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Nile River Basin

Ecohydrological Challenges, Climate Change and Hydropolitics

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Preface

Water is vital to life but its availability, distribution, and quality has been dwindling over time with population increase, climate change, and emerging new demands driven by economic and population growth. A large area of the globe is water-stressed. The severity and gravity of this issue is even much greater when water, a common good, needs to be shared among riparian countries. The most famous transboundary river for its rich history and service for over 238 million people in the basin in 11 countries is The Nile. The role of The Nile in human history and civilization has been well documented. The upper section of the basin provides nearly all the water and the lower section of the basin with no contribution is the sole beneficiary. This status quo water use is being challenged by the upper basin countries, mainly Ethiopia as economic growth and population pressure forces for the increased use of water for various consumptive and nonconsumptive uses. The sole historical users of Nile water, Egypt and Sudan, would like to see their use of water unchallenged while many upstream basin countries strive to develop various sizes of water resources development projects.

On the supply end, various studies have shown that flows from tributaries and hence Blue Nile River, a source of 62% of the Nile flow, 82% with Sobat (Baro-Akobo) and Atbara (Tekeze-Setit), has been declining due to population pressure in hydrologically sensitive areas, headwater contraction, land degradation as well as changes in rainfall regimes (quantity, timing, and distribution). The decline in the supply and the ever increasing demand of water in the basin calls for a new formula for water sharing as well as a collaborative effort to enhance water supply through watershed protection and management. Although this necessitates a forum for basin countries to take the lead and address the critical water resources issues the basin is facing on both sides of the water budget, the role of scientific information and reliable data for guiding dialogues and discussion to provide tools for informed decision is critical.

The availability of data and scientific studies on various aspects of the basin is scant and limited mainly to the lower section of the basin. The focus and priority for water resources research, especially in the upper basin is very limited and this contributes to the limited knowledge and understanding about the hydrologic processes in the critical part of the basin.

This book, *Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics*, presents results of various scientific studies ranging from state of the hydrology of the basin to land and water degradation, climate change impacts, watershed services, and transboundary water management. Under seven parts: (I) Hydrology and Water Availability, (II) Soil Erosion and Water Quality, (III) Lakes and Watersheds, (IV) Climate Change and Water Resources, (V) Water Accessibility, Institutional Setup and Policy, (VI) Transboundary Rivers, Water Sharing and Hydropolitics and (VII) Watershed Services and Water Management, 33 chapters are presented. Studies on data needed for stream flow simulation, satellite rainfall reliability, monitoring of surface water using remote sensing, surface and groundwater resources, and environmental challenges of drastic land use and ownership change and conversion of hydrologically sensitive areas to large scale commercial farms in the basin are presented. Various experimental and modeling-based studies on soil erosion estimation, sediment dynamics and impacts of land use change and management, and hydro-epidemiology of the Nile basin are also presented. Satellite-based land disturbance index for biomass mapping, lake bathymetry, spatial evapotranspiration modeling using satellite data and rainfall erosivity index are also discussed. The impact of climate change on water availability, adaptation strategies to cope with climate change and the role of indigenous knowledge to adapt, climate teleconnections of flows in the Nile basin and water management is addressed. Local and basin wide water governance and institutional setup in the basin and management of rainwater for resiliency of dryland areas are presented. International laws and norms that are the basis of transboundary river agreements are presented. Transboundary river management and the need for negotiation and dialogues to avoid unnecessary water conflict are covered. The Grand Ethiopian Renaissance Dam basic design features and simulation on its downstream flow impact during the reservoir filing and operation periods are included. Stakeholders' and institutions' engagement, perception, and willingness for the implementation of payment for watershed services are also presented.

The book contains the works of several water resources experts from the Nile basin and other countries. The book, as shown above, covers a wide range of topics that are timely and can be used by students, educators, researchers, policy makers, water and environmental resources managers, and others.

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Chapter 1
Introduction

A Scarce and Shared Resource: Hydrologic Threats, Trends, and Challenges in the Nile River Basin

Assefa M. Melesse, Wossenu Abtew and Shimelis G. Setegn

Abstract The Nile River basin is home to more than 238 million people covering 11 countries. The basin is characterized by unique ecological systems with varied landscapes including high mountains, tropical forests, woodlands, lakes, savannas, wetlands, arid lands, and deserts. The basin is also characterized by poverty, rapid population growth, environmental degradation, and frequent natural disasters. While the population in the basin is projected to increase significantly over the coming decades, the water resources are projected to decline, with an increase in environmental degradation. This will be a tremendous challenge in a basin where emerging water demands by upstream countries are forcing a new formula for the use of the scarce water resources. Unless a framework of agreement for equitable water sharing is reached soon between all riparian states, the potential for acute water conflict is high. Cooperation is essential for controlling watershed degradation and water quality decline.

Keywords Nile River · East Africa · Blue Nile · White Nile · Nile countries · Transboundary rivers

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1.1 Overview

The Nile River, at about 6,825 km, is the longest river in the world. It comprises two major tributaries, the White Nile and the Blue Nile (known as the Abbay in Ethiopia). The White Nile rises in the Great Lakes region of central Africa, with the most distant source in southern Rwanda and flows north from there through Tanzania, Lake Victoria, Uganda and South Sudan. The Blue Nile starts at Lake Tana in Ethiopia, and flows into Sudan from the southeast. The two rivers meet in the Sudanese capital Khartoum and flow north through Sudan and Egypt to drain into the Mediterranean Sea. The drainage area estimate varies between 3.1 Million km^2 (FAO 2007) to 3.3 million km^2 (CPWF 2007). The variation is due to difficulty in delineation of the sub-basin in the flat slope parts of Sudan and Egypt. Elven countries fall within the Nile basin these include Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda. The Nile River basin is home to approximately 238 million people, while over 443 million (based on World Bank 2006) live within the 11 riparian states. The Nile region is characterized by high population growth and considerable development challenges (Awulachew et al. 2008). The benefits of the Nile River need to be shared among these 11 countries, but the issues are hard to encompass.

1.2 Climate and Flow

The Nile River basin exhibits a varied climate and a spatiotemporal variability in precipitation. The northern part of the Nile basin is overwhelmingly described as desert, with little to no rainfall. The central portion of the basin is dominated by occasional, though infrequent, rainfall, and the headwater regions receive significant seasonal rainfall, although with large interseason and interannual variability. Analyzing the regional hydrological dynamics, therefore, requires intensive examination of the processes governing water balances, i.e., involving climatic and ecological forcings and feedbacks as well as population and industrialization pressures, both nationally and basin-wide. It is also evident that parts of the basin that receive lesser precipitation and, hence, contribute little to the basin's flow, utilize more water from the basin.

Hydrologically, flow of the Nile River is very small compared to the major international rivers of the world like that of Amazon but its historical significance and benefits to many people in the basin put the Nile in the forefront. Receiving its major annual flow mainly from the Blue Nile River in Ethiopia, the flow is highly dependent on rainy season runoff from the Ethiopian highlands. Various studies have indicated that these flows have shown a decline over a period of time attributed to factors ranging from poor headwater protection to land degradation to a decline in precipitation.

1.3 Climate Change and Nile Flow

It is projected that the decline in water resources availability will be exacerbated by the projected climate change impact on rainfall pattern and volume over the next century. According to Kim et al. (2008), the increased rainfall and resultant water supply in the upper Blue Nile that are anticipated through the middle of the century are likely to be positive in a region regularly beset by drought. However, according to El Shamy et al. (2009), over the longer term (2081–2098), the Blue Nile basin may become drier. Using the outputs from 17 Global Circulation Model (GCM) for the A1B scenario, their predictions varied between a -15 and $+14\,\%$ change in precipitation, with the ensemble mean suggesting little change. However, the projected increase in temperature and evaporation is expected to reduce the runoff.

According to the analysis by Beyene et al. (2010), much of the precipitation increase in the Blue Nile is anticipated in the winter (December, January and February) months, which may be of less value in this region, where the majority of the agricultural production systems are presently rainfed. However, the projections from Soliman et al. (2009) suggest that by the middle of the century, the annual discharge from the Blue Nile would be similar to recent historic levels, but with appreciable changes in the seasonality and spatial variability. This analysis used the A1B emissions scenario and the ECHAM5 (Max Planck Institute) GCM and considered the 2034–2055 timeframe. It suggested higher flows at the onset of the wet season, and reduction in flows at the end of the wet season and through the dry season.

1.4 Challenges in Sharing a Common Good

As the water resources of the Nile decline, the demand on the other hand is continuously increasing along with per capita demand and population increase. The need for more consumptive water resources development projects by the basin countries is putting the scarce and limited resource under pressure, requiring new thinking and collaboration for efficient use and sharing of the water equitably. This poses a challenge because major historical users of the water, Egypt and Sudan, do not want to accept the new reality but maintain their lion shares of the Nile. Upstream countries currently are progressing in developing a framework of basin management agreement, the Nile Basin Cooperative Framework Agreement. The agreement is signed by Ethiopia, Kenya, Uganda, Tanzania, Rwanda, and Brundi. South Sudan has stated to sign, while Egypt and Sudan have not shown willingness so far. New frame of agreement in sharing the Nile water that reflects the new emerging needs is critical for the transboundary water management that is inclusive and sustainable.

If basin counties are to successfully respond to the multifaceted threats that the next 20–50 years will bring, immediate action is required. Moreover, this action must be multinational, highly coordinated, and must be supported with the best scientific knowledge of the factors and processes responsible for the changes in the hydrology of the Nile River basin. In addition to the role of science in effective water resources management and help in the coordination and utilization of the common good, basin countries need to continue working together and face the new reality of both the supply and demand side of the water resources in the basin. The emerging needs from upstream basin countries as part of their economic development agenda and investment in the water sector will require a new framework of dialogues and understanding in accommodating these needs and rights.

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Part I
Hydrology and Water Availability

Chapter 2
The Nile River Basin

Wossenu Abtew and Assefa M. Melesse

Abstract The Nile River basin is one of the transboundary river basins that is in the forefront of water resource challenges of the century. As the basin's population is growing, water demand is increasing. Focus on basin hydrology, climate change, and water management is critically needed. The Blue Nile subbasin is relatively more efficient in generating runoff contributing most of the flow to the Nile compared to the White Nile. This makes flows susceptible to changes in the watershed. The basin's high rate of population growth is putting stress on natural resources including water. In 25 years, the population of the 11 Nile countries is projected to reach 726 million. A 64 % increase in water demand is projected in the Nile basin countries without factoring increase in per capita water demand. The link between river and watershed is becoming vivid as demand for water and power grows and becomes a source of conflict.

Keywords Nile River · East Africa · Blue Nile · White Nile · Nile countries · Transboundary rivers

2.1 Introduction

The Nile basin is one of the transboundary basins where the livelihood of millions will depend on its hydrology more than ever. The Nile, the longest river, 6,650 km in length, travels from East and East-Central Africa to the Mediterranean Sea with its watershed in 11 countries (Fig. 2.1). Growing population and limited water resources make hydrological variations more important. Historically, the Nile River has shown

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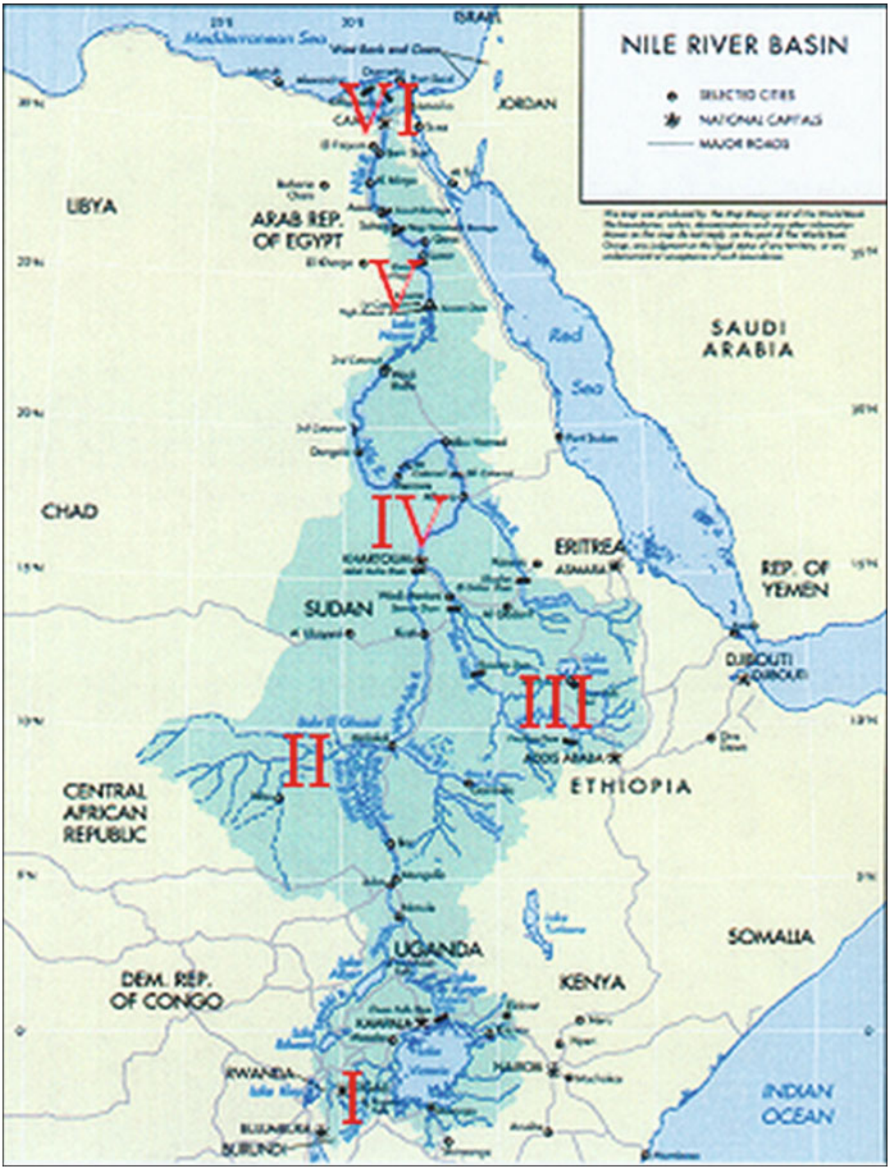

Fig. 2.1 The Nile River basin crosses six hydroclimatic zones: (*I*) lake plateau territory (Burundi, Rwanda, Tanzania, Kenya, and Uganda), (*II*) Sudd freshwater swamp (southern Sudan), (*III*) Ethiopian highlands, (*IV*) Sudan plains (central Sudan), (*V*) northern Sudan and Egypt (from the Atbara and Nile Rivers confluence to Cairo), and (*VI*) Mediterranean zone (coastal region with no measurable rainfall)

significant fluctuations in flow. Record droughts have been documented including the recent Sahelian drought of the 1970s and 1980s. A historical account of the Nile flow fluctuations is documented by Evans (1994). The reason why the Nile flow did

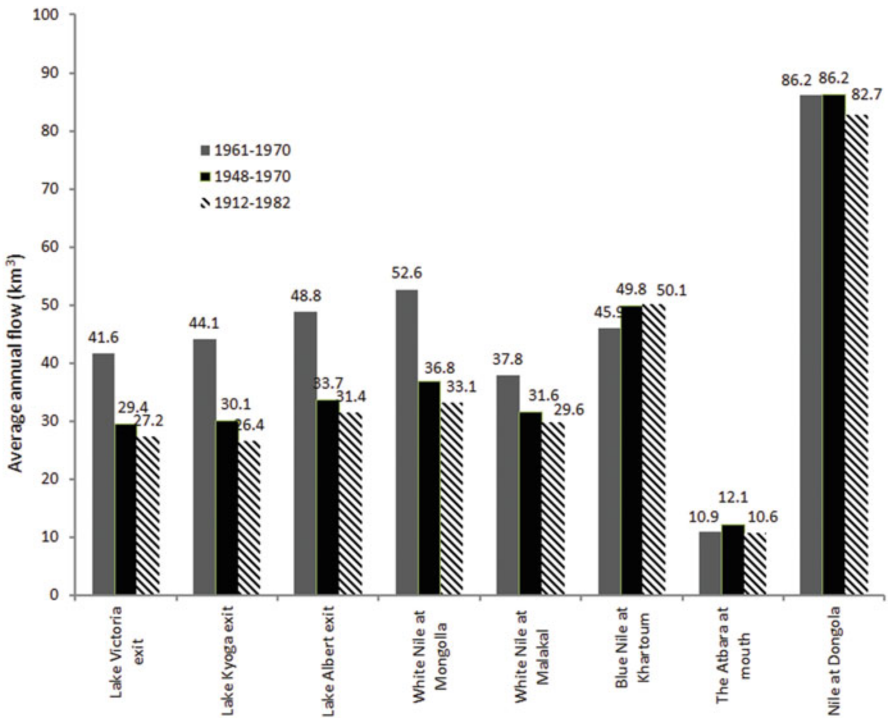

Fig. 2.2 Average annual flow variation for the Nile River system for different recording periods. (Data source: Karyabwite 2000)

not drastically decrease during the Sahelian drought was due to wet conditions in the Lake Victoria basin providing good flow through the White Nile. Historical intense droughts with dire impacts have been recorded by ancient Egyptians. Strontium isotopic and petrologic information indicated that around 4,000 years ago, the Nile flow was so reduced that it resulted in the downfall of a kingdom (Stanley et al. 2003). In recent periods, drastic fluctuation in flow has been reported. An estimated low flow record of 46 km^3 (billion m^3) occurred in 1913. A high flow estimate of 102 km^3 occurred from 1871 to 1898. Current mean flow at Aswan is 84 km^3 (Evans 1994). Flow record variation could be both climatic and measurement discrepancies. Figure 2.2 depicts average annual flow variation for three recording periods at main flow points on the Nile River system.

The Nile River basin drainage area is more than 3 million km^2 with 73 % of the drainage basin in Sudan and Egypt with net consumption of water. The ratio of the producing watershed to consuming watershed is low. Ethiopia, with 12 % of the drainage basin, generates 86 % of the river year-round flow. The remaining 14 % comes from the White Nile which has a larger drainage basin. The White Nile has year-round sustained flow mainly because of a rainfall pattern with less temporal variation. About half of the water generated by the equatorial lakes and watershed is lost in the Sudd marshes (Gedefu 2003). The climate of the Nile basin reflects the

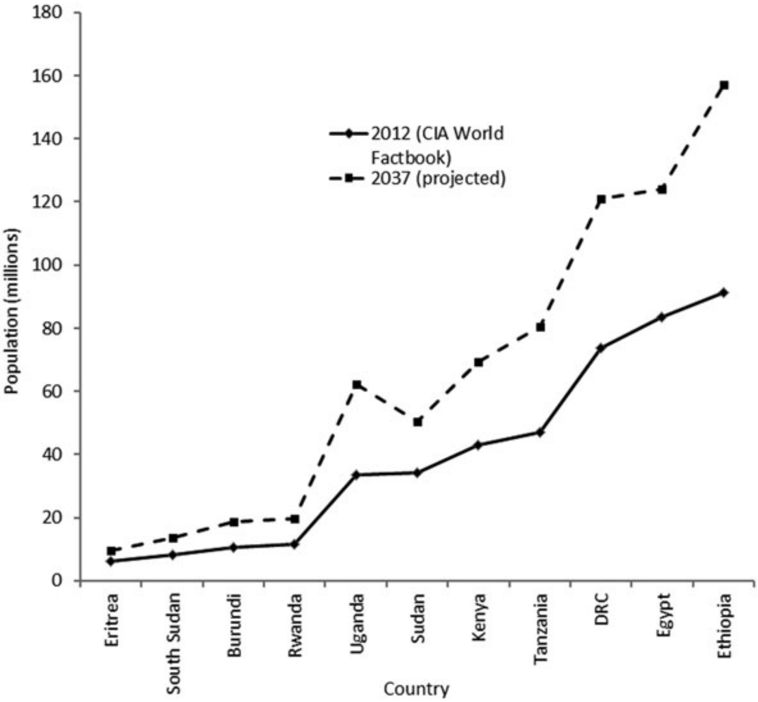

Fig. 2.3 Population of Nile countries. (2012 CIA World Factbook, South Sudan 2008 census)

latitude range (from 4° S to 32° N) and the altitude range (from sea level to more than 3,000 m). The basin extends from Mediterranean climate at the mouth of the Nile to tropical climate at the sources of the Blue and White Nile. In between is a large area with desert and semidesert climate changing into savannah in South Sudan. Rainfall varies from 2,000 mm in the southwest region of the Blue Nile basin to almost no rain in the Sudanese and Egyptian desert. The Rwenzori Mountains in the west rise as high as 4,500 m and annual rainfall can reach 3,000 mm contributing runoff to the White Nile.

The Nile basin countries, Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda, have a combined population of 443 million in 2012 with a projected population of 726 million in 25 years (Fig. 2.3). Overall, the watershed is not efficient in generating enough runoff to overcome losses; only 5 % of the rain results in runoff yield that makes it to the river terminus, 84 km^3 at Aswan. The average flow from all subbasins reaching Sudan is 90 km^3. The water demand in the Nile basin is growing due to population growth and increase in per capita water demand. Due to overpopulation and climate change, stress on water resources in the basin is growing.

Understanding the historical, current, and projected hydrology of the Nile is critical for managing the ever-increasing water demand in the basin with potential interests outside the basin too. Detail work on the hydrology of the Nile is presented by Sutcliffe and Park (1999). The seasonal pattern of rainfall in the Nile basin follows the movement of the intertropical convergence zone (ITCZ) with moisture sources from the Indian and Atlantic Oceans (Mohamed et al. 2005). The major lakes in the Nile basin system are Lake Victoria, Lake Kyoga, Lake Albert, Lake Tana, Lake Edward, and Lake Nasser. Numerous tributary rivers flow into the upper lakes. The major subbasins are the Blue Nile, Tekeze-Setit-Atbara, Baro-Akobo-Sobat, and the White Nile. The hydrology of each subbasin is important as drought in one subbasin may be compensated by wet condition in another subbasin.

2.2 Lakes of the Nile Basin

2.2.1 Lake Victoria

Lake Victoria with an area of 67,000 km^2 at an elevation of 1,134 m above sea level is the largest lake in Africa and the second freshwater lake in the world. It is the source of the Victoria Nile which is a major source of the White Nile and has a drainage basin of 194,000 km^2 (Piper et al. 2009). It is shared by Kenya (6 %), Uganda (45 %), and Tanzania (49 %). The drainage into the Lake is mainly from Kenya and Tanzania. The main inflow is from Kagera River on the west. The main rivers from Kenya are Kuha, Awach, Miriu, Nyando, Yala, Nzoia, Sio, Malawa, and Malikisi and from Tanzania are Mara and Kagera (Degefu 2003). Actually, the Kagera River flows from Burundi with contributions from tributaries in Rwanda and flow along the boundaries of Burundi and Rwanda, and Tanzania and Uganda. The lake has a maximum depth of 82 m with an average depth of 40 m. The Lake outflows at Owen Falls as the Victoria Nile. The Owen Falls has a hydropower dam since 1954. The dam has resulted in increasing the water level and storage of the lake. But in recent years, the water level has shown decline (Fig. 2.4). It has been difficult to provide a hydrological explanation for the sharp rise in water level from 1961 to 1964 (Piper et al. 2009). The Victoria Nile flows into Lake Albert through Lake Kyoga. Annual average (1912–1982) outflow from Lake Victoria is 27.2 km^3, while outflow from Lake Kyoga is 26.4 km^3 (FAO 1997). Periodic variation of flows from Lake Victoria is depicted in Fig. 2.2. The equatorial lakes region is shown in Fig. 2.5.

Rainfall seasonal characteristics in the Lake Victoria drainage basin are different from the Blue Nile basin. The Blue Nile subbasin wet season is distinct and it runs from June through September. Lake Victoria's drainage basin rainfall seasonal variation is smaller except for December, January, and February; the rest of the months have considerable rainfall ranging from 105 to 200 mm. Runoff has also lower seasonal variation with lows in January through March but between 20 and 40 mm from April through December as derived from Khan et al. (2011). Their study was on the major subbasin of Lake Victoria, Nzoia. The highest monthly rainfall is in April and the highest runoff is in May when the Blue Nile basin is in dry season. As a result of this type of rainfall temporal distribution, the White Nile has consistent month-to-month flow when compared to the Blue Nile.

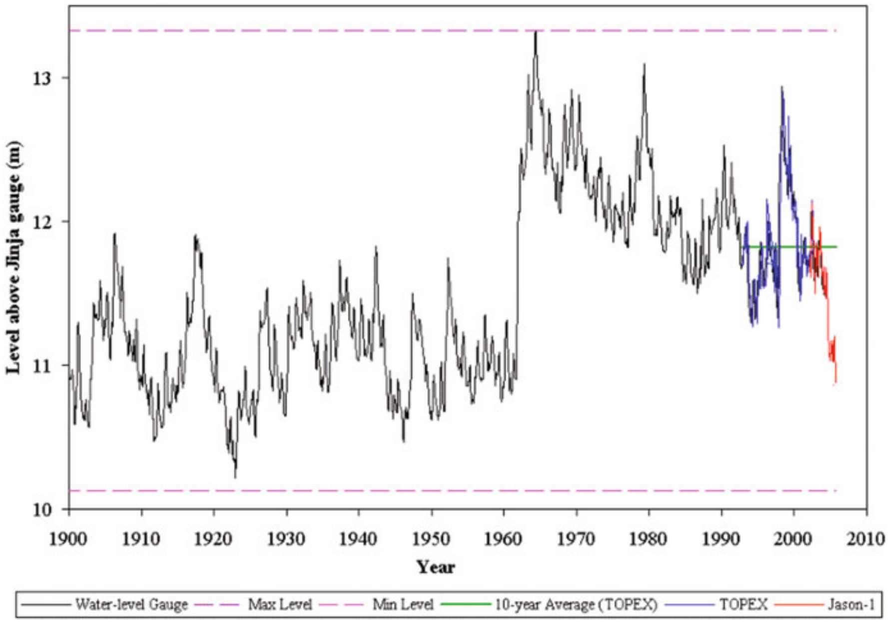

Fig. 2.4 Lake Victoria historical relative water level at Jinja, Uganda. (USDA, Production Estimate & Crop Assessment Division)

Fig. 2.5 Equatorial lakes, source of the White Nile. (Source: USDA)

2.2.2 Lake Albert

Lake Albert lies on the border of Uganda and Democratic Republic of Congo at an elevation of 619 m with an area of 5,374 km^2. When the Victoria Nile enters Lake Albert, the Albert Nile flows out to South Sudan entering the Sudd branching into Bahr El Zafar and Bahir El Jabal later joined by Bahr El Ghazal and local tributaries. At Malakal, the Sobat joins from the east forming the White Nile (Fig. 2.1). Although there are various rivers and streams that join the inflows and outflows of Lake Albert from the Rwenzori Mountains, the Semliki River is the major inflow. The Rwenzori Mountains, with annual rainfall between 2,000 and 3,000 mm, are also considered as source of the White Nile (Eggermont et al. 2009). The highest source of the Nile contributes significant flow to the White Nile from rainfall and glacier melts although not as much as Lake Victoria. Lake Edward in the same drainage basin at an elevation of 920 m and area of 2,325 km^2 flows into Lake Albert. Annual average (1912–1982) flow out of Lake Albert (Albert Nile) is 31.4 km^3 (FAO 1997). Variation in annual flows from Lake Albert is depicted in Fig. 2.2.

2.2.3 Lake Tana

The Blue Nile flows out of Lake Tana in the Ethiopian highlands. Lake Tana at an elevation of 1,786 m above sea level has an area of 3,156 km^2 (Fig. 2.1). It has drainage basin of 16,000 km^2 with inflows mainly from four rivers, Gilgel Abay, Ribb, Gumera, and Megetch (Chebud and Melesse 2000). It is a relatively shallow lake with a mean depth of 7.2 m and a maximum depth of 14 m (Wale 2008). Water level changes are attributed to human activities and changes in climate. Figure 2.6 depicts Lake Tana mean monthly water level fluctuations from a reference point at Bahir Dar. Increasing trend is shown since 1990 but decline started in the 2000s after operation of the weir, built to regulate flow into the Blue Nile. Water level fluctuation for Lake Tana is relatively smaller. A sustained severe drought for 7–8 years is expected to terminate outflow from the lake (Kebede et al. 2006). Lake Tana outflows as the Blue Nile with an estimated mean annual flow of 3,732 million m^3 and a minimum and maximum estimated range of 1,075 and 6,181 million m^3, respectively (Rientjes et al. 2011).

2.2.4 Lake Nasser

Lake Nasser is a man-made lake or reservoir result of the Aswan High Dam built on the Nile River by Egypt covering some territory of Sudan (Fig. 2.1). At a water surface elevation of 175 m, it has an area of 5,168 km^2 with a volume of 121.3 km^3 (Abdel-Latiff 1984). The lake area has no measurable rainfall, and evaporation losses are high, 2.7 m yr^{-1} (Omar and El-Bakry 1981). Mean annual inflow of the Nile at Aswan is 84.1 km^3 (Table 2.1).

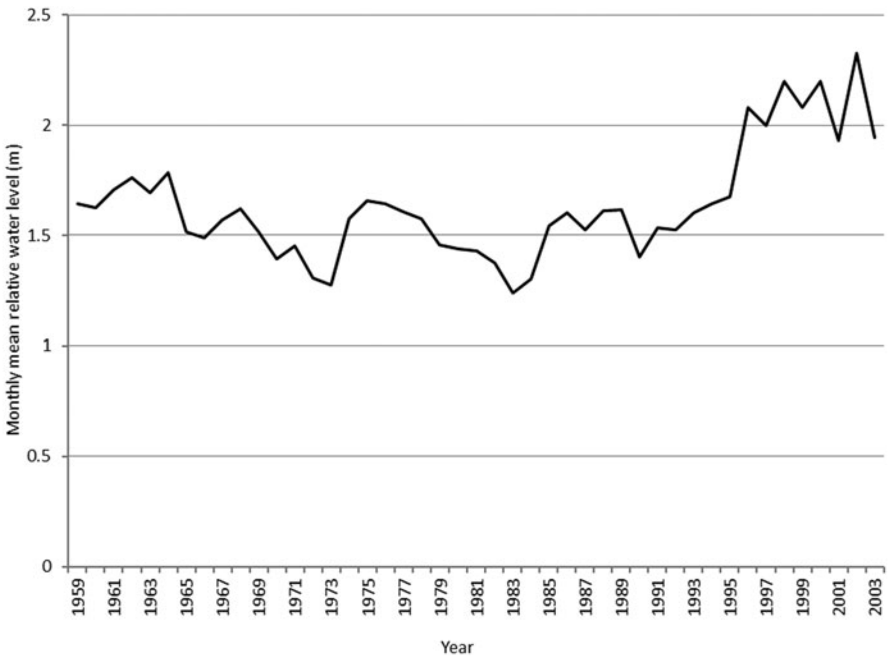

Fig. 2.6 Relative water level fluctuation of Lake Tana (1959–2003)

Table 2.1 Average annual flows of the Nile River system. (Modified from Sutcliffe and Park 1999)

Watershed	Annual flow (km^3)
Nile at Aswan	84.1
Atbara at mouth	11.1
Blue Nile at Khartoum	48.3
White Nile at Khartoum	26.0
Sudd at Malakal	16.1
Sobat at Malakal	9.9

2.3 Watersheds and Tributaries

The source of the Nile is not much of hydrologic significance as most of the flows come from the tributaries. A spring in the Ethiopian highland is the source of the Blue Nile. The Kagera in Burundi or the Rwenzori Mountains at the border of Uganda and the Democratic Republic of the Congo either or both may be referred as the source of the White Nile. The major river systems of the Nile are the Blue Nile, the Sobat, the Atbara, and the White Nile contributing 55, 12, 15, and 18 %, respectively (Sutcliffe and Park 1999).

2.3.1 The Blue Nile

The Blue Nile River basin is the main source of the Nile River with a drainage area of 324,530 km^2 (Peggy and Curtis 1994). The Upper Blue Nile basin is 176,000 km^2

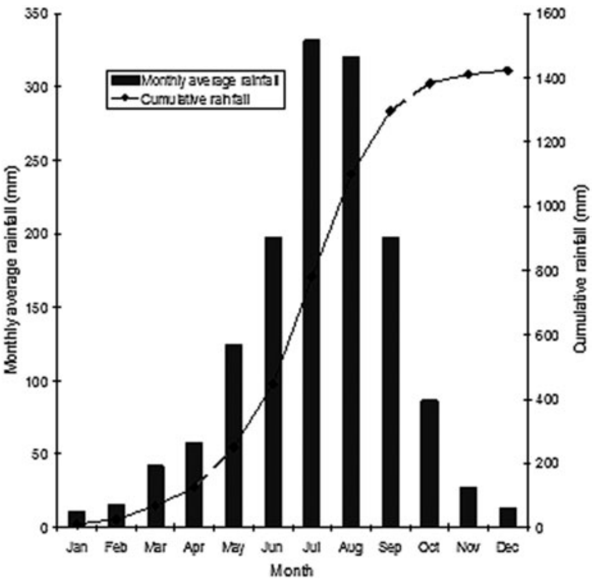

Fig. 2.7 Monthly distribution of rainfall over the Blue Nile basin. (Abtew et al. 2009)

in area (Conway 2000). The major tributaries of the Blue Nile River in Ethiopia are Gilgel Abbay, Megech, Ribb, Gumera, Beshlo, Woleka, Jemma, Muger, Guder, Chemoga, Wenchit, Fincha, Dedessa, Angar, Dura, Rahad, Dinder, Dabus, Gulla, and Beles. The upper Blue Nile River basin is wet when compared to the lower basin (part of the Blue Nile drainage basin outside Ethiopia until it joins the White Nile River).

Rainfall over the Blue Nile basin has distinct seasonal variation with June, July, August, and September being the wet months. May is the transition month from dry to wet season and October is the transition month from wet to dry season. Mean monthly rainfall distribution over the basin is shown in Fig. 2.7. Dry season rainfall variation is high. Annual rainfall ranges from more than 2,000 mm in the southwest of the basin to 800 mm in the northeast (Abtew et al. 2009). Mean annual rainfall is 1,423 mm with a standard deviation of 125 mm. It is a relatively wet basin. The estimated 100-year drought annual basin rainfall is 1,132 mm while the 100-year wet annual rainfall is 1,745 mm. A basin-wide anomaly of ± 300 mm of rainfall would result in extreme drought or high stream flows. Spatial variation of annual rainfall in the Blue Nile basin is depicted in Fig. 2.8.

The mean annual flow of the Blue Nile from Lake Tana at Bahir Dar is 3.7 km^3 with 70 % of the flow occurring from June to September. Seventy-three percent of the rainfall in the basin occurs from May through September (Abtew et al. 2009). With tributaries joining along its journey, mean annual flow at the Sudan border at Roseires reaches 48.7 km^3. At Khartoum, the Blue Nile with a mean annual flow of 48.3 km^3 joins the White Nile to become the Nile (Table 2.1). Periodic variation of the Blue Nile flow is shown in Fig. 2.2.

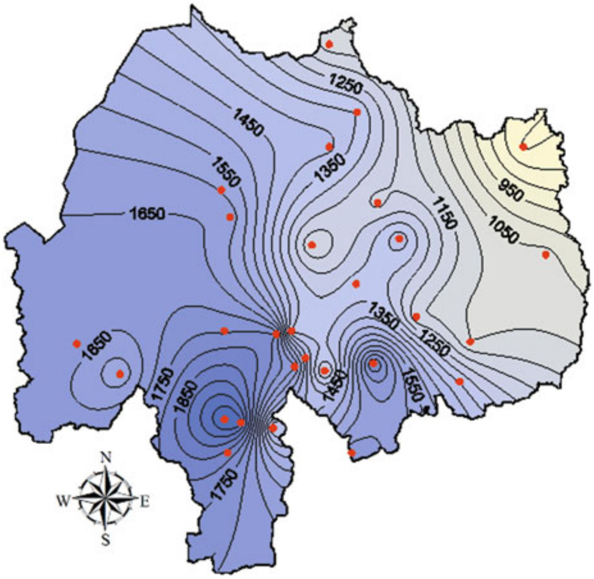

Fig. 2.8 Spatial variation of annual rainfall in the Blue Nile basin. (Abtew et al. 2009)

2.3.2 The White Nile

The farthest source of the White Nile is said to be the Kagera River that flows from the mountains of Rwanda and Burundi or streams and glacial melt from the Rwenzori Mountains, a border between the Democratic Republic of the Congo and Uganda (Eggermont et al. 2009; Sutcliffe and Park 1999). The White Nile at Khartoum basin area is about 1.7 million km^2 (Tesemma 2009). From the east, Lake Victoria drains into Lake Albert through Lake Kyoga as the Victoria Nile (Fig. 2.1). The western drainage flows into Lake Albert through Lake Edward and the Semliki River and exits from Lake Albert as Albert Nile. The Albert Nile, also known as Bahr El Zeraf, flows into the flat marshes of the Sudd branching and joining Bahr El Ghasal and local tributaries. The Sobat joins from the east as the White Nile travels north to Khartoum to join the Blue Nile and become the Nile. Later, the Atbara joins from the east, north of Khartoum. Mean annual flow of the White Nile is estimated as 26 km^3 (Table 2.1) and variation of periodic flow is shown in Fig. 2.2.

2.3.3 The Sudd

The Albert Nile flows into a large flatland and forms one of the world's largest wetlands extending to 125,000 km^2 of marshes during high flows but averaging 30,000 km^2 in area. Lateral branching forced by flat topography creates the maximum opportunity for evapotranspiration. The slow flow through the vegetated marsh results in as much as 50 % of the water being lost in evapotranspiration and seepage.