Assefa M. Melesse *Editor*

Nile River Basin

Hydrology, Climate and Water Use

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Editor
Dr. Assefa M. Melesse
Florida International University
Department of Earth and Environment
Modesto A. Maidique Campus
33199 Miami Florida
USA
melessea@fiu.edu

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Foreword

The River Nile Water is the lifeblood for 180 million people who live in the river basin. Nile water supports hydropower, agriculture, navigation, and a multitude of ecosystem services all essential for economic growth, poverty reduction, and stability in the region. The region has the potential for rapid growth, and many individuals, communities, companies, and countries have high hopes that the Nile waters can support growth and prosperity. While the future expectation of what the Nile can deliver to its people is extremely high, in fact the resource is limited, and there is a real danger that ill-planned development can lead to degradation and conflict.

Underpinning good planning and development is knowledge about the hydrology of the Nile system. While there has been millions spent on development, and there are large plans for more development, it is surprising how little basic data and analysis is readily available, especially data for the upstream countries in the basin. For historic reasons, Egypt and Sudan possess a wealth of knowledge about the Nile waters and its use. This is not true for upstream countries who have tapped very little of the Nile River water resource, but who are looking to gain more benefits from the Nile in the future. Information in the book plays an important role to bridge this gap. There is a wealth of new modeling and information techniques that can really help build a better picture of water resources in the region. This book makes an advance in bringing these techniques to bear on the Nile basin.

The book covers a range of biophysical issues important for the Nile basin. For example, fundamental to water management are the water budgets of the major lakes in the region which are revisited in this book. Ultimately rain is the source of water for the Nile River basin, yet the knowledge of historic, let alone real time rainfall across the huge basin is scant. Satellite rainfall estimation provides some exciting opportunities to fill in this void, and there is a great opportunity for their application in planning and real time management as the book reveals. Ultimately many decisions are made in a watershed context, and GIS and remote sensing provide the spatial tools needed for communities and countries to explore options for development. Climate variability and climate change are major unknowns in the region, but people have to contend with climate variability in their day to day lives. Chapters in the book shed light on basic processes and provide tools which are useful to better analyze and understand the implications of climate change and climate variability.

Ultimately decisions have to be made about the allocation of Nile waters amongst different users, and different countries. While it can be argued that these decisions are largely political, science has an important role in informing better ways to serve all, to highlight tradeoffs that need to be made, and to minimize negative consequences. Making better water decisions requires better knowledge of water availability, how water is accessed now, what is the productivity of its use, environmental flows, and the implications of future demands and development scenarios. The book, *Nile River Basin: Hydrology, Climate and Water Use* represents an important milestone for work on Nile waters. It is an important reference for professionals, policy makers, practitioners, researchers and students who are required to find solutions for the people dependent on Nile waters, and their children. It provides a critical resource for the people managing this transboundary river, and thus the people dependent on its water. It is an important milestone for those addressing one of the most pressing challenges of our time, water scarcity.

David Molden

Introduction: Hydrology of the Niles in the Face of Climate and Land-Use Dynamics

Assefa M. Melesse, Seleshi Bekele, and P. McCornick

1 Nile River Basin 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 southern Sudan. The Blue Nile starts at Lake Tana in Ethiopia, and flows into Sudan from the southeast. The two rivers meet at 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. Ten countries fall within the Nile basin and these include Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda (Molden et al., 2010). The Nile River basin is home to approximately 180 million people, while over 350 million (based on World Bank, 2006b) live within the 10 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 10 countries, but the issues are hard to encompass. The unbalanced distribution of water, wealth, and power have made the issues even more challenging for gaining information and creating appropriate interventions (Molden et al., 2010).

A.M. Melesse (✉)
Department of Earth and Environment, Florida International University,
Modesto A. Maidique Campus, Miami, FL 33199, USA
e-mail: melessea@fiu.edu

2 Hydrometeorological Variability

Historical hydro-meteorological data analysis of the basin showed a high variability in the river flows and rainfall pattern. The variability of dry season precipitation hence river flows is higher than that of the wet season rainfall and river discharges. The spatial variability of rainfall and river discharges is also high with the upper basin receiving more rainfall and thereby generating most of the runoff than downstream, with virtually no flow generated in the lower basin. The relative contribution to the mean natural Nile River at Aswan of 84.1 Gm^3/year (mean of 1900–1950) is approximately 4/7 from the Blue Nile, 2/7 from the White Nile (of which 1/7 is from the Sobat), and 1/7 is from the Atbara River (Molden et al., 2010), signifying that over 85% of the Nile flow is generated in the Ethiopian highlands. The long term mean flow of the Nile at Aswan is in fact higher than 84.1 Gm^3/year (Awulachew et al., 2010).

A close examination of the seasonality of rainfall and flow using wavelet analysis showed different frequency recurrence for the rainfall and river flows for the upper Blue Nile River basin (Figs. 1 and 2). Figures 1 and 2 show the Continuous Wavelet

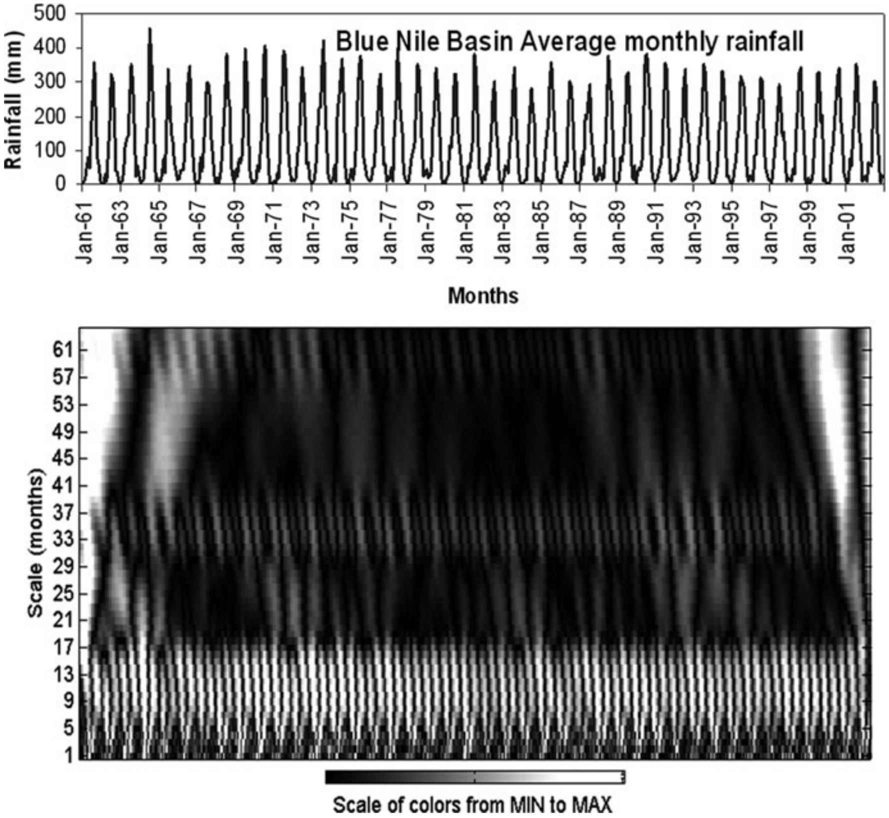

Fig. 1 Continuous wavelet transform for Blue Nile basin-wide Rainfall (Melesse et al., 2009)

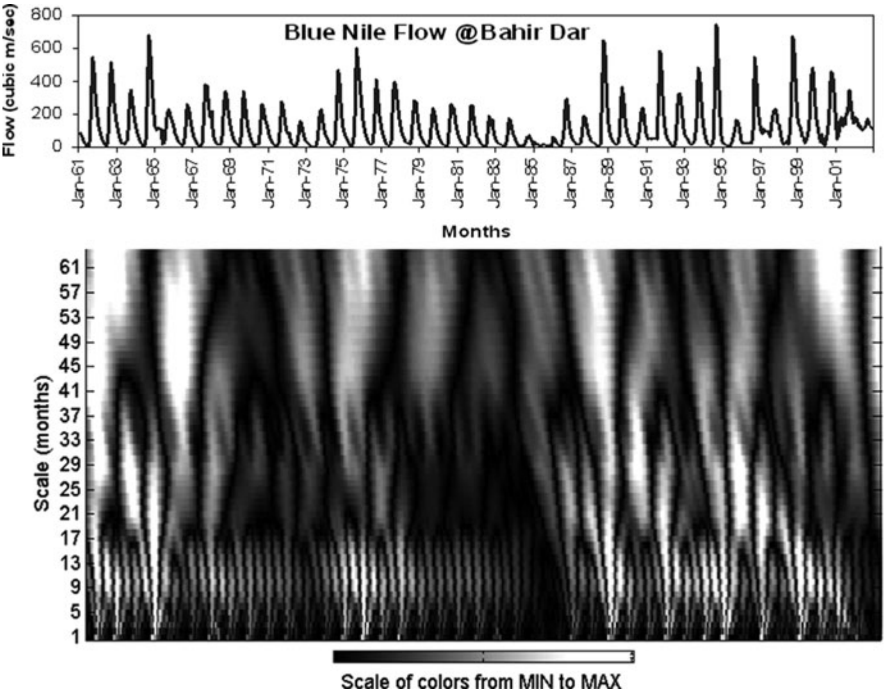

Fig. 2 Continuous wavelet transform for the monthly average flow Blue Nile at Bahir Dar (Melesse et al., 2009)

Transform (CWT) maps of the basin-wide average monthly rainfall and Blue Nile flow at Bahir Dar, respectively. The wavelet time-frequency analysis of the rainfall and flow in the upper Blue Nile River basin has shown various trends at different time scales. As depicted in Fig. 1, approximately a 10-year trend is shown for the Blue Nile basin wide rainfall around 1963, 1973, 1983, 1993 and 2003 at a scale of 17–30 months. The wavelet spectral power of the Blue Nile basin-wide average rainfall was also strong for the period of 1961–1963 at a scale of 41–64 months. The time-frequency representation for the monthly average flow of Blue Nile River at Bahir Dar (Fig. 2) for the period from 1987–2003 has shown some trend which is consistent at different scales (9–17, 17–30 and 30–61 months). The 17–30 months scale trend was very strong for the 1987–1997 period.

Scale represents the width or frequency of the signal. When the scale factor is relatively low (high frequency), the signal is more contracted which in turn results in a more detailed time series graph. However, low scale does not last for the entire duration of the signal. On the other hand, when the scale factor is high (low frequency), the signal is stretched out which means that the resulting graph will be presented in less detail. Nevertheless, it usually lasts the entire duration of the signal.

The Gravity Recovery and Climate Experiment (GRACE) (GRACE, 2010) satellite-based monthly changes in gravity converted to equivalent water in the Nile River basin is shown in Fig. 3. These maps demonstrate that the stored water and

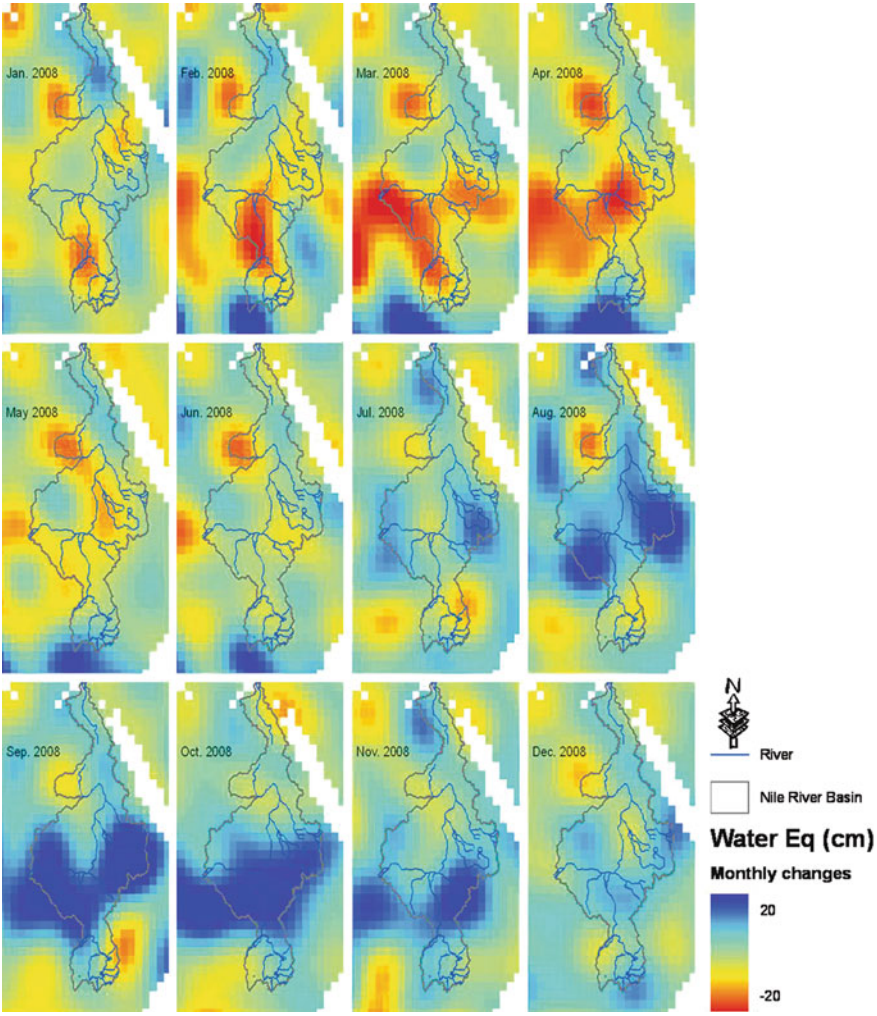

Fig. 3 GRACE-based monthly changes of water equivalent for the Nile River basin in 2008

monthly moisture flux within the basin are highly seasonal as well as spatially variable. The Blue Nile (Lake Tana) and middle part of the Nile River basin receives large amount of water in the July-September period resulting in positive monthly changes (see Fig. 3). On the other hand, the maps for January-May indicate a negative moisture flux, due to limited rainfall and increasing evaporation.

The potential evapotranspiration (PET) maps of the Nile River Basin (Fig. 4) based on the Penman-Monteith (PM) equation (FEWS NET, 2010) demonstrates the considerable temporal and spatial variation in potential evaporation across the basin.

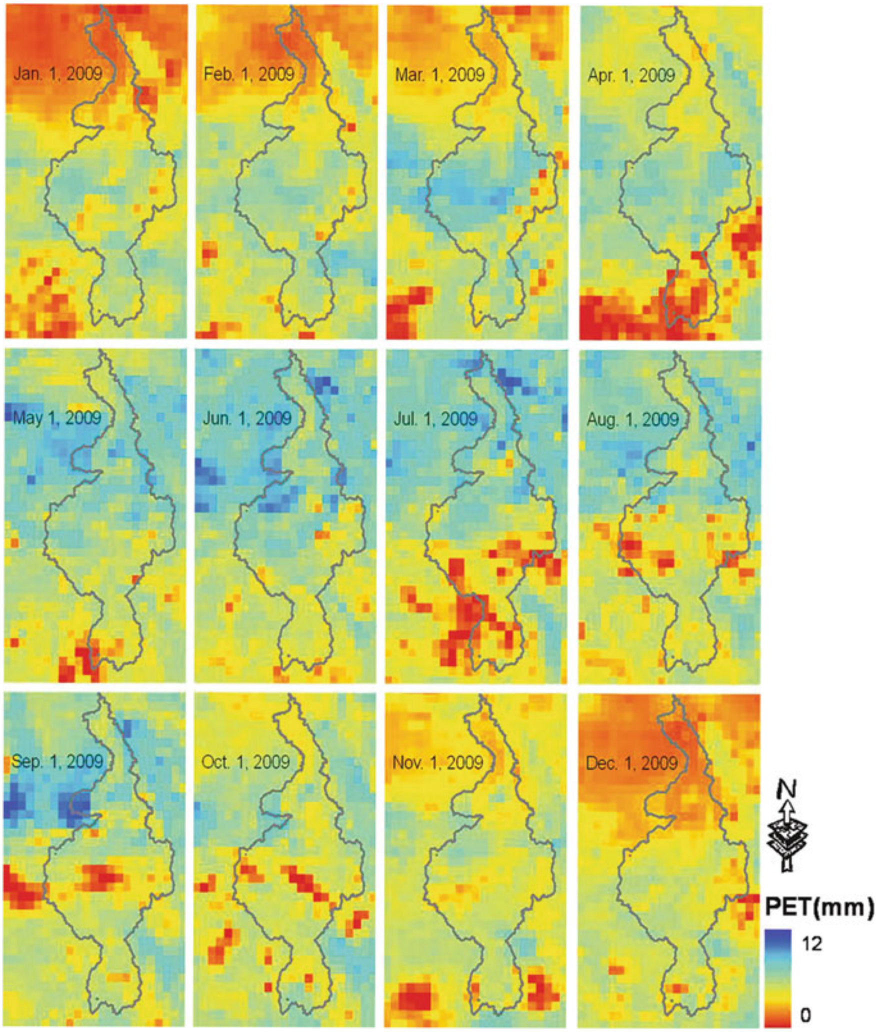

Fig. 4 Daily potential evapotranspiration (PET) across the Nile River basin

3 Land Use/Land Covers Change and Land Degradation

Although the Nile River is the longest river in the world, the total volume of water in the Nile River system is much smaller than the Amazon (2%), Mississippi (15%) and Mekong (20%) Rivers. But the river is historically important and the livelihood of many people depends on it. The basin is characterized as one of the most degraded mainly due to rapid population growth, poverty, political instability, poor watershed management, poor or absence of effective water use policy and frequent natural disasters. Home of the second and the third populous countries of Africa, the Nile basin is under continuous pressure to provide the water needs of the basin. The population pressure in the Blue Nile River part of the basin has led to serious land degradation and land conversion to agricultural areas. This has led to increased soil erosion, loss of soil fertility and reduction in dry season flows. Although there is no a reliable basin wide systematic analysis of land use and land cover change, satellite images shows land cover changes in the upper Blue Nile River and other parts of the basin.

Numerous challenges face the basin. Fifty percent of the countries in the basin such as Burundi, DR Congo, Eritrea, Ethiopia and the Sudan face the challenge of food security due to poor agricultural productivity, climate change, degradation and conflicts. Subsistence and rain-fed agriculture, together with high rainfall variability is one of the main causes of food insecurity and the most daunting challenge the basin faces. Degradation is extensive in the upstream countries such as Ethiopia, Eritrea, Rwanda and the Lake Victoria region. Drought and floods are critical issues in most of the upstream countries, including Sudan, with the potential to be exacerbated by climate change.

Large wetlands are found in eight of the Nile basin countries. Preservation of some of these wetlands such as the Sudd is a topic of considerable transboundary and international importance. The benefits of the Nile River need to be shared among the 10 riparian countries, but the issues are hard to encompass and often appear as sources of disagreements and conflicts. On the other hand, many believe that if the difficulties of the Nile basin hydro-political impasse is resolved, the significant potential of the water resources (i.e. hydropower) can benefit the people of all riparian countries.

Over 70% of the basin's people depend on subsistence, rain-fed agriculture (http://eastafrica.iwmi.org/) (IWMI, 2010). However, the resource base of land and water is not well utilized, nor appropriately managed, and is degrading very rapidly due to population pressure and poor agricultural practices. Water related diseases are common and a major cause of the relatively low life expectancy in the region. Livestock, fisheries and aquaculture are fundamental in the daily lives of people along the Nile, but have been neglected topics in the water discourse (Molden et al., 2010). Livestock are essential to many groups in the Nile basin; they establish the wealth of a family, determine the ability to marry and indicate the social standing of several groups within the basin. Water, food and health issues for animals and humans are crucial. The potential to develop fisheries along the Nile River is very promising (Molden et al., 2010).

4 Climate Change and Predicted Impacts on Available Water

There is generally good agreement on anticipated temperature increases across the Nile basin over the course of the coming century (Beyene et al., 2010; Jeuland, 2009; and Conway, 2005), but for the projections on likely trends in precipitation and runoff, there is less concurrence. Jeuland (2009) concluded that, while there remains considerable disagreement on the likely effects of climate change on the water resources in the basin, the research to date suggests that the rainfall and runoff in the Lake region (White Nile) is likely to increase, the Eastern Nile (including the Blue Nile) is highly uncertain, and even where precipitation increases the increased temperatures may reduce runoff.

Recognizing that there are considerable differences in results, using the mean output from a number (ensemble) of models results does greatly reduce the range of projections (Jeuland, 2009). Using this approach with the results from 11 GCMs, Beyene, et al. (2010)[1] suggested that the effects of climate change would cause the basin to become wetter over the next three decades, and thereafter drier. Furthermore, the average results suggest a wetter winter (DJF) in both the Blue and White Nile, and mixed results in the summer (JJA).

We should recognize that there are other changes in the basin that are likely to have a greater effect on the water resources over this same time-scale, especially the increasing demand for agriculture and other productive uses.

According to Kim et al. (2008), the increased rainfall and resultant water supply in the upper Blue Nile that is anticipated through the middle of the century, is likely to be positive in a region regularly beset by drought. However, according to ElShamy et al. (2009), over the longer term (2081–2098), the Blue Nile basin may become drier. Using the outputs from 17 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 projected to reduce the runoff.

Based on 15 GCMs, Setegn et al. (2011) (Chapter 12 by Setegn et al. this book) downscaled the temperature and precipitation to a watershed scale for the upper Blue Nile River basin for the 2046–2065 and 2080–2100 periods and assessed the impact on the hydrology of the Blue Nile River at selected gauge stations. The Soil and Water Assessment Tool (SWAT) model output based on the downscaled data shows that flow, soil moisture, evapotranspiration and groundwater levels can change significantly but also were highly variable across the different GCMs leading to high uncertainty and less conformity in the predication.

The seasonal distribution of these possible increases also needs to be considered. According to the analysis by Beyene et al. (2010), much of the precipitation increases in the Blue Nile are anticipated in the winter (DJF) 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)[2] suggest that by the middle of the century the annual discharge from the Blue Nile

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[1] Beyene et al. (2010) compared the results of eleven Global Change Models (GCM) on water resources in the Nile basin for both the A2 and B1 IPCC climate change scenarios. The B1 scenario assumes continuing economic growth and global trade, population growth gradually slowing down to a maximum of close to 9 billion people by 2050 and the adoption of clean and resource efficient technologies, and the A2 assumes less globalization and cooperation, relatively slow economic and technological development, and the continuing expansion of the world's population that would reach 15 billion by the end of the century.

[2] This analysis used in the A1B emissions scenario and the ECHAM5 (Max Planck Institute) GCM and considered the 2034–2055 timeframe.

would be similar to recent historic levels, but with appreciable changes in the seasonality and spatial variability. This analysis 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.

Where there is irrigated agriculture, the anticipated effects of climate change on the already highly variable seasonal and spatial variation is likely to be a complicating factor. While overall the eastern portion of the Nile basin is likely to be wetter in coming decades, the expectation is that there will be a greater frequency and magnitude of extreme and localized climatic events (e.g., heavy precipitation, flooding and drought).

Similarly on the White Nile, the effects of climate change on the spatial variability of the water resources at the lower scales are expected to be relatively high. The lakes are expected to have a moderating effect on the downstream flows, although lake level changes are anticipated to be modified with climate change (Beyene, et al., 2010).

5 Impacts of Climate Change to Economic and Other Sectors (Agriculture, Health, Energy)

The predicted changes in climate discussed above, while potentially beneficial in some cases, add further uncertainty to water resources systems in the Nile basin that are already naturally highly variable. In addition to the impact on the existing situation, this increases the uncertainty associated with major investments in water and other related sectors, especially agriculture, energy, transportation (i.e. roads) and urban development.

Based on the projections by Beyene et al. (2010), the annual inflows into the High Aswan Dam would increase by approximately 10% above recent historic averages through 2040, which would allow for approximately 6% increase in annual irrigation over this time period. However, using the same predictions, inflow into the reservoir is projected to decline to 15% less than the historical average by the end of the century due to the drying trend and increased evaporative demand. Should this occur, by around the middle of the century the irrigation releases are predicted to decline to 87% of recent historical averages and remain at this level thereafter. Hydropower is expected to follow a similar trend over the same time period that is increase through 2040 and then decline thereafter.

The situation becomes more ambiguous upstream of the High Aswan Dam, in part because of the existing spatial and temporal variation of the precipitation and runoff, the increased uncertainty of the projections at lower scales, a higher dependency on rainfed agriculture, and the relatively low levels of development of water resources. The more vulnerable countries and communities are in many cases the least able to cope and adapt. Securing and sustaining water supply to these communities, creating the resilience to survive extreme events, and enhancing the capacity to use water productively will be a challenge (Sadoff and Muller, 2009). This is of particular concern where there is a strong correlation between the hydrologic shocks, and reduced economic growth and increasing poverty, as is the case in many of the countries within the basin (World Bank, 2006a).

The future impacts of climate change would introduce additional risks of negative health impacts from the increasingly limited and poor-quality global water supply (WHO, 2009), especially in parts of the basin where significant portions of the population continue to be exposed to the disease burden brought on by poor water quality, water shortages and the effects of floods. The anticipated climate change conditions that include a greater frequency and magnitude of extreme climatic events (e.g., heavy precipitation, flooding and drought) will have potential impacts on population health as such conditions make securing clean drinking water more difficult. In addition, these same extreme events can further destabilize an already food-insecure situation and the nutritional status of the local population, even where the overall climate is wetter.

6 Adaptation Strategies to Future Climate Change Related Disasters

Effective water resources management is fundamental to successful adaptation, and adaption efforts need to be appropriately integrated into on-going development and resource management systems, in a fashion that compliments climate change mitigation. Failure to do this not only means missed opportunities, but could result in mal-adaptation, including infrastructure that is not designing for the conditions or institutional (i.e. water rights) and organizational arrangements that don’t have the flexibility or capacity to respond.

Efforts to adapt to climate change need to recognize and integrate with the broader sustainable development and the effects of the other drivers affecting the particular context; implement good water management practices, such as improving efficiency, enhancing storage and risk management, that will improve resilience to cope with the uncertainties of climate change; improve governance from communities up to basin or national level frameworks; recognize the economic consequences of inaction and securing the necessary financing (economics and financing); and enhance and disseminate the knowledge and information required for local adaptation, and to reduce uncertainties, including early warning (adapted from the Nairobi Principles[3])

The planning, development and management of water resources in the Nile basin, which has historically been undertaken in a highly variable and relatively data sparse environment, must further allow for the uncertainty associated with the potential

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[3] The Nairobi Statement on Land and Water Management for Adaptation to Climate Change Nairobi, 17 April 2009. Dialogue on Land and Water Management for Adaptation to Climate Change. http://landwaterdialogue.um.dk

non-stationarity of the resource and disagreement in predictions. Given that the spatial and temporal changes are expected to be relatively extreme, and that there is more uncertainty on the impacts of the water resources, adaptation approaches in the sub-basins of both the Blue and White Niles need to be more nuanced.

The book,"Nile River Basin: Hydrology, Climate and Water Use" is a collection of various reviews, analysis and study results covering a wide range of topics and issues. The chapters cover from the physical hydrology and climate change to water use and allocation. The chapters are organized in 6 thematic areas (Hydrology and water budget, Satellite rainfall estimation, GIS and Remote sensing in watershed modeling, Climate variability and hydrologic response and Water resources management, allocation and policy I and II).

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Contributors

Wossenu Abtew South Florida Water Management District, West Palm Beach, FL, USA, wabtew@sfwmd.gov

Enyew Adgo Bahir Dar University, Bahir Dar, Ethiopia, enyewadgo@gmail.com

Tilahun Amede International Livestock Research Institute (ILRI), International Water Management Institute (IWMI) and Challenge Programme on Water for Food (CPWF), Addis Ababa, Ethiopia; International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, t.amede@cgiar.org

Asmare Atalay Virginia Tech University, Blacksburg, VA, USA

Seleshi B. Awulachew International Water Management Institute (IWMI), Addis Ababa, Ethiopia, s.bekele@cgiar.org

Essayas K. Ayana Department of Water Resources and Environmental Engineering, Bahir Dar University, Bahir Dar, Ethiopia; Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, USA, ekk45@cornell.edu

Haimanote K. Bayabil Cornell Master's program in Integrated Watershed Management and Hydrology, Bahir Dar, Ethiopia; Amhara Regional Agricultural Research Institute, Debra Tabor, Ethiopia, hkb24@cornell.edu

Menberu M. Bitew Department of Civil and Environmental Engineering, University of Connecticut, Storrs, CT, USA, menberu@engr.uconn.edu

Martijn J. Booij Water Engineering and Management, Faculty of Engineering Technology, Twente University, 7500, AE Enschede, The Netherlands, M.J.Booij@ctw.utwente.nl

Pietro Ceccato International Research Institute for Climate and Society, The Earth Institute at Columbia University, New York, NY, USA, pceccato@iri.columbia.edu

Amy S. Collick Cornell Master's Program in Integrated Watershed Management and Hydrology, Bahir Dar, Ethiopia; Department of Water Resources and Environmental Engineering, Bahir Dar University, Bahir Dar, Ethiopia;

Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, USA, asc38@cornell.edu

Stephen Connor International Research Institute for Climate and Society, The Earth Institute at Columbia University, New York, NY, USA, sjconnor@iri.columbia.edu

Bijan Dargahi Department of Land and Water Resources Engineering, The Royal Institute of Technology (KTH), Stockholm, Sweden, bijan@kth.se

Dereje T. Desalegn Water Works Design and Supervision Enterprise, Addis Ababa, Ethiopia, der_tadesse@yahoo.com

Katrien Descheemaeker International Water Management Institute (IWMI), Addis Ababa, Ethiopia; International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia; Current Address: CSIRO Ecosystem Sciences, Glen Osmond, SA 5064, Australia

Tibebe Dessalegne Natural and Water Resources Department, BEM Systems, Inc., West Palm Beach, FL, USA, tdessalegne@bemsys.com

Tufa Dinku International Research Institute for Climate and Society, The Earth Institute at Columbia University, New York, NY, USA, tufa@iri.columbia.edu

Zachary M. Easton Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, USA, zme2@cornell.edu

Mohamed Elshamy Nile Forecast Center, Ministry of Water Resources and Irrigation, Cairo, Egypt, meame_69@yahoo.com

Tegenu A. Engda Cornell Master's Program in Integrated Watershed Management and Hydrology, Bahir Dar, Ethiopia; Amhara Regional Agricultural Research Institute, Debra Tabor, Ethiopia, tegenu@gmail.com

Temesgen Enku Department of Water Resources Engineering, Bahir Dar University, Bahir Dar, Ethiopia, enku_te@yahoo.com; temesgenku@gmail.com

Daniel Gann Geographic Information Systems-Remote Sensing Center, Florida International University, Miami, FL 33199, USA

Woubet Gashaw Department of Natural Resources Management, Bahir Dar University, Bahir Dar, Ethiopia, wubetga@gmail.com

Mekonnen Gebremichael Department of Civil and Environmental Engineering, University of Connecticut, Storrs, CT, USA, mekonnen@engr.uconn.edu

Mekonnen Getahun Amhara Design and Supervision Works Enterprise, Bahir Dar, Ethiopia, mekonnengetahun2001@gmail.com

Ambro S.M. Gieske Department of Water Resources, Faculty of Geoinformation Science and Earth Observation (ITC), Twente University, 7500 AA Enschede, The Netherlands, gieske@itc.nl

Emad Habib Department of Civil Engineering, University of Louisiana at Lafayette, Lafayette, LA 70504, USA, exh5102@louisiana.edu

Alemseged T. Haile Department of Water Resources, Faculty of Geoinformation Science and Earth Observation (ITC), Twente University, 7500 AA Enschede, The Netherlands, haile07634@itc.nl

Amare Haileslassie International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, A.Haileslassie@cgiar.org

Eman Hasan National Water Research Center, Cairo, Egypt, Dr_eman30@hotmail.com

Christina Hoffman School of Natural Resources, University of Nebraska, Lincoln NE, USA; Department of Earth and Environment, Florida International University, Miami, FL, USA, christina.hoffman@huskers.unl.edu

Mark R. Jury Physics Dept, University of Puerto Rico, Mayagüez, Puerto Rico; University of Zululand, KwaDlangezwa, South Africa, mark.jury@upr.edu

Elias S. Legesse Cornell Master's program in Integrated Watershed Management and Hydrology, Bahir Dar, Ethiopia; Department of Water Resources and Environmental Engineering, Bahir Dar University, Bahir Dar, Ethiopia, 2003sime@gmail.com

Dagnachew Legesse Department of Earth Sciences, Addis Ababa University, Addis Ababa, Ethiopia, dagnachewl@yahoo.com

Ben H.P. Maathuis Department of Water Resources, Faculty of Geoinformation Science and Earth Observation (ITC), Twente University, 7500 AA Enschede, The Netherlands, maathuis@itc.nl

Liya M. Mango Department of Earth and Environment, Florida International University, Miami, FL 33199, USA, lmango@fiu.edu

Everisto Mapedza International Water Management Institute (IWMI), Addis Ababa, Ethiopia; International Water Management Institute (IWMI), Pretoria, South Africa

Matthew McCartney International Water Management Institute (IWMI), Addis Ababa, Ethiopia, m.mccartney@cgiar.org

Michael E. McClain Department of Earth and Environment, Florida International University, Miami, FL, USA; UNESCO-IHE Institute for Water Education, Delft, The Netherlands, michael.mcclain@fiu.edu

P. McCornick Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, NC, USA, P.McCornick@duke.edu

Mulatie Mekonnen Bureau of Agriculture and Rural Development, Amhara Region, Bahir Dar, Ethiopia, mulatemekonnen@yahoo.com

Assefa M. Melesse Department of Earth and Environment, Florida International University, Modesto A. Maidique Campus, Miami, FL 33199, USA, melessea@fiu.edu

Semu A. Moges Department of Civil Engineering, Addis Ababa University, Addis Ababa, Ethiopia, semu_moges_2000@yahoo.com

Don Peden International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia

Janaka B.U. Perera National Water Supply and Drainage Board, Ratmalana, Sri Lanka, upuljanaka@gmail.com

David Rayner Department of Earth Sciences, University of Gothenburg, 405 30 Gothenburg, Sweden, David.Rayner@gvc.gu.se

Paolo Reggiani Unit Inland Water Systems, Hydrology, DELTARES, 1772600 MH Delft, The Netherlands, paolo.reggiani@deltares.nl

Bianca Reitberger Faculty of Biology and Geography, Applied Hydrogology/Hydrobiology, University of Duisburg-Essen, Essen, Germany, bianca.reitberger@gmail.com

Tom H.M. Rientjes Department of Water Resources, Faculty of Geoinformation Science and Earth Observation (ITC), Twente University, 7500 AA Enschede, The Netherlands, t.h.m.rientjes@utwente.nl

Alon Rimmer The Kinneret Limnological Laboratory, Migdal, Israel, alon@ocean.org.il

Shimelis G. Setegn Department of Earth and Environment, Florida International University, Miami, FL 33199, USA, ssetegn@fiu.edu

Yilma Sileshi Shiferaw Department of Civil Engineering, Addis Ababa University, Addis Ababa, Ethiopia, base_et@ethinoet.et

Ragahavan Srinivasan Spatial Science Laboratory, Texas A&M University, College Station, TX, USA, r-srinivasan@tamu.edu

Tammo S. Steenhuis Cornell Master's Program in Integrated Watershed Management and Hydrology, Bahir Dar, Ethiopia; Department of Water Resources and Environmental Engineering, Bahir Dar University, Bahir Dar, Ethiopia; Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, USA, tss1@cornell.edu

Seifu A. Tilahun Department of Water Resources and Environmental Engineering, Bahir Dar University, Bahir Dar, Ethiopia; Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, USA, sat86@cornell.edu

Paulo van Breugel International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia

Christiaan van der Tol Department of Water Resources, Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, 7500 AA Enschede, The Netherlands, vandertol@itc.nl

Anders Wörman Land and Water Resources Engineering, Stockholm, Sweden, worman@kth.se

Fasikaw Dessie Wubet Arba Minch University, Arba Minch, Ethiopia, fasiwork@yahoo.com

Muluneh Yitayew Agricultural and Biosystems Engineering Department, University of Arizona, Tucson AZ, USA, myitayew@email.arizona.edu

Part I
Hydrology and Water Budget

Chapter 1
Hydrological Variability and Climate of the Upper Blue Nile River Basin

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

Abstract This chapter discusses the hydrometeorology, land use, soils, topography, agroecological zones, extreme flows, climatic variability and climatic teleconnections of the upper Blue Nile River basin. The basin has a varied topography, rainfall and temperature resulting in different agroclimatic zones. Spatial distribution of annual rainfall over the basin shows high variation with the southern tip receiving as high as 2,049 mm and the northeastern tip as low as 794 mm annual average rainfall. The analysis of the basin's river flow and El Niño Southern Oscillation (ENSO) index connectivity indicates that the upper Blue Nile River basin rainfall and flows are teleconnected to the ENSO index. Based on event correspondence analysis, high rainfall and high flows are likely to occur during La Niña years and dry years are likely to occur during El Niño years at a confidence level of 90%. Low and high flow analysis for selected tributaries and flow at the Blue Nile River flow shows different recurrence intervals of the high and low flows.

Keywords Blue Nile River basin · Rainfall frequency analysis · Climatic teleconnections · ENSO · Lake Tana · Blue Nile River flow

1.1 Introduction

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). Degefu (2003) states that 86% of the annual flow of the Nile comes from the Blue Nile River basin (59%), from the Barro-Akobo-Sobat sub-system (14%), and from the Tekeze/Atbara/Gash subsystem (13%). The remaining 14% comes from the equatorial lakes after losses of evaporation in the Sudd region and Machar marshes (Degefu, 2003). The upper Blue Nile River basin (Fig. 1.1) is 176,000 km^2 in area (Conway, 2000). The

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A.M. Melesse (✉)
Department of Earth and Environment, Florida International University, Modesto A. Maidique Campus, Miami, FL 33199, USA
e-mail: melessea@fiu.edu

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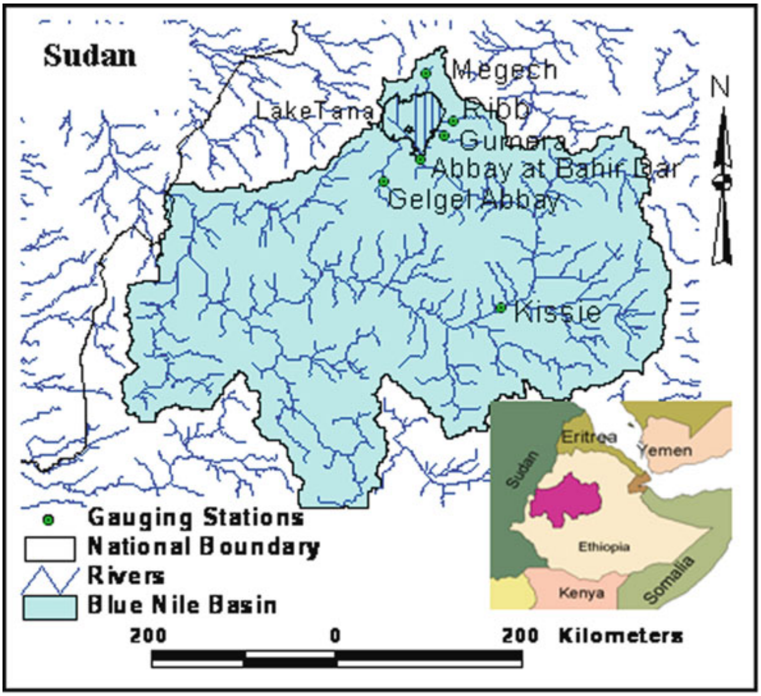

Fig. 1.1 Location of the upper Blue Nile River basin in Ethiopia (Abtew et al., 2009a)

major tributaries of the Blue Nile River in Ethiopia are Gilgel Abbay, Megech, Ribb, Gumera, Beshlo, Woleka, Jemma, Muger, Guder, Chemoga, Fincha, Dedessa, Angar, Dura and Beles. The upper Blue Nile River basin is relatively wet when compared to the lower basin (part of the Blue Nile drainage basin outside Ethiopia until it joins the White Nile River). Annual rainfall ranges from over 2,000 mm in the Southwest of the basin to a 1,000 in the northeast (Conway, 2000). Bewket and Conway (2007) reported mean annual point rainfall of 1,445, 1,665, 1,542, 1,349 mm rainfall at Bahir Dar, Chagni, Dangla and Debremarkos, respectively. Peggy and Curtis (1994) reported 1,521 and 1,341 mm long-term average annual rainfall for Bahir Dar and Debremarkos, respectively. Kebede et al. (2006) reported 1,451 mm average annual rainfall for Bahir Dar based on observations from 1960 to 1992. Analysis of spatial variation of annual rainfall over the upper Blue Nile River basin showed the southern tip receiving as high as 2,049 mm and the northeastern tip as low as 794 mm (Abtew et al., 2009a).

In Ethiopia, rain-fed agriculture is the main source of food production. Temporal and spatial fluctuations of rainfall result in low food production from droughts or unfavorable wet conditions. Point rainfall frequency analysis characterizes the temporal and spatial variation of rainfall at a gauge and analysis from many gauges can help detect temporal trends. Spatial mapping of the characteristics of all gauges in a region provides the spatial characteristics of rainfall. Regionally averaged rainfall frequency analysis characterizes rainfall over the region. Sufficient data length and quality is needed for temporal and spatial characterization of rainfall. Conway et al. (2004) studied the history of rainfall and temperature monitoring network and available records in Ethiopia and concluded that there are very few numbers of sites where continuous rainfall and temperature measurement records are available. In the absence of long term concurrent rainfall observations in a basin, the use of available data is warranted to conduct as much analysis as possible.

1.2 Hydrometeorology

1.2.1 Air Temperature

Air temperature of the Blue Nile River basin was analyzed using monthly minimum and maximum data from nine stations (Fig. 1.2). The period of record varies from 13 to 44 years for Jiga (1978–1990) and Bahr Dar (1961–2004) stations, respectively, and the average length of record is 23 years. Table 1.1 summarizes average monthly air temperature for the nine stations in the Blue Nile River basin. As shown in Table 1.1, the majority of the stations have maximum average air temperature in

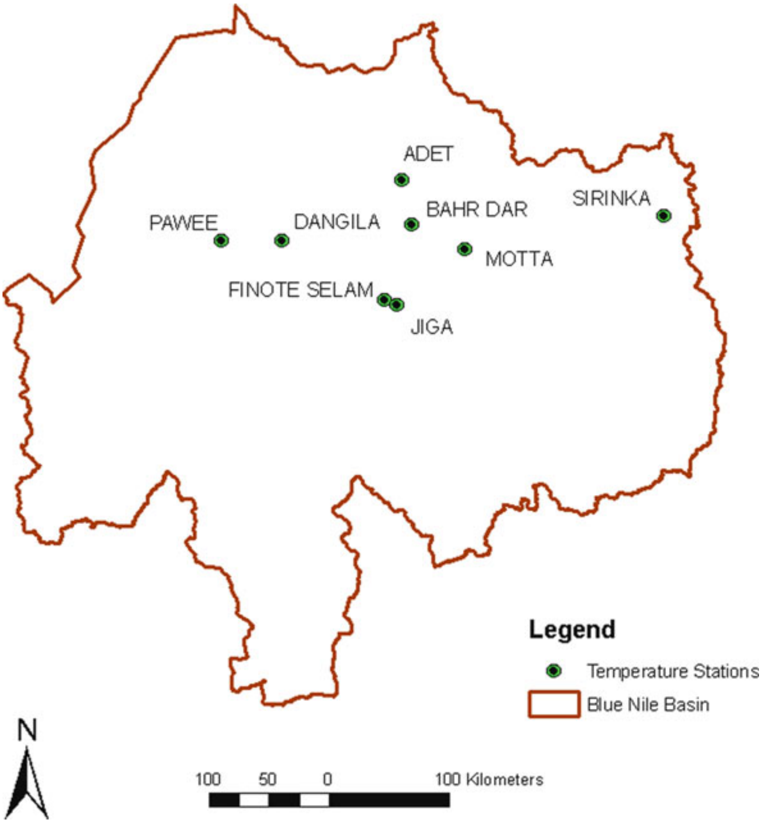

Fig. 1.2 Air temperature measurement stations of the upper Blue Nile River basin

Table 1.1 Summary of average air temperature in the Blue Nile basin (^{o}C)

	Adet	Bahir Dar	Deddessa	Dangila	Finote selam	Jiga	Motta	Pawee	Sirinka
Jan	15.85	16.90	22.09	15.27	19.08	22.45	15.48	23.23	17.05
Feb	17.51	18.49	23.46	16.68	20.06	22.88	16.94	25.23	17.90
Mar	19.01	20.66	25.36	17.95	21.03	23.44	18.07	27.44	19.41
Apr	19.56	21.43	25.61	19.05	21.34	23.50	18.68	28.14	20.61
May	19.67	21.60	23.94	18.84	20.91	23.23	18.81	26.51	21.99
Jun	18.30	20.22	22.40	17.58	19.42	22.14	17.63	23.91	23.60
Jul	16.89	18.78	21.39	16.71	17.89	21.65	15.84	22.54	22.30
Aug	16.83	18.61	21.29	16.70	17.68	21.50	15.61	22.49	21.24
Sep	16.98	18.90	22.00	16.89	18.21	21.64	15.65	23.09	20.76
Oct	16.93	19.22	22.18	16.67	18.43	21.80	15.57	23.36	19.17
Nov	16.16	18.28	21.88	15.56	18.64	21.95	15.31	23.18	17.99
Dec	15.64	16.98	21.60	15.02	18.43	21.77	15.09	22.93	17.04
Min	15.64	16.90	21.29	15.02	17.68	21.50	15.09	22.49	17.04
Max	19.67	21.60	25.61	19.05	21.34	23.50	18.81	28.14	23.60
Avg	17.44	19.17	22.77	16.91	19.26	22.33	16.56	24.34	19.92

the months of April or May and the minimum in the months of August or December. The average annual temperature at the nine stations ranges from a minimum of 16.6°C to a maximum of 24.3°C for Motta (eastern part of the basin) and Pawee (western part of the basin) stations, respectively.

Further, to summarize the upper Blue Nile River basin air temperature, mean monthly temperature was calculated using simple averaging of air temperatures at the nine stations (Fig. 1.3). As depicted in Fig. 1.3, the monthly distribution of the upper Blue Nile River basin temperature suggest that the maximum occurs in the month of April (22.0°C) and the minimum in the month of December (18.3°C).

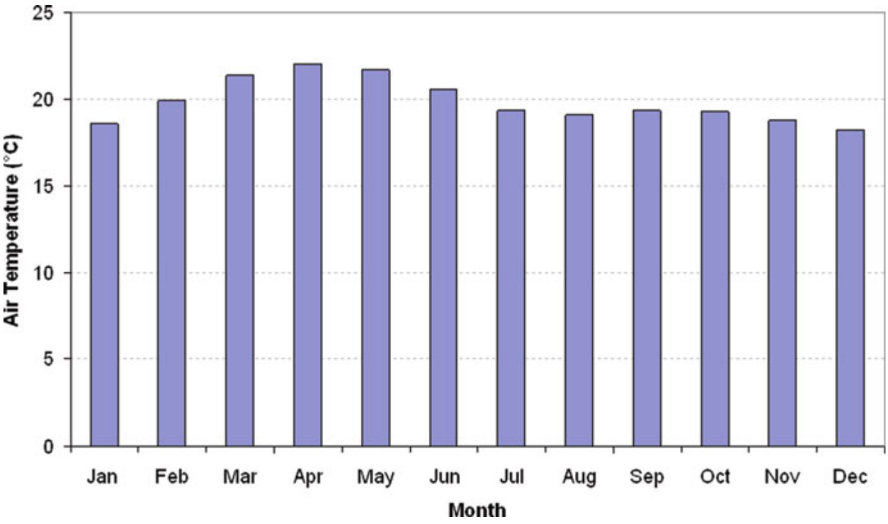

Fig. 1.3 Monthly distribution of mean air temperature in the Blue Nile basin