HYDROLOGICAL AND ENVIRONMENTAL IMPACTS OF GRAND ETHIOPIAN RENAISSANCE DAM ON THE NILE RIVER

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ABSTRACT

The Nile River (NR) is an international river shared by eleven riparian countries. It is the primary water resource and the life artery for its downstream countries such as Egypt and Sudan. In Ethiopia which is one of most important water sources of the NR, a study for constructing the Renaissance dam on the Blue Nile close to its border with Sudan was initiated. The dam is designed to create a reservoir that will have a capacity of holding about 74 billion cubic meters of water at the full supply level. This paper aims to study the effects of constructing such dam on the NR streamflow, especially downstream the dam and its impacts on Egypt and Sudan. The study includes simulation works for all possible scenarios from starting the dam construction up to reaching the full capacity of its reservoir to identify impacts of this dam on the Ethiopia and the downstream countries. The possibility of the dam damage also investigated via simulations from HEC-RAC model. Results showed some merits and many drawbacks of this project on the Nile streamflow. Results showed also the weakness of the design and referred to the possibility of impacts due to the dam breach.

Keywords: Nile River, dam impacts, stream flow, water management, environmental impacts, dam safety

1 INTRODUCTION

The living standards rise and population growth have put more stress on water resources. With the increasing demand for water, the world is facing serious water crisis since the beginning of the 21st Century (Cabrera and Cobacho, 2002). Rivers are most important resources of fresh water worldwide and their waters must be managed in a convenient way especially when the river passes through several countries. Blocking and harnessing rivers for a variety of purposes, including hydropower, flood control, water storage and irrigation must be agreed and arranged by all countries sharing these rivers. Dam construction on rivers is a significant project having many merits and drawbacks and should be studied by all effected countries. These impacts can lead to problems between neighbouring regions. The Nile River is the best example for this dispute, which is shared by eleven riparian countries for their water needs particularly the downstream countries, i.e. Egypt and Sudan, (Duiker and Spielvogel, 2009). Therefore, Nile water resources management are essential among its riparian countries. Constructing any projects at any location of the Nile tributaries will affect the other riparian countries especially downstream countries. The seasonal and annual changing in Nile's stream flow may cause water shortage problems to people in these countries.

Nile's water runs through very different climatic regions. Due to climate change, the amount of water in the Nile Basin may fluctuate and water availability will not increase. The Nile Basin is characterized by water scarcity, rapid population growth, and poverty which they will likely compound the difficulty for the foreseeable future to be very complex. Development projects in the basin's countries include irrigation projects, hydropower dams, and other water-diversion projects may cause difficulties for the other partners (Batisha, 2011).

The Nile water that Egypt relies on comes from two sources. The first, and most important, is the Ethiopian Plateau, which supplies the country with nearly 85 per cent of its needs only during the summer months, July to October. Some 65 per cent of these come from the Blue Nile (BN), and the remaining 20 per cent comes from the Atbara River. The second source that compensates the rest of the year is the Great Lakes region of Africa, which provides about 15 per cent of Egypt's needs. The Upper Blue Nile Basin (UBNB) is located in the Ethiopian Highlands, which is the most important sub-basin of the Nile. Typically, during July-October about 80% of the Nile River total stream flow at Aswan, Egypt coming from the Blue Nile (Abbay) river (Elsanabary and Gan, 2013).

In early twentieth century, engineering proposals for the regulation of Lake Tana, at the headwaters of the Blue Nile were investigated (Garstin, 1904), and several subsequent studies have focused on the feasibility of regulating its outflow. In past, it was suggested two possible reservoir sites along the Blue Nile, however, there were some difficulties due to the fact that the Blue Nile flows through deep valleys. For the Blue Nile, Hurst et al. (1951) suggested constructing high dams with probably small capacities. Garstin (1904) highlighted a concern about the huge volumes of sediment carried by the Blue Nile. The US Bureau of Reclamation (1964) prepared a detailed study of the Blue Nile region, including its hydrology, water quality, geology, physiography, mineral resources, sedimentation, land use, ground- water and local economy. Some irrigation and hydroelectric projects were recommended. The Bureau concluded that there are approximately no lands along the Blue Nile which can be irrigated between Lake Tana and the Sudanese border. Four dams for the hydroelectric projects were proposed for the Blue Nile downstream of Lake Tana, namely Karadobi, Mabil, Mendaia and the Border Project.

The Border Project which is known now as the Grand Ethiopian Renaissance Dam (GERD) is a hydropower project being built recently on the Blue Nile (Abbay) River to generate 6,000 MWh of electricity by exploiting the river's flow which has an average 1,541 m3/s of annual water discharge. The dam is designed to create a reservoir that will have a holding capacity of about 74 Billion Cubic Meters (BCM) of water at the full supply level. The idea of constructing the GERD arose after 2009 (Bakheit, 2013, Hammond, 2013 & CGE, 2013). Therefore, studies on the hydraulic, environmental and social impact of the dam on the area and the communities have not yet been published; it is not even known whether such studies exist in the first place that makes it difficult to conduct project assessment.

In this paper, the hydrological and environmental impacts of constructing GERD on the Blue Nile, close to the border of Sudan were studied to evaluate the merits and drawbacks of such project to the countries downstream the dam i.e. Sudan and Egypt. In light of the above literature review, this study aimed to identify, predict and analyse the effect of the dam project on the following aspects:

River Nile stream; the environmental impacts those are likely to arise from the project stages and the possibility of the dam damage and their effects on the downstream countries, Sudan and Egypt.

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2 METHODOLGY

2.1 Study Area

The suggested position of GERD in Ethiopia is located on the Blue Nile, only five kilometres away from Sudan's borders as shown in Fig. 1. The proposed dam is located in a region characterized by elevated plateaus from which rise the various mountains that constitute the Ethiopian Highlands. The Upper Blue Nile Basin (UBNB), of 176,000 km2 in area, occupies 17 % of Ethiopia, and has a mean annual stream flow volume of 48.5 BCM, i.e. approximately 1541 m3/sec. The Blue Nile (Abay) begins at the Tana Lake (2150 km2 area) of an approximate elevation of 1800 a.m.s.l, as the water leaves the lake at the Tississat Falls via dropping over 50 m (Shahin, 1985). The UBNB, which forms the western part of the Ethiopian Highlands, receives annual precipitation of 1600 mm with a range of ± 600-800 mm/year (Sutcliffe and Parks, 1999) than the eastern, northern and southern parts of the Ethiopian Highlands. This is expected since the western part is higher than other parts of the Highlands and precipitation generally increases with altitude because of orographic effects. UBNB essentially has two rainy seasons, a small rain season called Belg during February-May (FMAM) and a big rain season called Kiremt during June-September (JJAS) (Kloos and Legesse 2010).

2.2 Model Data

The data required for driving the models are topographic, land use and hydrometric data. The DEM data set of UBNB was extracted from the Global 30 Arc-Second (1km) Elevation Data Set (GTOPO30), a global raster Digital Elevation Model (DEM) with a horizontal grid resolution of 30 arc seconds (approximately 1 km). The data is expressed in latitude and longitude and is referenced to the World Geodetic Survey (WGS) system of 1984. The DEM data were used to determine the drainage area, drainage network and flow direction of the rivers and streams of the UBNB. For the UBNB terrain analysis that does not require high accuracy, the basic delineation procedure used in this study should be sufficient, although, for determining the drainage network, this could cause some problems.

2.3 Model Description

The model used for this study is HEC-RAS model which is a 1-D model. It is a part of the family of public domain generalized simulation models are available from the Hydrologic Engineering centre (HEC) which was developed by U.S. Army Corps of Engineers, USA since 1998 (USACE, 2010). The model is used to simulate the impact of the GERD failure, with low and high releases on the Sudanese lands downstream of dam. The model is designed for calculating water surface profiles for steady or gradually varied flow. The steady flow approach is capable of handling a full network of channels or a single river reach.

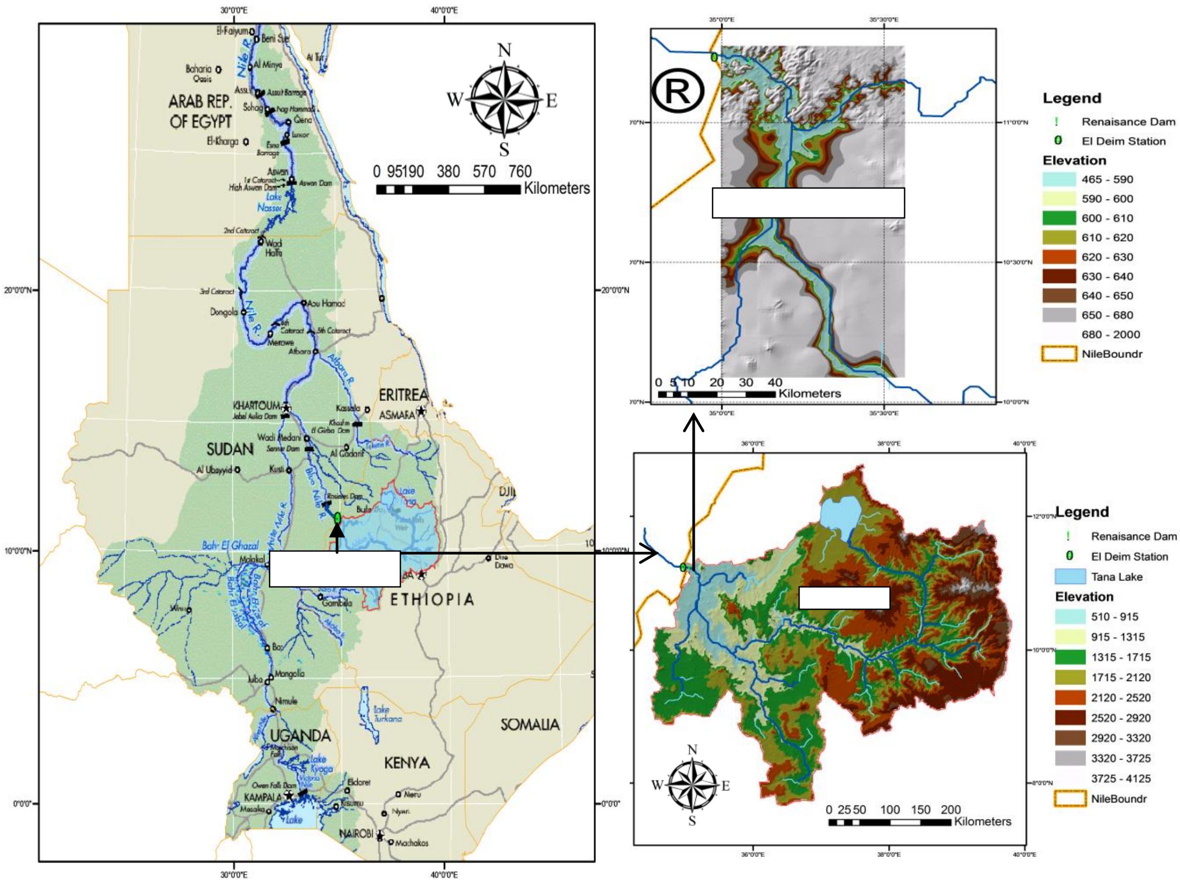

Figure 1. Maps for the study area and the dam location

The model computational procedure is based on the solution of one-dimensional energy equation. The model input data includes geometric and hydrologic data. Cross-sections are one of the main inputs to the model. DEM data are used to extract the elevation data from the terrain to create a ground profile across channel flow. The cross sections are used to compute HEC-RAS attributes such as bank stations (locations that separate main channel from the floodplain), downstream reach lengths (distance between cross-sections) and Manning's (n). Therefore, creating adequate number of cross-sections to produce a good representation of channel bed and floodplain is critical. The geometric data is composed of about 30 cross-sections with spacing of 40 kilometres in between extracted from the DEM data. The inflow boundary was defined as the inflow discharge is as the discharge downstream the GERD (276 mm/year) at all the main junctions along the River Nile. Manning's coefficient ranging from 0.05 to 0.1 as described in Pietrangeli et al (2013). The manning values were estimated according to the normal wet season flow. According to Chow (1959) the roughness coefficient decreases with the increase in water level. The study focused on the steady state simulation. Therefore, all the simulations considered the filling during the average flow years between the flood and drought seasons to address the total effect of the proposed dam on the downstream countries.

3 RESULTS AND DISCUSSIONS

3.1 Dam Reservoir

The GERD was planned initially to create a lake that would store 14 BCM of water; however, the lake's capacity increased to 74 BCM. According to Ethiopian officials (CGE, 2013), this volume should cover a surface area of 1680 km2 with maximum water level of 145 m behind the proposed dam. In this study, the reservoir surface area and volume were calculated via Arc GIS software based on different water level scenarios. These scenarios included storing water at different elevations behind the dam beginning from 590 m, i.e. 96 m behind the dam and by increasing 10 metre in each scenario up to 640 which gives water level at 146 m. According to the elevations of the ground in the study area, the model results showed different suggestions for the area and volume of the reservoir as shown in Figs. 2 and 3. Results showed that there is no correlation between the values declared about the dam reservoir. As at level of 640, i.e. 146 m behind the dam, the reservoir has 1561 km2 and a volume of water equal to 79 BCM. Results show also that the volume of 74 BCM need only 1426 km2 and 136 m water level. Moreover, declared reservoir authorities (CGE, 2013) area of 1680 gives a storage capacity of 84 BCM.. In a comparison to the different cases generated by the model as shown in Fig. 3, Fig 4 shows that the declared proposed reservoir is greater than the shape of the biggest storage volume of 79 BCM. This refers to either the shortage in data collection for this project or may the intention to hide such theses values. In hydroelectric dams, the lakes are usually less than 14 BCM in capacity. This increase in size contrasted with the declared goal of building the dam to supply the country with hydroelectric power. Storing water at level 600 which gives 106 m behind dam and 19 BCM will be the suitable and sufficient scenario for generating power.

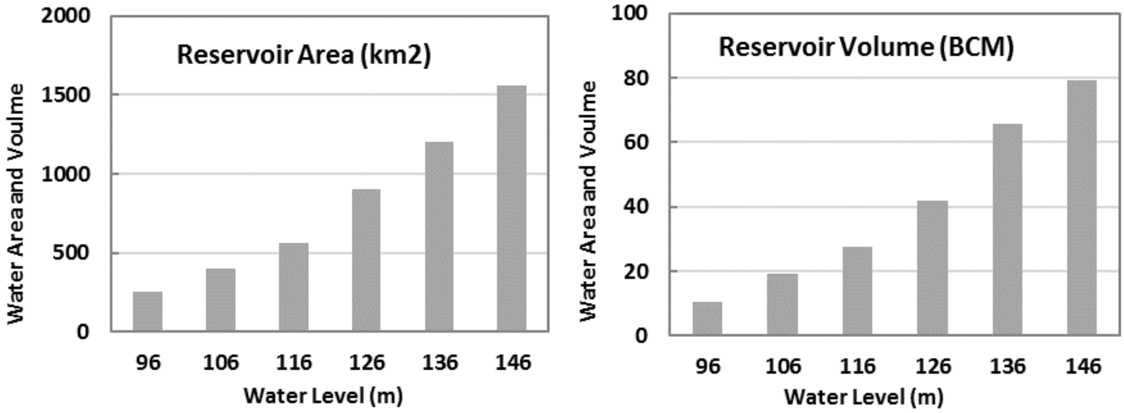

Figure 2. Reservoir volume and area at different water levels behind the dam

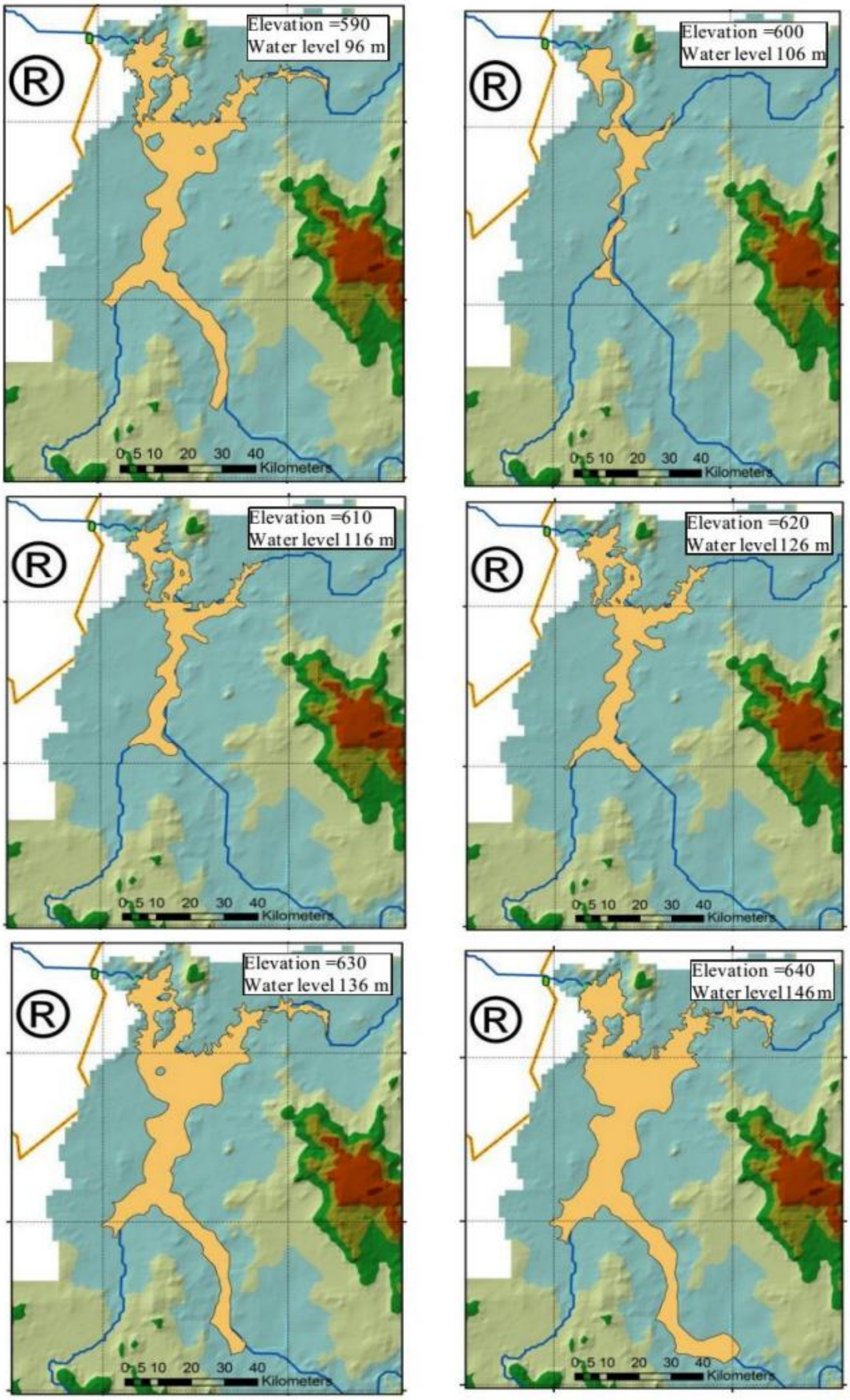

Figure 3. Reservoir volume according to different filling water head

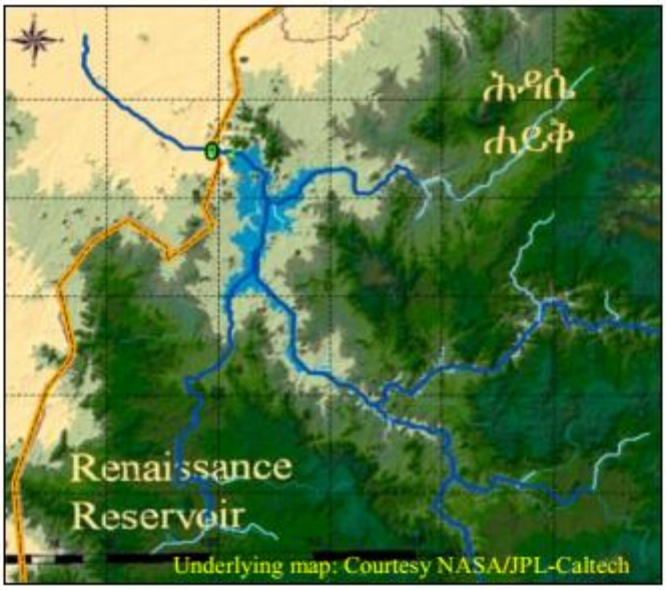

Figure 4. Proposed impounded lake behind Renaissance Dam published by Ethiopian

3.2 Flow Stream Scenarios

The outflow boundary condition was used as water level at the end of the Blue Nile, near to Khartoum. The simulated runs were performed to forecast the effect of dam failure (276 mm/year) on the water profile. The average slope of Blue Nile is about 10.77%. The approximate average velocity is between 1.22 to 2.13 m/s (Chow et al., 1988). With constructing GERD, the hydrological and physical properties of the river will change. The water quantity discharging the river after the dam will be reduced which may lead to reduce the flow velocity. In this study, several scenarios of water charging in the reservoir were studied via the model to check their impacts on the flow stream behind the dam. Four time charging scenarios namely 2, 5, 10 and 20 BCM/year were adopted to estimate the sufficient time to charge the reservoir for the six water level scenarios discussed in the above section. Results showed that the time periods needed to fill the reservoir at 146 m of water level behind the dam were 39.5, 15.8, 7.9 and 3.95 years for the four time scenarios respectively as shown in Fig. 5. For case of 74 BCM with water level 146 m, times needed were 37, 14.8, 7.4 and 3.7 BCM/year respectively. These results refer to a significant problem coming with charging the reservoir even at a long period time such as 40 years. The effects of charging time sceneries of the reservoir on Egyptian water demand were studied. The results showed that a sever water shortage problem will affect Egypt even with using the storage water in Nasser Lake which may help to solve the problem for 70% of the charging periods in most of these scenarios as shown in Fig. 6. Based on results shown and discussed herein, the best accepted scenario for constructing the dam is by charging a reservoir with 19 BCM or less in 3.8 years. This amount of water will be sufficient for power generation and having less impact on the downstream counties, i.e. Sudan and Egypt.

3.3 Damage Scenario

Dams provide important water storage for flood control and hydroelectric production. Also, the reservoirs retained upstream these dams provide water for human and agricultural consumption. However, dams can also pose serious risk for the downstream river basin, agricultural and, historical sites, wildlife habitat and communities in the event of a catastrophic dam failure or breach. A catastrophic event such as dam failure, caused by geological/foundation weakness (example: earthquakes), dams overtop due to extreme storms, structural problems, old age, and terrorism or military attack etc., is of great concern to the dam downstream countries officials in terms of community preparedness and response.

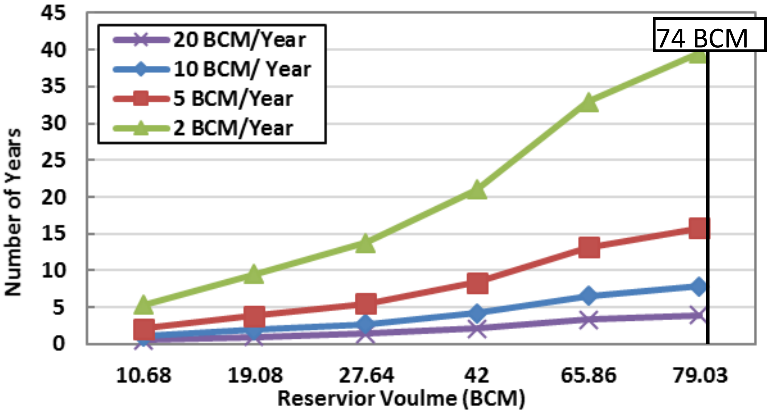

Figure 5. Reservoir volume at different charging time sceneries

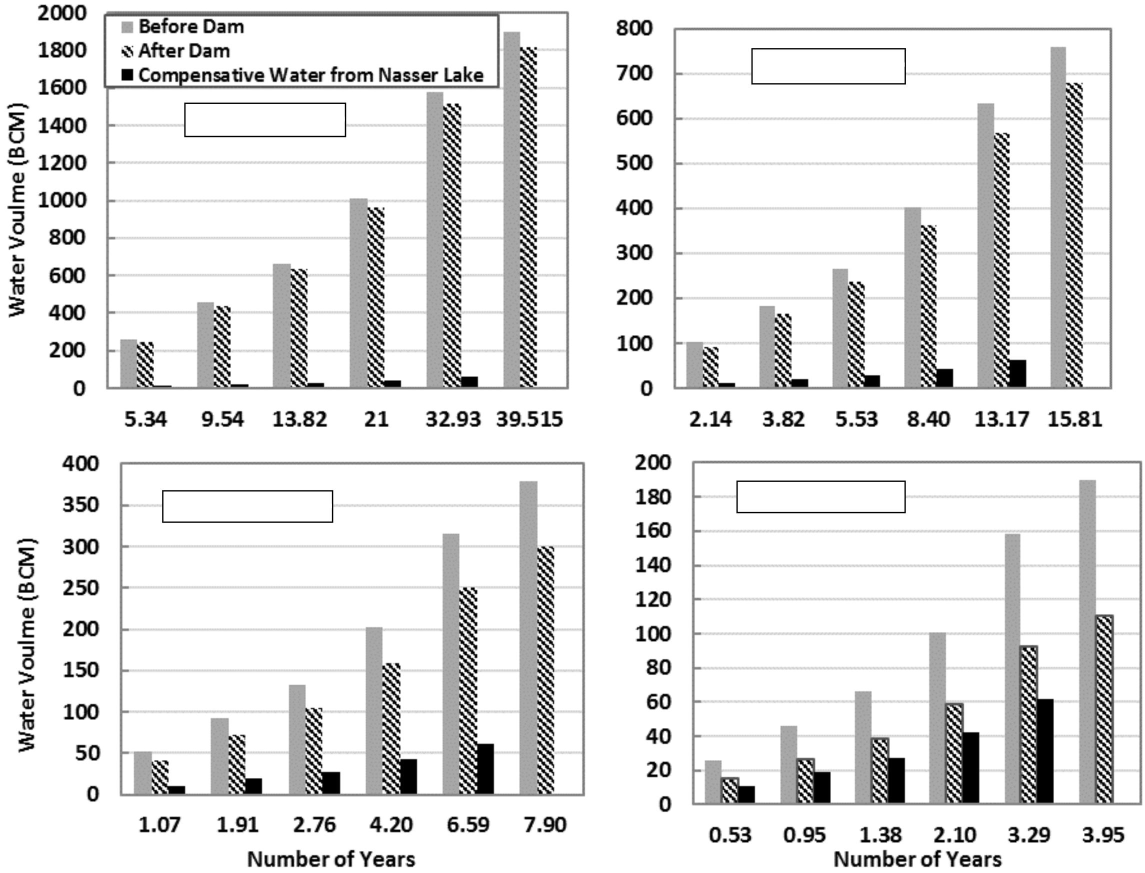

Figure 6. Effects of charging time sceneries of the reservoir on Egyptian water demand

A failure impact assessment must be prepared to evaluate the population at risk if failure of a water dam was to occur. A dam is considered to have failed, if there is a physical collapse of all or part of the dam or an uncontrolled release of any of its contents.

The main purpose of this section is to simulate the expected flood due to the failure of the proposed GERD and its impacts on Khartoum, Sudan and if possible the main Nile at the entrance of Lake Nasser, Egypt. A one dimensional steady flow mathematical model was used to achieve that purpose. The used model is (HEC-RAS), which has been developed for the U.S. Army Corps of Engineers by the Hydrologic Engineering Centre, to predict the possible impacts of different low and high releases. Different releases are simulated (e.g. 1541, 1478, 1383, 1224, 907, and 2506 m3/sec) which represent the original streamflow before constructing the dam, reduced streamflow by 2, 5, 10, 20 BCM, and sudden failure of the dam, respectively, to evaluate the impacts of inundation process as shown in Table 1. The original streamflow is assumed based on the average annual discharge (48 BCM) coming from the Blue Nile. After crossing the Sudan boarder, the Blue Nile flows for a distance of about 7000 km till it meet with the White Nile at Khartoum. The White Nile adds 24 BCM while Atbara provides 12 BCM/ year. Also, because the Blue Nile receives additional flow from additional tributaries near Senner dam until it reaches Khartoum the flow coming from El Diem station was increase by 10%. Each release effect on land and infrastructure inundations was analysed and evaluated. The planned releases may have impacts on the downstream countries of the dam. Many problems for human properties and activities especially in the area of encroachment are evident specifically under the dam damage or even failure. By taking a cross section in the Blue Nile near to Senner, the section result shows a water surface rise by about 2 to 3 meters as shown in Fig. 7. After the dam failure the cross section is experience excessive flood with high water level. Results showed also that the flooded area covers the extension of 15 km width for 200 km long around Senner and 210 km from Senner to Khartoum.

Table 1. Input streamflow for different reaches on the Nile River

River reach	Discharge (m^3/sec)					
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
BLUE NILE(ElDiem-Khartoum)	1541	1478	1383	1224	907	2506
Khartoum to Atbara	2456	2386	2282	2107	1759	3518
Atbara to Nasser Lake	2837	2767	2662	2488	2139	3898

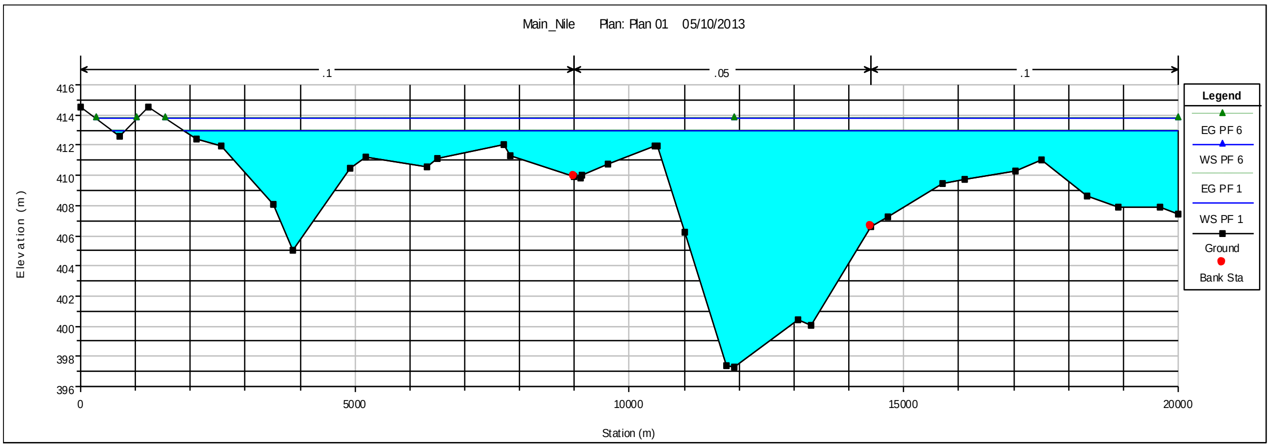

Figure 7. Water profile after dam failure the release of stored water

3.4 Environmental Impact Assessment of the Dam

3.4.1 Impacts of dam reservoir on the host country

The most important negative effect of constructing the reservoir, upstream the GERD, on the host country, Ethiopia, is the displacing people living in the area of the proposed reservoir. 20,000 to 140,000 people will be relocated due to the different scenarios of reservoir volumes mentioned above results are shown in Fig. 8. Furthermore, Tropical Shrub is the common plantation in the site of the proposed reservoir. The initial filling of the reservoir floods the existing plant material, leading to the death and decomposition of these plants. The decaying plant matter settles to the non-oxygenated bottom of the reservoir, and decomposes and eventually releases dissolved methane. The amounts of carbonation for each scenario of reservoir volumes ranged between one to eight millions tone of carbon dioxide emission as shown in Fig. 8. In addition, the dam also will affect fish because they inhibit fish migration in a river. Some fish species have been able to spawn and grow to substantial size. Due to the high water level expected between 96 to 146 m in the different scenarios as shown previously in Fig. 2, many fish that try to swim up or down a river become disoriented by the warm waters and slower current of the reservoirs. Some of fish that try to pass directly through a dam's turbines are killed. The upriver spawning migrations of seven endemic Labeobarbus species of Lake Tana are also will be affected by development activities such as small-scale irrigation and dam construction at the inflowing rivers (McCartney et al., 2010)

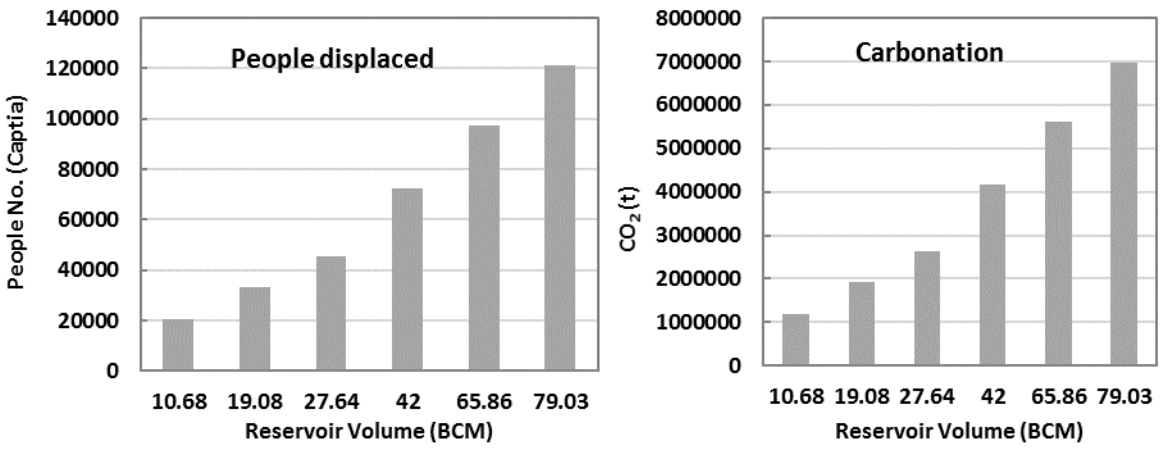

Figure 8. Environmental impact assessment of the GERD on, a) people displaced and b) carbonation at different scenarios of reservoir volumes

3.4.2 Impacts of dam reservoir on the downstream countries

The obvious impacts, commonly happen with construction such large dam, are the transformation downstream of the dam from a free-flowing river ecosystem to an artificial water canal habitat. According to model results in the different four time scenarios for filling the reservoir discussed above, water velocity will be reduced by 5, 11, 20 and 42% respectively. Furthermore, the water temperature in the river will be colder than it should be and this reduction can be estimated according to Duru (2008) by 0.5 to 1.5 Co. these changes in temperature and other water characteristic such as chemical composition, dissolved oxygen levels and the physical properties of the water are often not suitable to the aquatic plants and animals that evolved with a given river system. The dam also holds back sediments that would naturally replenish downstream ecosystems. The agricultural lands and scattering millions of families will be affected due to the reduction in the water share of downstream countries especially Egypt. Results presented previously (Figure 5) show different scenarios of charging the reservoir and the sever water demand in Egypt. It would also result in increasing the pollution of the water streams and creating problems in the supply of water for drinking and industry. There will also be problems in river transportation, Nile tourism and threats to the fish farms. When a river is deprived of its sediment load, it seeks to recapture it by eroding the upstream river bed and banks which can undermine bridges, dams and other riverbank structures.

When a river is deprived of its sediment load, it seeks to recapture it by eroding the upstream river bed and banks which can undermine bridges, dams and other riverbank structures. From the flood inundation areas resulting from the GERD failure scenario, the area surrounding the Senner dam will be flooded and considered as a major thread to that dam. Therefore such scenario will lead to flooding the most fertile lands in Sudan which is the home land to large population there.

3.5 Policy implications

The development of water resources of the UBNB in Ethiopia is very important to the country and the downstream countries (i.e. Sudan and Egypt). However, the implications of the likely long-term development of the Blue Nile resources in Ethiopia on Egypt and Sudan must be studied carefully. In the middle of this century, The US Bureau of Reclamation (1964) prepared a detailed study of the Blue Nile region and hence some hydroelectric projects were recommended. The Bureau suggested four dams to be established on Blue Nile downstream of Lake Tana, namely: Karadobi, Mabil, Mendaia and the Border Project. Together these four dams would have an initial active storage capacity of about 51 BCM and an estimated electricity generation of over 2900 MWh, about three times the actual production of the Aswan High Dam (Guariso and Whittington, 1987). One of these four dams is the Border Project which is known recently as GERD and discussed herein. It was planned, in the past by Bureau of Reclamation (1964) to store 11 BCM and generate electricity of 1400 MWh. Recently; the plan was changed to store 74 BCM. This great change in the original plan refers the misuse of the water resources of Blue Nile and has significant effects on the allowance of Egypt and Sudan from Blue Nile water. In addition, as discussed earlier, using such huge reservoir and dam without peer studies has the potential of the collapse and increase the negative environmental impacts of the project on its area and neighbors. Biswas (2004) stated that a main reason why the current non-productive argument on dams has succeeded is because of the absence of objective and long run in-depth ex-post analyses of the physical, economic, social and environmental impacts of large dams after their construction. Biswas & Tortajada (2001) reported also that various alternatives may be selected for the construction of properly planned and designed dams, which could be large, medium or small. It should be realized that in the real world of water resources management, small may not always be beautiful and big could be sometimes a disaster. Each alternative should be judged on its own value and within the context in which it is to be applied. The solutions selected must not be rigid, and should always reflect the needs of the areas with consideration the needs of neighbors

4 CONCLUSIONS AND RECOMMENDATIONS

Constructing a dam on the major Nile tributary, Blue Nile, considered as a challenge to the downstream countries. This paper investigated the impacts of constructing such a dam. Finally, the simulation study showed the following results:

- There is no correlation between the values declared about the dam reservoir. As at level of 640, i.e. 146 m behind the dam, the reservoir has 1561 km2 and a big volume of water equal to 79 BCM. This refers to either the shortage in data collection for this project or may the intention to hide theses values
- The results referred to a significant problem coming with charging the reservoir even at a long period time such as 40 years.
- The storage water in Nasser Lake may help to compensate the reservoir filling problem for around 70% of the charging periods in most of all studied scenarios.
- Based on results shown and discussed herein, the best accepted scenario for constructing the dam is by charging a reservoir with 10 BCM/year or less in 3.8 years. This amount of water will be sufficient for power generation and less impacts on the upstream counties.
- In case of dam breach, a severe flood will result in inundation of the Senner dam with 15 km width and 200 km long and the areas in between until it reaches Khartoum. Also, excessive water level rise with 3 m is expected from the dam until it reaches Nasser Lake.
- With the huge reservoir scenario of 79 BCM, 122,000 people will be displaced and 7 million tons of CO2 emissions.
- The agricultural lands and scattering millions of families will be affected due to the reduction in the water share of downstream countries especially in Egypt.
- With the presence of the dam, river water velocity will be reduced between 5 to 42% and temperature reduced by 1.5 Co. These physical properties along with other alerted characteristics of the water are often not suitable to the aquatic plants and animals that evolved with a given river system.
- The new plan of Ethiopia dam refers to the misuse of the water resources and has significant effects on the allowance of Egypt and Sudan from Blue Nile water. The solutions selected must not be rigid, and should always reflect the needs of the areas with consideration the needs of neighbours.

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