Middle East Journal of Applied Sciences, 4(2): 151-156, 2014
ISSN: 2077-4613

Scenarios of the Ethiopian Renaissance Dam Altitude and Relevant Reservoir by Using DEM and 3D Analysis

R.R. Ali

Soils and water Use Dept., National Research Centre, Egypt

ABSTRACT

Egypt has been suffering from severe water shortage. The River Nile is the lifeline of the country as it services the country's agricultural, industrial and domestic demand. Currently, Ethiopia (upstream country) began to construct the Renaissance Dam, where a negative impact on Egypt's share of Nile water is expected. This study aims to estimate the quantity of water in the reservoir of Ethiopian Renaissance Dam under five scenarios of Dam altitude (i.e. 88, 117, 137, 145 and 170 meter). Digital Elevation Model (DEM) and 3D analysis were used to fulfill this objective. The evaporation rate over the reservoir was estimated by using ETo calculator and CLIMWAT 2.0 database. The quantity of water cached in the reservoir was estimated to be 14.05, 37.91, 66.29, 80.57 and 111.45 billion m^3 under the dam altitude of 88 (scenario I), 117 (scenario II), 137 (scenario III), 145 (scenario IV) and 170 m (scenario V) respectively. The average of evaporation rate was estimated to be 1508.49 mm/ year over the lake.

Key words: DEM, 3D analysis, Ethiopian Renaissance Dam, Egypt.

Introduction

The River Nile is the world's longest river of about 6671 km length. The Nile Basin catchment area spans 11 countries i.e. Burundi, the Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania and Uganda. It drains an area of about 3349000 square kilometers, i.e. 10% of the African continent. It is estimated that by 2025 some 600 million people will be living in the Nile Basin countries and more than 300 million in the basin (UN, 2011). In Egypt, about 98% of fresh water comes from the Nile (55.5 billion m^3 per year). The annual per capita share of fresh water is less than 700 cubic meters per year. With predicted population growth the per capita share is expected to fall to less than 300 cubic meters per year in 2050 (UN, 2009). The agricultural sector is the largest consumer of fresh water in Egypt with a total share of about 81% from the total demand (FAO, 2003). Water is now scarce in some parts of the Nile basin and the upcoming supply of the waters will be essential to the development processes of the respective countries (Tvedt, 2004). The Nile basin comprises five major reservoirs i.e. High Aswan Dam, Roseires, Khashm el Girba, sennar and Jebel Aulia and four important hydroelectric power dams i.e. High Aswan Dam, Tis Isat, Finchaa and Owen Falls. Very recent, Ethiopia began to construct the Renaissance Dam, where a negative impact on Egypt's share of Nile water is expected due to the huge amount of water storage in the Dam reservoir. The main objective of this study is to estimate the total amount of water in the reservoir of Renaissance Dam under five scenarios. Digital Elevation Model (DEM) and 3D analysis will employed to fulfill this objective.

Materials and Methods

- *The Renaissance Dam area:*

Figure 1 represents the location of the Renaissance Dam area , the area is bounded by longitudes 34° 24́ and 35° 29́ E and latitudes 10° 21́ and 11° 27́ N. The area is dominated by volcanic rocks and resent alluvial deposits. The volcanic rocks include basalt, Trachyte, Ignimbrite and fall/surge deposits. These rocks are highly weathered and fractured due to stream cuts (Geremew, 2012). The area is generally characterized by warm climate with a mean annual maximum temperature of 30°C and a mean annual minimum temperature of 14°C. The annual rainfall ranges from 1138 mm to 1690 mm. Maximum precipitation occurs during the three months period, June July and August, while the minimum rainfall is observed in December and January (NCDC, 2013).

- *Digital Elevation Model (DEM):*

Digital Elevation Model (DEM) is a 3D electronic model of the land's surface (Brough, 1986). It provides better functionalities than the topographic maps. Information derived from a DEM, i.e. surface elevation, slope % and slope direction, could be used with the satellite images to increase their capabilities for water

Corresponding Author: R.R. Ali, Soils and water Use Dept., National Research Centre, Egypt
E-mail: bediertop@yahoo.com

management at regional scale (Lee *et al*., 1988). The digital elevation model (DEM) of the study area was extracted from the Shuttle Radar Topography Mission (SRTM) available at: http://srtm.csi.cgiar.org/. The SRTM is a respected space data of land surface that obtained by accurate positioned radar scanning earth at 1-arc seconds intervals with absolute and relative height errors less than 16 and 10 m respectively (Bamler, 1999). Four SRTM images covers the study area i.e. n10/e034, n10/e035, n11/e034 and n11/e035, these images have been processed in ENVI 4.7 software for voids fill and mosaicking them into one image. Then the DEM was overlaid on the available topographic map of the area (scale 1:250000) to examine the elevation accuracy by using the accurate spot elevation on the map (Figure 2).

- *3D analyses:*

The elevations of the dam base height and crest have been used to reclassify the DEM of the study area into two classes. The first class includes the elevations limited by the dam base height and crest, while the second includes other elevations. The first class represents the expected reservoir area at a specific dam elevation. The area of the first class was used to extract the DEM of the expected reservoir. The 3D analysis function was used to calculate the water volume in the reservoir under five scenarios of dam crest elevations (e.g. Yu *et al*., 2005; Liu, 2008).

- *Open water evaporation:*

The Reference Evapotranspiration (ETo) values could be considered equal to evaporation from a large body of water, such as a pond or lake (Brown, 2000). CLIMWAT 2.0 is a climatic database developed by FAO to be used in combination with ETo calculator program and allows the estimation of ETo for a range of 5000 climatological stations worldwide. This database provides long-term monthly mean of daily maximum temperature (°C), daily minimum temperature (°C), relative humidity (%), wind speed (km/day), sunshine hours per day, solar radiation (MJ/m^2/day), monthly rainfall (mm) and monthly effective rainfall (mm). In this study the ETo calculator software was employed to estimate the expected evaporation from the Renaissance Dam reservoir using the CLIMWAT 2.0 database (FAO, 2012). Climatic parameters of the nearest climatological stations (i.e. Nejo, Mendi, Kurmuk, Bambesi, Asosa and Chagni) were used.

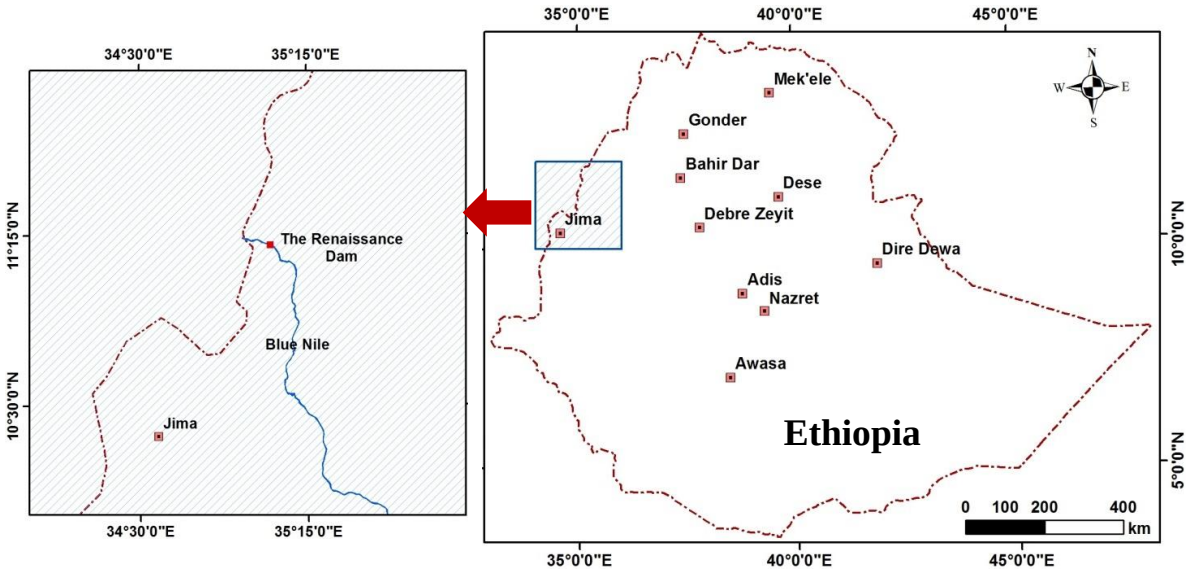

Fig. 1: Location of the Renaissance Dam area.

Results and Discussion

With a relative vertical accuracy of (± 5-10 m), the surface elevation of the investigated area differs widely from 446 to 2620 meter a.s.l., high elevations characterize the southern parts. To the north of the area the elevation decreased to reach 495 meter a.s.l. at the Renaissance Dam location. On the other hand in the northwest area the surface elevation differ from 583 to 605 meter a.s.l. The stored water will be leaked out from this area when the Renaissance Dam exceeds the height of 88 m. In view of this, construction of a saddle dam (5 km length) to the west of the Renaissance Dam was projected.

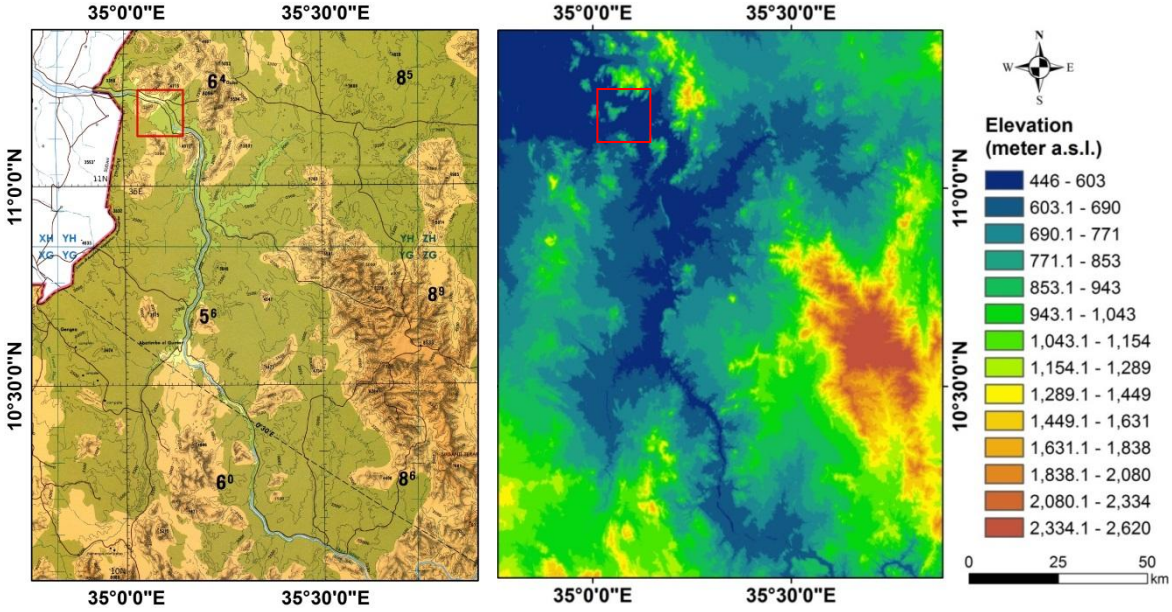

Fig. 2: Digital Elevation Model (right) and topographic map (left) of the study area, red square outlined the Renaissance Dam area

Considering the surface elevation of the investigated area, five scenarios of dam elevation were proposed as the following:

- **Scenario I:** the altitude of the Renaissance Dam is 88 m, i.e. the difference between base height of Renaissance Dam (495 m) and the Dam crest (583 m), the saddle dam is not required in this case.
- **Scenario II:** with a saddle dam of 30 m height, in this case the altitude of the Renaissance Dam will be 117 m i.e. the difference between the Renaissance Dam base height (495 m) and the altitude of the Dam crest (612 m)
- **Scenario III:** the height of saddle dam is 50 m; in this case the altitude of the Renaissance Dam crest will be 137 m.
- **Scenario IV:** the proposed heights of the Renaissance Dam and the saddle dam are 145 m and 58 m respectively.
- **Scenario IV:** the height of saddle dam is 83 m where the Renaissance Dam crest could be increased to be 170 m.

Table 1: Reservoir area and water quantity under five scenarios of Renaissance Dam altitude.

Dam height	Saddle dam height	Plane height	Reference	Z Factor	2D Area (km^2)	3D Area (km^2)	Lake average depth (m)	Water volume (billion m^3)
88 m	00 m	583.0	BELOW	1.0	575.76	585.20	24.17	14.05
117 m	30 m	612.0	BELOW	1.0	1201.35	1212.43	30.92	37.49
137 m	50 m	632.0	BELOW	1.0	1818.30	1834.95	36.13	66.29
145 m	58 m	640.0	BELOW	1.0	2042.36	2061.19	39.09	80.57
170 m	83 m	665.0	BELOW	1.0	2283.96	2288.82	48.69	111.45

Note: estimations based on a DEM of ± 5-10 m relative vertical accuracy

The quantity of the stored water in the Renaissance Dam reservoir was estimated under the above mentioned scenarios. The data indicate that the total amount of water sorted in the reservoir will be about 14.05 billion m^3 under the first scenario (Dam elevation 88 m). In this case the total 3D area that would be filled with water is about 585.20 km^2 and the average depth of the reservoir is about 22.45 m. Under this scenario there is no need for a saddle dam. The altitude of the Renaissance Dam in scenario II is 117 m, where a saddle dam of 30 m elevation and 5 km length should be constructed to the north west of the area. In this scenario, the reservoir 3D area is estimated to be 1212.43 km^2 with an average depth of 30.92 m. The amount of water that could be stored in the reservoir is about 37.91 billion m^3. Scenario III supposes that the altitude of the Renaissance Dam is 137 m and then the altitude of the saddle dam must be 50 m. About 66.29 billion m^3 of water could be cached in the reservoir where the total 3D area is about 1834.95 km^2 and the average depth is 36.13 m. Dam height is suggested to be 145 m in scenario IV accordingly a saddle dam of 58 m height is required. The water quantity stored in the reservoir could be reach 80.57 billion m^3 and the reservoir 3D area is expected to be 2061.19 km^2 with a mean depth of 39.09 m. In scenario V the elevation of the Renaissance Dam

height is suggested to be 170 m, so the altitude of the saddle dam must be 83 m, the reservoir 3D area, mean depth of the reservoir and water volume were estimated to be 2288.82 km^2, 48.69 m and 111.45 billion m^3 respectively. Table 1 and Figure 3 represent the reservoir area and water quantity under the different altitude of the dam.

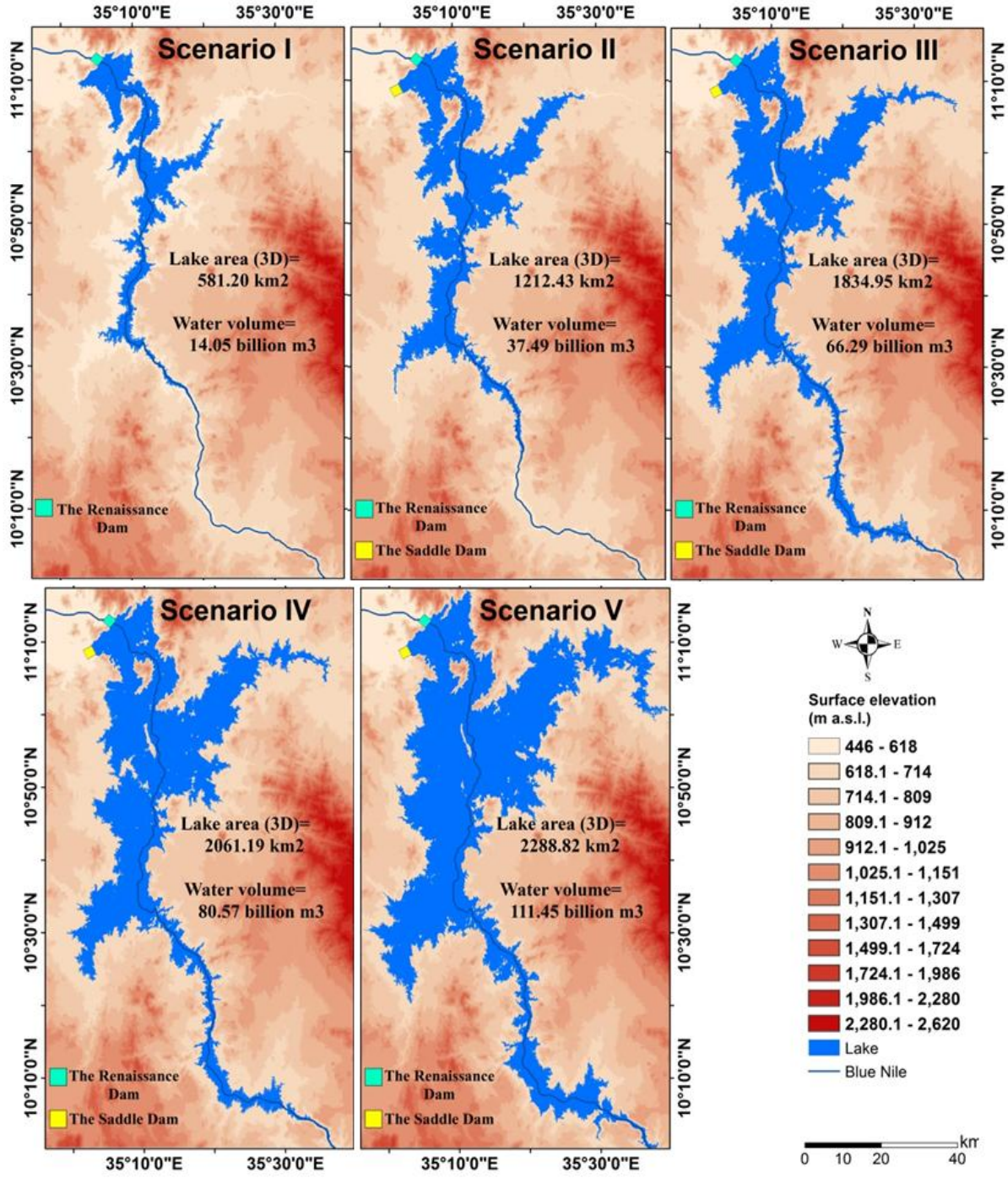

Fig. 3: The reservoir of the Renaissance Dam under five scenarios of Dam altitude i.e. 88 m (scenario I), 117 m (scenario II), 137 m (scenario III), 145 m (scenario IV) and 170 m (scenario V).

The open water evaporation (ETo) over the area was estimated from the available nearest stations. The data in Table 2 represent the average of ETo differs from 1294.53 in Nejo station to 2030.54 mm/year in Kurmuk with an average of 1508.49 mm/year. Considering the 2D area of the reservoir under different scenarios the water loss by evaporation will be 0.87, 1.81, 2.74, 3.08 and 3.45 billion m^3/year in scenarios I, II, III, IV and V respectively. The evaporation has a permanent impact on Egypt share as a creation quantity will be deducted

from the Egypt share annually. Negative impacts on Egypt's share of Nile water is anticipated under scenarios III, IV and V due to the huge amount of stocked water in the Dam reservoir. This would lead to a temporary reduction of water availability due to the filling of the dam and a permanent reduction because of evaporation from the reservoir. Also it will cause a permanent lowering of the water level in Lake Nasser. The total irrigated lands in Egypt amount to 8.2 million acre from which about 1.25 million acre considered as saline soils of a marginal productivity (FAO, 2003). The saline soils occupy the northern parts of the Nile Delta and El Fayoum depression (FAO/ISRIC/ISSS, 1998). These soils located at the end of downstream where the water shortages occur and will be completely degraded under water stress. Under scenarios I and II Egypt could compensates the water shortage from Lake Nasser within 2-5 years. Agricultural lands will be affected under scenarios III, IV as well as V, for example the published information on the Renaissance Dam indicated that the Dam height is 145 m (scenario IV) and the required period for filling the reservoir is 5 years, so about 80.57 billion m^3 of water will be stocked in the reservoir. Consequently the temporary shortage of Egypt share is 16.1 billion m^3/ year. Considering the ILRI (1999) information the net amount of irrigation water per acre is about 4700 m^3/year, hence a total of 3.4 million acre will be out of production for 5 years.

Table 2: Average of climatic parameters and ETo of the nearest 6 stations to the reservoir area

Station	Min Temp (C°)	Max Temp (C°)	Humidity (%)	Wind (km/day)	Sunshine (hours)	Radiation (MJ /m2 /day)	EEo (mm/year)
Nejo	13.10	25.50	67.00	96.00	5.80	17.40	1294.53
Mendi	14.10	26.40	66.00	96.00	6.30	18.10	1360.94
Kurmuk	20.90	33.90	50.00	175.00	7.90	20.40	2030.54
Bambesi	13.40	28.00	66.00	132.00	6.40	18.30	1461.63
Asosa	15.40	27.80	66.00	132.00	6.50	18.40	1480.94
Chagni	12.00	27.00	65.00	119.00	6.50	18.30	1422.36
Average	14.82	28.10	63.33	125.00	6.57	18.48	1508.49

Conclusion:

In this study Digital Elevation Model and 3D analysis were used to estimate the areas and volumes of the expected lake of the Renaissance Dam, Ethiopia. Five scenarios of Dam altitude are considered i.e. 88m (scenario I), 117m (scenario II), 137m (scenario III), 145m (scenario IV) and 170 m (scenario V). Under these scenarios the water volume in the reservoir could reach 14.05, 37.91, 66.29, 80.57 and 111.45 billion m^3 water per year respectively. The estimated average of evaporation rate over the lake area reaches 1508.49 mm/ year. Negative impacts on Egypt's share of Nile water is anticipated, for example an area of 3.4 million acre will be out of production for 5 years in case of scenario IV.

References

Bamler, R., 1999. The SRTM Mission: A World-Wide 30 m resolution DEM from SAR interferometry in 11 days. in Photogrammetric Week, R. Fritsch and R. Spiller, Eds, pp: 145-154.

Brown, P., 2000. AZMET Evapotranspiration Estimates: A Tool for Improving Water Management of Turfgrass. Arizona Meteorological Network, University of Arizona, Tucson; available at: http://ag.arizona.edu./azmet/et1.htm (accessed February, 2005).

FAO, 2012. The ETo Calculator, Evapotranspiration from a Reference Surface. Food and Agriculture Organization of the United Nations (FAO), Via delle Terme di Caracalla, 00153 Rome, Italy.

FAO, 2003. The Strategy of Agriculture Development in Egypt until the Year 2017. FAO, Rome, Italy.

FAO/ISRIC/ISSS, 1998. World Reference Base for Soil Resources. World Soil Resources Report, no. 84. FAO, Rome, 88pp.

Geremew, L., 2012. Hydro Geophysical Investigation of Shebe Watershed, Jimma, South Western Ethiopia. Science, Technology & Arts Research Journal, 1(3): 45-58.

ILRI, 1999. Impacts of the Irrigation Improvement Project, Egypt on Drainage Requirements and Water Savings. Final report. R.J.Oosterbaan, International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.

Liu, N., 2008. Management Project in Tangjiashan Barrier Lake Disaster Reducing. China Engineering Science, 10(12): 67-72.

NCDC, 2013. Daily Weather Data for Ethiopia (1977-2013), National Climatic Data Center (NCDC), available at: http://www.geodata.us/weather/list.php?cs=ET&c=Ethiopia&y=2000.

Tvedt, T., 2004. The River Nile in the Age of British, Political Ecology and the Quest for Economic Power. London – New York, I.B. Tauris, p 20.

UN, 2009. Water Annual Report. United Nations (UN), New York, USA.

UN, 2011. World Population Prospects the 2010 Revision. Annual report, volume I, United Nations (UN), New York, USA.

Yu, X., Y.F. Zhou, S.Z. Peng, 2005. Stability Analyses of Dam Abutments by 3D Elasto-plastic Finite-element Method: A Case Study of Houhe Gravity-arch Dam in China. International Journal of Rock Mechanics and Mining Sciences, 42(3): 415-430.