victoria Nile and is oriented roughly E-W for 55 km immediately above the confluence, at which point it divides into two arms. The northeastern arm continues up the valley of the Omunyal River for a further 55 km, while the southeastern arm extends up the valley of the Mpologoma River for some 34 km. Many tributaries enter the Omunyal arm, the valley of which contains only minor swamps. By contrast, a vast permanent swamp extends up the Mpologoma arm for 102 km above the lakehead, including many minor lakes, the largest of which are lakes Adois (1°20′-1°25′N/33°30′-33°37′E), Kiando (1°23′N/33°24′E), Naragaga (1°23′N/33°27′E), Nyaguo (1°20′-1°22′N/33°41′-33°45′E), Nyasala (1°17′-1°22′N/33°34′-33°40′E), Namasajerl (1°21′N/33°22′E), Nakuwa (1°05′-1°17′N/33°24′-33°30′E), Nawampasa (1°16′N/33′22′E), Kawi (1°12′N/33°37′E), and Lemwa (1°07′N/33°41′E). The swamp belt reaches widths of 20 km and extends up several side valleys, covering more than 106,000 ha if the very variable lake surfaces are included. The maximum recorded depth is 5.4 m at high water and mean depth is estimated as 4 m. There are several small swamps around the lake margin.

5.1.3 Lake Albert and Semliki River

Lake Albert lies between two parallel escarpments in the Western Rift Valley, at an altitude of 619 m, with an extreme length of 180 km and a maximum width of

43 km. Just over 56 % of its surface is in Uganda and the rest in the Democratic Republic of the Congo (DRC). Its deepest point, 56 m, lies 7 km off the western shore, from where the land rises steeply to a high plateau more than 2,000 m asl. The lake floor slopes gently upward toward the east, but the eastern escarpment rises abruptly just a few kilometers from the east bank in Uganda. The lake is subject to violent windstorms which cause the upwelling of bottom waters, but even without these happenings, the lake is generally well mixed. During calm periods, which frequently occur between November and February, a degree of stratification are develops, and dissolved oxygen levels falls down, but not deleteriously for the fauna.

Semliki River is one of the most important rivers that forms Uganda's natural drainage system found in Bundibugyo District, in the Western Uganda. The river derives its origin from Lake Edward through Mt. Rwenzori and also through a series of tributaries that join along its 140 km course in the Albertine Rift (Western Rift Valley) before draining into Lake Albert. Over 10 m of the riverbank on Uganda's territory is eroded annually at various points of the river, and as a result, the river seems to have doubled its width within the last ten years. Increased riverbank erosion due to overgrazing, melting of ice on the Mount Rwenzori, and degradation of the water catchments has resulted in siltation, changing the river course significantly over the years as it enters the Lake Albert. The bathymetry of Lake Albert shows that the lake is shallower in the south where the Semliki River drains into the lake.

5.1.4 Lake George

Lake George, which straddles the equator, is situated on the floor of the Western Rift Valley. It has a maximum E-W length of 30 km, a N-S width of 16 km, a maximum depth of 7 m, and a mean depth of 2.4 m. It is fed by several rivers and drains from the southwestern end by the Kazinga Channel which leads to Lake Edward. This is 36 km long with a mean width of about 1 km. The principal affluent streams (Nyamwamba, Rukoki, Mubuku, Ruimi rivers) drain the eastern slopes of the Rwenzori Mountains and enter the lake through extensive swamps (0°03′–0°16′/%1130°09′–30°19′E) on the north shore. These swamps are 21 km long, up to 14 km deep, and occupy some 2,600 ha. The Mpanga also enters these swamps from the eastern edge of the rift valley escarpment, while two other affluents enter on the southern shore, from the Virunga Massif, and the westward flowing section of the Katonga River enters the eastern extremity of the lake. Other swamps are situated north and south of the small western basin of the lake, and another is situated on the central southern lakeshore. There are three large islands close to the western shore, one of which almost blocks the channel connecting the main basin with a smaller basin in the northwest.

The Lake George area has seen much volcanic activity over the past 12,000 years, and a small crater lake is connected to the main lake by a narrow channel just south of the beginning of the Kazinga Channel. There are four isolated crater lakes north of the Kazinga Channel and a dozen south of it.

5.1.5 Lake Edward

Lake Edward is 76 km long with a maximum width of 39 km. Just over 29 % of its surface is situated in Uganda. It is connected to Lake George, effectively a bay of Lake Edward, by the Kazinga Channel, 36 km long and about 1.5 km wide. Lake Edward reaches a maximum depth of 112 m, just 5 km from the western shore, above which the land rises precipitously to a high plateau, over 2,000 m asl, carrying mountain peaks over 3,000 m. By contrast the lake floor slopes up gradually to the Ugandan shore. There are extensive swamps at the mouths of the Ishasha and Chiruruma rivers covering about 14,000 ha (Fig. 8).

Fig. 8 The Great Equatorial lakes Nile subbasin [1]

5.2 Eastern Nile Subbasin Lakes

5.2.1 Lake Tana

Lake Tana, found in the Amhara region in the northwestern Ethiopian Highlands, is the largest freshwater lake in Ethiopia. It is situated in a wide depression and has a surface area ranging between 3,000 and 3,600 km^2 depending on the season. It is about 84 km in length and 66 km wide, with a maximum depth of 14 m and an elevation of 1,788 m. Lake Tana is fed by four main rivers, the Gilgel Abay, Ribb, Gumara, and Magech, and discharges at Bahir Dar through the Blue Nile. The four inflowing rivers contribute 93 % of the lake's inflow. The average flow from Lake Tana was estimated at 3.8 BCM/year swelling to 54 BCM by the time it reaches Khartoum as a result of contributions from the rivers Dinder and Rahad. A water regulation weir constructed in 1996 at the point where the lake discharges into the Blue Nile helps to control the lake levels for the downstream hydropower plant. The mean annual rainfall is estimated at 1,248 mm/year, while the mean annual evaporation is approximated at 1,690 mm/year [14, 23–25]. The flow of the Blue Nile can be described as torrential; it also carries a very heavy load of silt. Figure 9 shows Lake Tana and its water catchment areas.

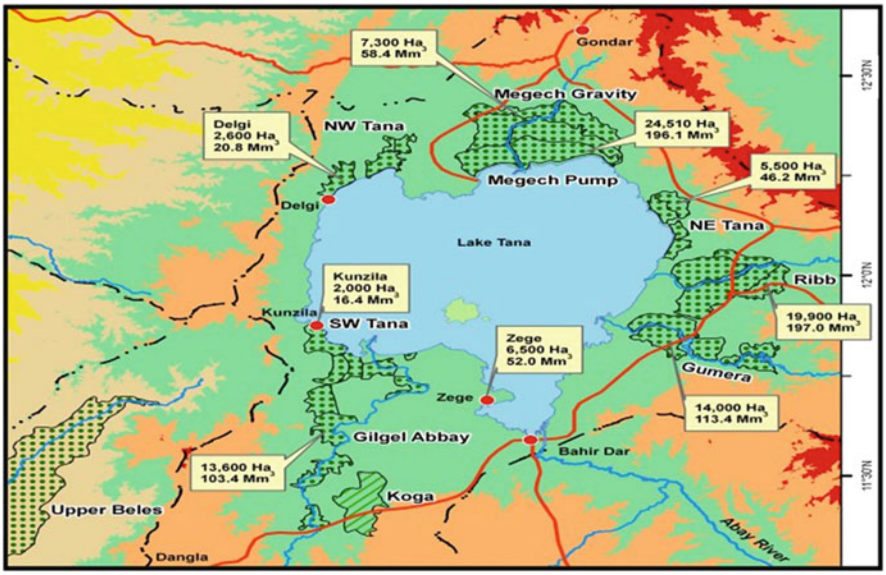


Fig. 9 Lake Tana Eastern Nile subbasin [25]

Wetlands

Wetlands cover about 100,000 km^2 or 3 % of the Nile Basin area [2]. They include swamps, marshes, seasonally inundated grasslands, swamp forests, floodplains, and riparian wetlands (at the edges of lakes and rivers). These wetlands have critical ecosystem functions: they provide a buffer protecting against the impacts of the strong seasonal variations in rainfall patterns, store floodwaters, and help to maintain river flows even during dry spells. They also trap sediments and purify agricultural, industrial, and urban wastewater, and they can influence local microclimates especially when very large as in the case of the Sudd. Wetlands are among the most biologically productive ecosystems, and because of this they are under great pressure.

The Sudd and Machar Swamp in South Sudan

Once in South Sudan, the White Nile breaks up to form the Bahr el-Jabal and Bahr az-Zaraf rivers. These rivers spread over a broad flat plain and expand into a vast wetland – the Sudd swamp. The Sudd in South Sudan is the largest wetland in Africa covering a dry season area of 8,000 km^2 and between 30,000 and 40,000 km^2 during the wet season [1, 21]. It includes the Bahr el Ghazal swamps and the Machar Marshes as shown in Fig. 10. The Bahr el Ghazal basin has the highest rainfall in South Sudan, most of which is absorbed by the swamps, and as such there is hardly any runoff to the White Nile. In fact, it is estimated that the outflow from the Sudd is only about 50 % the inflow due to losses to evapotranspiration [14, 24, 25].

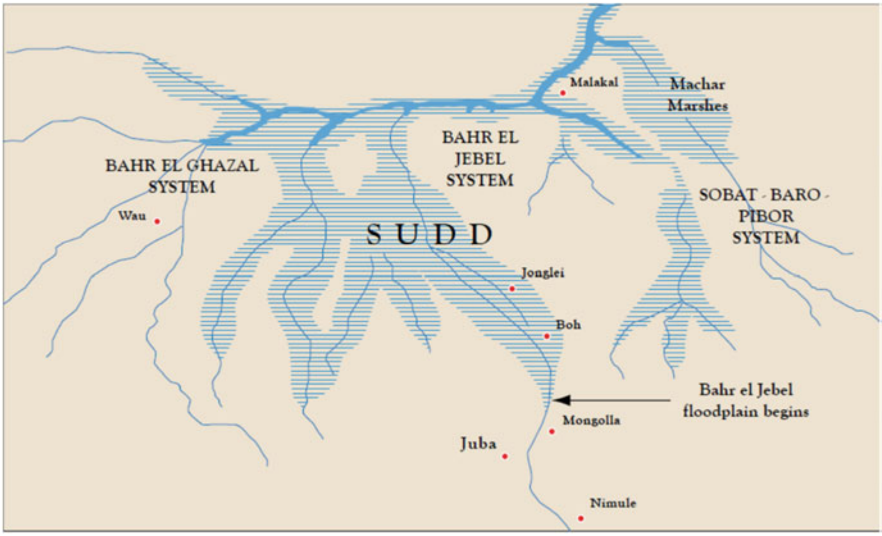


Fig. 10 Swamps area in South Sudan [1]

Despite this, outflows from the Sudd are fairly constant with little seasonal variation. According to [23], the total discharge from the Sudd to the White Nile at Malakal approaches 15.5 BCM per year.

Mara Wetland

The Mara wetland is a riverine floodplain situated near the discharge mouth of the River Mara to Lake Victoria in Tanzania part. In the upstream river catchment, there are numerous economic activities and significant land-use changes. There are also changes occurring in the rivers' hydrological regime with impacts on water quality and the ecological status of both Lake Victoria and the Mara wetlands.

The Ethiopian Wetlands

Ethiopia has many wetland ecosystems. These include alpine, riverine, lacustrine, and floodplain wetlands, and they are found in both the highlands and lowlands. They occur most commonly in the northwestern and western highlands, the rift valley, and the eastern highlands [26].

Wetlands in Rwanda

Rwanda has seven types of swamps, classified on the basis of relief, altitude, soil type, vegetation type, slope of the watershed, population density, hydrology, and size of the swamp [27]. They are mainly seasonal with floodplains of less than 200 m overall. Rugezi and Kamiranzovu are high-altitude wetlands, while most of the others are low altitude. Four wetlands have been classified as critical: Kamiranzovu wetland in Western province, Rweru-Mugesera wetland in Eastern province, Rugezi-Ruhondo wetland shared by Musanze and Gicumbi in Northern provinces, and Akagera wetland shared by Kibungo and Umutara in Eastern province.

Dams of Different Kinds, Financed in Different Ways

Dams come in many shapes and sizes and have many different purposes. Some 52,000 large dams have been built over the last century. These have been funded by governments, private banks, donor agencies, and private investors and built under a hundred or more different national and international regulatory systems that have evolved over the years. Dams may be multipurpose projects that combine several functions. Larger-scale dams offer the potential for hydropower, irrigation, water supply, navigation, and flood management projects [26]. There are many different types of hydropower at different scales, ranging from isolated household supplies to small, mini-, and microscale hydropower for decentralized grids to large grid-feeding projects serving national or regional power markets.

While the main bodies of national and international standards for environmental and social performance are broadly applicable to all types of dams, hydropower dams present unique considerations, not only in terms of financing sources but also in terms of low-carbon energy strategies. There are also much better data sets for planned hydropower plants due to intense private- and public-sector activity in this market. Data for planned flood control or irrigation dams are much harder to find and collate, and these tend to be purely public-sector projects.

Through its focus on hydropower, this review necessarily touches on the relationship between hydropower and other intermittent renewable energy sources for grid-scale power. Large hydropower dams may serve to complement solar and wind power sources as part of a low-carbon energy supply mix. Run-of-river hydropower projects may fit into low-carbon energy systems in developing countries.

Large dams are expensive infrastructure projects that are built within a complex legal and financial regulatory landscape. Social and environmental measures can be expensive, in some cases reaching up to 40 % of project cost or more. For private investors significant costs in these areas affect the profitability (and therefore viability) of the project. While some developers may have internal corporate social responsibility guidance that provides a framework for addressing these issues, the majority decide their environmental and social measures based on the legal requirements stemming from national legislation, usually through environmental assessments. If international financing is involved, however, then donors or private banks may impose additional conditions.

Hydropower has specific impacts that are significantly different from other infrastructure projects such as roads or airports and often have far-reaching effects on resources. Water is used by many communities, both upstream and downstream, and river valleys have traditionally been the focus of settlement and agricultural activity. Large dams have impacts on ecosystems, communities, and other water users (cities, agriculture, fisheries) many miles downstream, and the range of additional safeguards, processes, and policies addressed in this review have been developed specifically to address them.

The major reservoirs on the Nile River Basin – the Roseires, Sennar, and Khashm El-Girba in Sudan and the Aswan High Dam in Egypt – are important for irrigation purposes. In the delta, there are four main barrages: the Delta barrage (actually consisting of two separate dams), the Zifta barrage and Farascour Dam in the Damietta, and the Edfina barrage in the Rosetta. A barrage is an artificial barrier used to increase depth or sustain a separation between fresh- and saltwater. Figure 11 shows the location of some of these dams on the Nile.

The Aswan High Dam and Lake Nasser, Egypt

Located in the lower Nile River Basin, Lake Nasser is situated on the border between Egypt and northern Sudan. The lake was created following the

Fig. 11 Dams along the Nile River [2]

construction of the Aswan High Dam in 1963 to provide a multipurpose storage reservoir for water supply, hydropower, irrigation, and improved navigation. This artificial lake extends from southern Egypt to northern Sudan and has a surface area of 5,248 km^2 and a total volume capacity of 162.3 km^3 [28–30]. This capacity varies depending on the extent of the annual flood upstream. Although approximately 84 BCM flows each year to Lake Nasser in Egypt, heavy use of the lake's waters means that only about 0.4 BCM actually reaches the Mediterranean Sea [29]. It is situated in a hot, dry area, and therefore annual losses to evaporation can be quite high – ranging from up to 10 % when full to about 3 % when at minimum capacity [31].

The Aswan High Dam has had a large impact on the river's flow regime downstream of the dam. This reservoir fully controls the Nile's water flows by eliminating the normally high flows during August and September and limiting maximum discharges to 270 MCM/day or less than one-third of the earlier peak values [29]. One side effect has been a gross reduction in the deposition of the silt that used to annually renew the fertility of Egypt's agricultural lands.

Tekeze Dam and Renaissance Reservoir in Ethiopia

The River Tekeze in northern Ethiopia is a tributary of the Atbara River, which joins the main course of the Nile 300 km north of Khartoum. The Tekeze Dam was completed in early 2009 primarily to produce hydropower and is expected to produce 300 MW of hydropower when fully operational. There are concerns about the dam's environmental impacts. In 2008, a large landslide necessitated the addition of massive retaining walls to keep the slopes from eroding [10].

In the spring of 2012, work began on Ethiopia's Grand Renaissance Dam, also called the Millennium Dam, which has become the key project in the nation's plan to increase its electricity supply fivefold by 2015. It will have a capacity of about 6,000 MW and a reservoir capacity (74.5 BCM) two times that of Lake Tana. The dam will span a part of the Blue Nile in the region of "Benishangul-Gumuz," and when finished, it will be Africa's largest hydroelectric power plant. There are also plans to build four additional dams on the Blue Nile.

Grand Ethiopian Renaissance Dam (GERD), situated on the Blue Nile River immediately upstream of Sudanese border, is a cornerstone piece of this plan as seen in Fig. 12. Upon completion it will be the largest hydropower producer in all of Africa (National Geographic Daily News), with a catchment area of nearly 200,000 km^2 [32, 33], accelerating Ethiopia's transition into a power generation hub. Construction of the hydropower project started in mid-2011 and is scheduled to be fully operational by 2017. The GERD is not only unique for its 6,000 MW of potential [30, 34], more than twice the existing potential in Ethiopia, but for the substantial hydrologic implications it poses for downstream countries. The policies adopted for filling and managing the massive reservoir, with a total storage volume of 74,500 billion cubic meters (BCM), will directly impact the millions of people in downstream countries who rely on the Blue Nile's waters. Implications of climate

Fig. 12 The location of the Grand Ethiopian Renaissance Dam GERD (Google map)

Fig. 13 The location of GERD and the expected Blue River dams [35]

variability and emerging climate change within Ethiopia cast further uncertainty on potential filling policies and system operations.

Ethiopia also plans to build another four dams in the Blue Nile because of the huge amount of silt effluent which reached 136.5 million tons a year, and that need some trap dams to catch some of this silt behind the suggested four dams (Fig. 13).

The Sinnar, Jebel Aulia, and Khashm El-Girba Dams in Sudan

According to the World Commission on Dams (WCD 2000), the Sinnar Dam is the oldest in Sudan. It was built on the Blue Nile some 300 km south of Khartoum in 1926 to irrigate the Gezira Scheme, one of the world's largest irrigation projects. It is thus crucial to Sudan's economy. About 50 km southwest of Khartoum is the Jebel Aulia Dam, which was built in 1937 to support the Aswan Dam in southern Egypt. It was only in 1977 that Sudan gained control of the Jebel Aulia Dam.

The lake formed by the dam has a thriving fish population from which about 15,000 tons of fish is harvested annually.

The Khashm El-Girba Dam on the Atbara River some 200 km downstream of the Ethiopian border was built in 1964 to irrigate the Khashm El-Girba Agricultural Scheme and later the New Halfa Scheme. Later on, it began to produce hydropower. The reservoir lost 50 % of its capacity within 40 years due to siltation, with that proportion rising to 60 % over time. This concurrently impacted the amount of water available for irrigation and also affected hydropower production, which is now limited to only the flood season. The reservoir is flushed occasionally to remove sediment [33].

Roseires and Merowe Reservoirs in Sudan

The Roseires Dam on the Blue Nile was built for flood retention, irrigation, and hydropower purposes. Since its commissioning in 1966, the reservoir's capacity has declined by about 30 % due to sedimentation. It now generates a fraction of the potential hydropower available during the rainy season because the turbine intakes are frequently blocked by sediment. Dredging to remove sediment is conducted frequently [34]. Merowe multipurpose dam, one of Africa's largest hydroelectric projects, was completed in 2009. It is located in north-central Sudan near the Nile's fourth cataract. It was designed to generate about 6,000 GWh of electricity per year and to irrigate approximately 400,000 ha of crops. However, despite the expected economic benefits, there have also been some negative social, environmental, and archaeological costs, including significant loss of land for agriculture and human settlement.

Owen Falls Dam in Uganda

The Owen Falls Dam, now known as the Nalubaale Dam, is located near Jinja in Uganda. It was built in 1954 to generate hydroelectricity for Uganda and Kenya. The dam controls the upstream discharge from Lake Victoria and was Uganda's largest power station. In 1999, the Kiira Power Station extension was built about 1 km from Nalubaale, which allowed more water to be released and increased the hydropower capacity. This fact, along with a protracted drought in 2003, is thought to have contributed to the lowering of the lake to an unsustainable level [32, 33, 36] (Fig. 14).

Fig. 14 Nalubaale and Kiira dams in Uganda (Google Earth 2009)

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