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Grand Ethiopian Renaissance Dam Impact on Long Term Operation of High Aswan Dam Reservoir

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Abstract: Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile River became a reality and its operation will begin at the early of 2017. Many researchers assessed the impact of the GERD on the performance of the High Aswan Dam (HAD) during the filling period. However, it is expected that filling period impact will continue on the long term operation due to the uniformity in the input discharge into HAD reservoir (Nasser Lake) after the impounding period of GERD dam reservoir.Also, all the previous studies focused on the reduction in the storage capacity not on the decrease in reservoir water level which will affect hydropower generation and evaporation losses from the reservoir. In this research, a long term flood routing for HAD reservoir begin one year before the beginning of GERD reservoir filling to the end of 15 yearsis carried out to assess the long term effect of GERD dam operation on water level and storage capacity of HAD reservoir. Three scenarios were adopted for beginning of filling in this study as follows; water level at Nasser Lake equals to 178, 173 and 168, respectively at first of August (beginning of flood season). The impounding period is changed two times, three and five years, respectively. Besides, effect of reduction in river inflow due to agricultural uses by Sudan and Ethiopia is studied. Besides, effect of GERD dam operation on the energy production from Aswan High Dam turbines is discussed.

Key words: GERD dam · Nasser Lake · Water level · Nile River

INTRODUCTION

Today's, there is agap between the available and demand water in Egypt. This may affect the economic development or cause depletion of the resources and degradation of the environment (Mohamed, [1]). Moreover, water shortage has already been exacerbated by rapid growth in population and economic development in the Nile Basin. Also, climate changes in the Nile Basin will decrease water availability significantly in this century. Thereby, it is imperative to develop adaptation strategies to reduce the adverse effects of climate change on the water availability in the region (Mohamed, [2]). Studying the water resources development of the Nile River basin was the subject of interest for many researchers, among of them Mohamed [2], Ramadan *et al*. [3], Mulat and Moges [4], Zhang *et al*. [5] and many others.

In 2011, Ethiopia started construction of Grand Ethiopian Renascence Dam (GERD) replacing previously proposed Border Dam. The dam will have a dimension of 145 m height and 800 m long, gravity-type composed of roller compacted concrete and will have two hydroelectric power houses; each on either side of the spillway, containing total of fifteen 350 MW Frances turbine generators. The capacity of dam's reservoir is 74 Billion m^3. It is expected that full commissioning of the dam is planned to be on 2017 (Nour El-Din, [6]). Abdel Salam *et al*. [7] assessed the negative impact of the Nile water inflow reduction on hydropower generation and irrigation. They suggested different alternatives to cope with water reduction in agriculture and carried out financial evaluation for the impact of Nile water inflow reduction on hydropower generation. Ahmed and El Sanabary [8] studied the effects of constructing GERD dam on the Nile River stream flow and its impacts on Egypt and Sudan if dam failure occurred.

Irrigation Development Plan in Ethiopia recommends expansion of irrigated crop land along the western border region. The plan incorporates approximately 250,000 hectares, or 35 percent of the estimated total irrigable land in the Blue Nile basin (Arsano and Tamrat [9]). Irrigating

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these areas from the Nile could reduce the river's flow to Egypt. There is a doubt that the basin produces enough renewable fresh water to satisfy the irrigation plans of both Ethiopia and Egypt (Ramadan *et al*., [3]).

The rapid growth of population number and extension of irrigated land areas in Ethiopia will need no less than 14 $km^3$of the Nile water. Because of this, the inflow of water to Egypt may decrease to 40- 45 km^3; considerable problems related to the water budget will be resulted even to the extent of water resources deficiency (Ismaiylov *et al*., [10]). So, the objective of the present study is the estimation of the effect of filling period on the long term water levels in Nasser Lake under different scenarios of beginning of fillings and how to accommodate with this situation.

The paper is organized as follows. It starts with introduction along with the presentation of importance and the previous studies for the subject. The second section is devoted to the detailed description of water budget analysis for the flow in and out of Nasser Lake. In the result section, the concept is applied on different scenarios to predict water level and energy production from AHD. In the final section some concluding remarks and recommendation are drawn.

Water-Budget Analysis: This method expresses the change in the reservoir content over a certain period of time as the difference between the in- and outflow volumes over the same period. The hydrological budget of Nasser Lake can be conceptually calculated by means of an ordinary differential equation (AbdelSalam *et al*.; [7]) such that:

$$\frac{dV(h)}{dt} = Q_{in} - Q_{out} - E(A) \quad (1)$$

V = Volume of water (storage) in the reservoir (Billion cubic meters).

Q_{in} = Inflow rate into the lake from White Nile, Blue Nile and Atbara (BCM/month).

Q_{out} = outflow rate from Nasser Lake to satisfy Egypt and Sudan demands (BCM/month)

E(A) = Evaporated volumetric rate of water from the lake surface (BCM/month).

A = Surface area of water in the lake (Km^2).

h = Water level in the lake (m).

Equation (1) can be written in differential form as follows;

$$\frac{V_i - V_{i-1}}{\Delta t} = Qin_i - Qout_i - E(A_{i-1}) \quad (2)$$

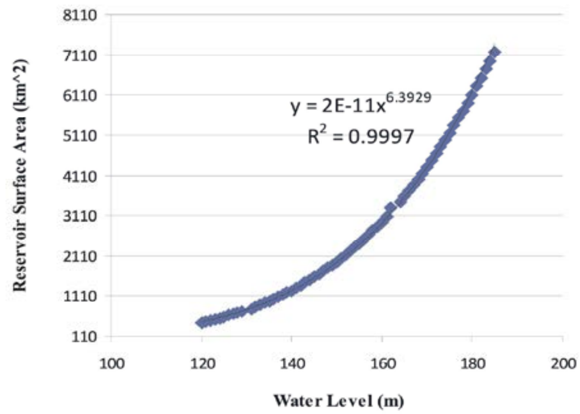

Fig. 1: Variation of Nasser Lake water surface area with water level in the reservoir.

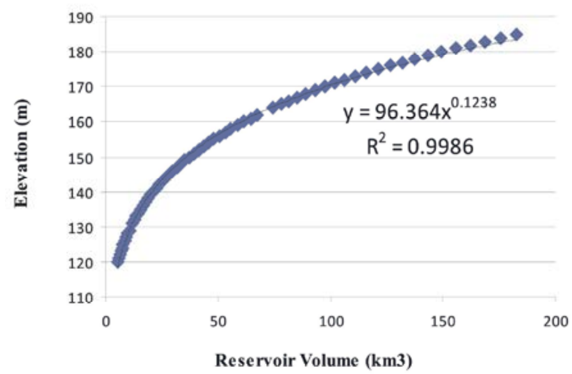

Fig. 2: Variation of water level in Nasser Lake with storage volume in the reservoir.

where the time step (Δt) is taken as one month, $V_i$is the reservoir volume at month i, $V_{i-1}$is the reservoir volume at month i-1, Q_{ini} is the inflow into the reservoir at month i, Q_{outi} is the outflow from the reservoir at month i and E is the evaporation volume from the reservoir as a function of reservoir surface area (A). During the target month, the inflow and outflow from the reservoir are knownand volume of reservoir in the preceding month (V_{i-1}). Also, rate of evaporation in mm/day is known for all months during the year (Table 1). To calculate the total evaporation from the reservoir during any month, the surface area of the reservoir is plotted versus the water level in the reservoir (Fig. 1) and a regression equation 3 is deduced which can be inserted directly in equation 2 (Shafik [11]). Then the volume of reservoir in month (i) can be calculated. To estimate the water level in the reservoir, values of water elevation are plotted against reservoir volume as shown in Fig. (2) and empirical equation 4 is used directly to compute the water level in the reservoir as a function of volume of water in the reservoir.

Table 1: Monthly average inflow and outflow from Nasser Lake (BCM).

Month	White Nile	Blue Nile	Atbara River	Egypt Demand	Sudan Demand	Nasser lake Monthly Eva. (mm/day)
Aug	1.435	18.154	5.126	6.3	0.8	8.47
Sep	2.236	11.699	3.306	4.5	1.2	7.9
Oct	3.024	5.075	0.77	3.6	1.4	7.13
Nov	2.786	2.258	0.145	3.3	1.41	5.53
Dec	2.747	1.156	0.046	3.2	1.8	4.43
Jan	2.469	0.687	0.017	2.6	2.4	4.1
Feb	1.905	0.457	0.006	3.4	2.4	4.27
Mar	2.014	0.432	0.001	4.2	2.2	5.6
Apr	2.225	0.375	0.003	4.3	1.5	6.53
May	2.026	0.672	0.008	5.5	1.2	8.1
Jun	1.792	1.668	0.088	7.3	1.2	8.73
Jul	1.368	8.938	1.536	7.4	1	8.67

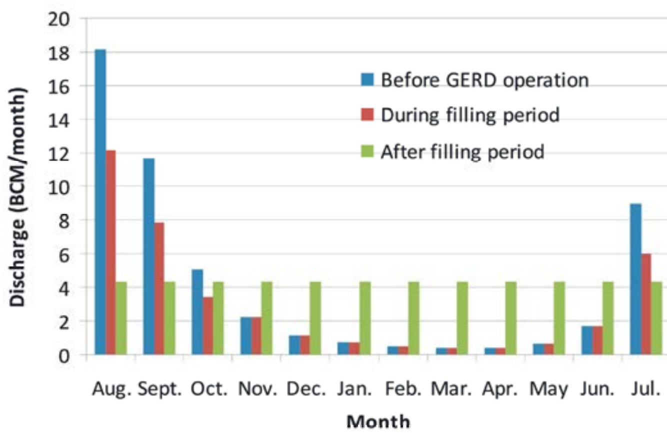

Fig. 3: Monthly Discharge at the mouth of Blue Nile before GERD operation, during filling period and after operation.

$$A_i = 2 \times 10^{-11} (h_i)^{6.3929} \quad (3)$$

$$h_i = 96.364 (V_i)^{0.1238} \quad (4)$$

In the above analysis, the sources of inflow are White Nile, Blue Nile and Atbara River, respectively. For each of them, the historical average monthly values are taken as shown in Table (1) for more details can be found in Sutcliffe and Parks [12].The outflow discharge is taken as the average monthly demand for Egypt and Sudan according to 1959 agreement for water allocating between them.The routing calculations were carried out for a period of 15 years, where the first year is considered before GERD reservoir filling and the filling process will take five years from beginning of the second year and nine years after the operation of the GERD dam with its full capacity. As the GERD DAM reservoir need 74 BCM to arrive to its full capacity, this volume is reduced from Blue Nile discharge during the flood period from July to October and this volume will be one third of Blue Nile discharge. After finishing the operation period,the discharge of the Blue Nile is taken a uniform value equals the average of the monthly discharge. Fig. (3) shows the monthly discharges at the mouth of the Blue Nile before, during and after filling of GERD reservoir.

RESULTS AND DISCUSSIONS

Water Levels in Lake Nasser Variation: Three scenarios were investigated. In the first scenario, the impounding period of GERD dam is taken as three years; in the second, the filling period is taken as five year and in the third scenario, the filling period is taken five years with a reduction value of 0.5 BCM in the monthly discharge after the operation of the GERD dam.Fig. (4) shows the variation of water levels in Nasser Lake for a period of 15 years assuming that the filling period of GERD dam's reservoir is three years and the water levels upstream HAD before beginning the filling can be 175, 173 or 168 m, respectively, depending on the flood quantities in the period before GERD reservoir filling. It is shown from this Fig. that the water level in Nasser Lake decreases gradually during the filling period and arrives to a minimum value at the end of filling period, i.e. three years.

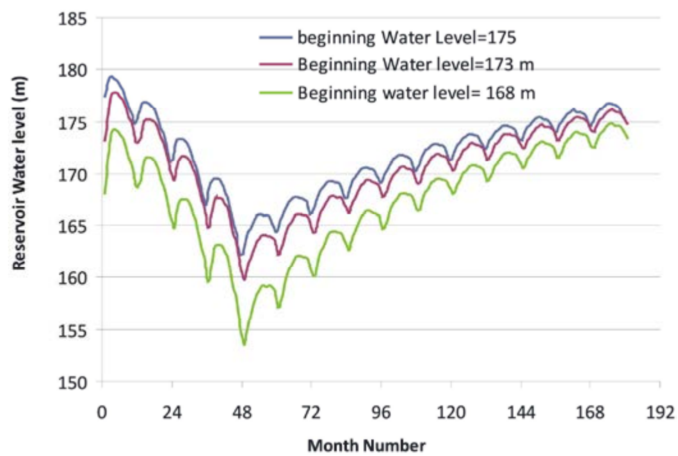

Fig. 4: Water level variation in Nasser Lake during and after filling period of GERD dam's reservoir for impounding period of 3 years.

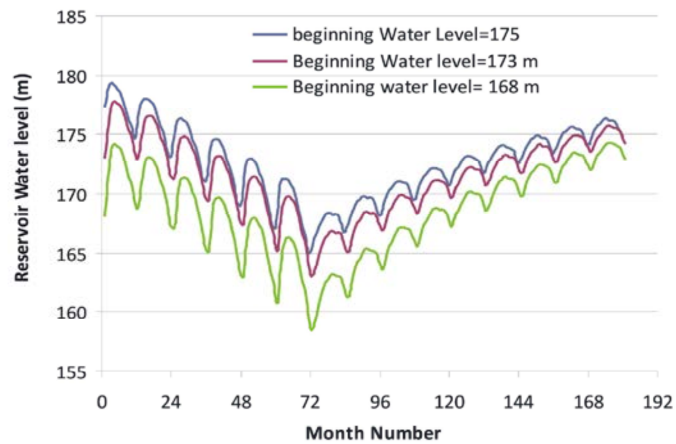

Fig. 5: Water level variation in Nasser lake during and after filling period of GERD dam's reservoir for impounding period of 5 years.

These minimum values are 162.138, 159.7 and 153.4 for beginning water levels 175, 173 and 168 m, respectively, then begin to increase again gradually to arrive to 175.28, 174.66 and 173.29 by the end of routing period.

Fig. (5) shows the variation of water levels in Nasser Lake for a period of 15 years assuming that the filling period of GERD dam's reservoir is five years and the water levels upstream HAD before the filling period is 175, 173 and 168 m, respectively. It is shown from this figure that the water level decreases gradually with advance of time of filling till arrive a minimum value at the end of filling period then begin to increase again. In comparison between Figs. 4 and 5, it is clear that the minimum level is higher for five years filling period than three years.

As a consequence of construction of GERD dam, it is expected that the Nile river inflow reduces due to irrigation expansion in Sudan and Ethiopia. In Fig. (6), the water levels in HAD reservoir is shown with a reduction monthly value of 0.5 BCM of inflow discharge after the filling period. As shown from this Fig., the water level at Nasser Lake will be affected severely and will not return to the original water level before the filling period of GERD reservoir.

Lake Nasser Water Losses: The only gain for Egypt from GERD dam construction is the reduction of evaporation rate from Nasser Lake due the reduction in water levels in the lake. Fig. (7) shows the evaporation rate before and after GERD operation. The total amount of water losses during one year before GERD operationis 11.523 BCM and that after GERD operation is 8.376 BCM but must be taken into account the losses from the GERD dam reservoir itself.

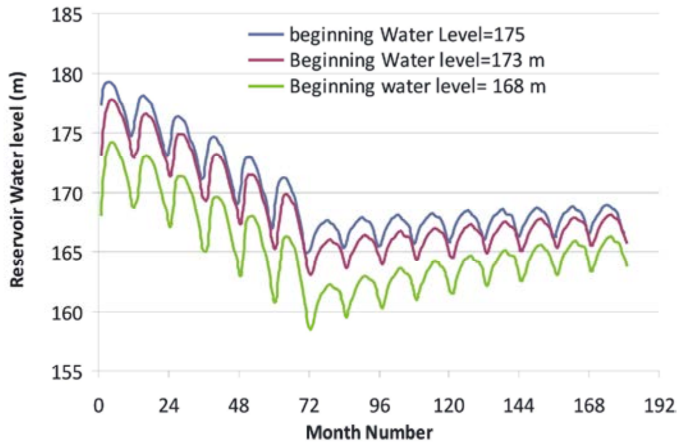

Fig. 6: Water level variation in Nasser lake during and after filling period of GERD dam's reservoir for impounding period of 5 years with 0.5 BCM monthly reduction in discharge.

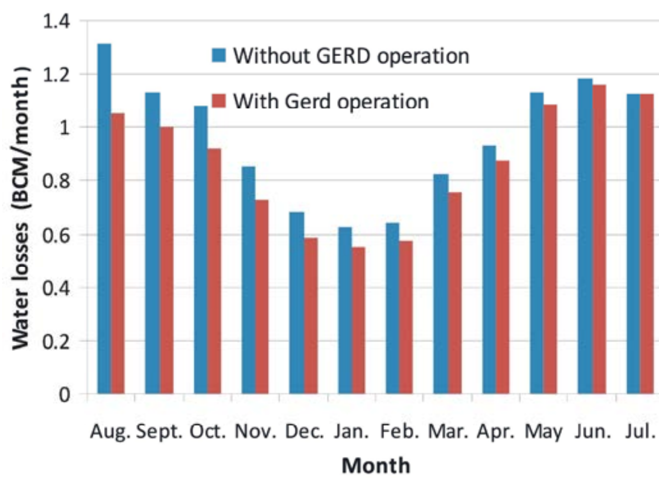

Fig. 7: Evaporation losses from Nasser Lake before and after GERD operation.

Hydropower Generation: The power generated from High Aswan Dam Turbines can be calculated from the following equation;

$$P = 9.81\eta QH \quad (5)$$

where

P= the power in KW

η = the turbines efficiency and is taken 0.85

Q= discharge (m^3/s)

H= average height of water above turbines in month (t) and equal to reservoir monthly mean water level -110. 110 meters assumed to be the constant level downstream of AHD (the water level downstream AHD ranges between 105 and 112 m above sea level (Eshra and Qottob[13]).

Fig. (8) shows percentage of yearly energy production from AHDT to that of the base year before beginning of GERD impoundment for three values of beginning water level in Nasser lake, 175, 173 and 168 respectively and period of GERD reservoir filling 5 years. As shown from that figure, the energy production decreases and arrive a minimum value at the end of filling period which is 0.85 of the base value due to the decrease in water level in Nasser lake then begin to increase further to arrive to its original values with the normal operation of the two reservoir.

Fig. (9) shows the same scenarios illustrated in Fig. (8) with a reduction in inflow to Nasser lake by a value of 0.5 BCM after GERD operation due to agricultural uses of Ethiopia and Sudan. It is clear from that figure, the energy production arrives a minimum value directly at the end of

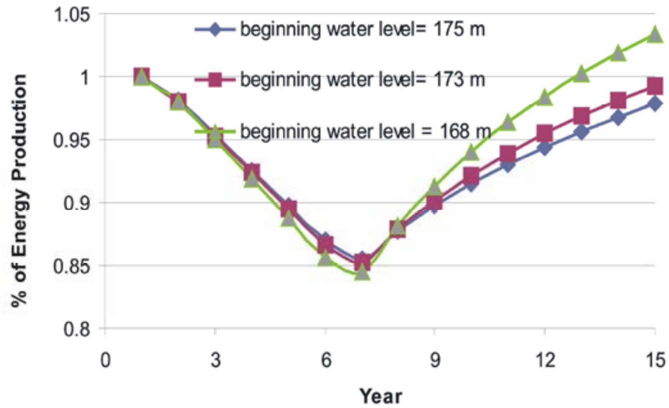

Fig. 8: Ratio of yearly energy production to the base year during and after GERD filling.

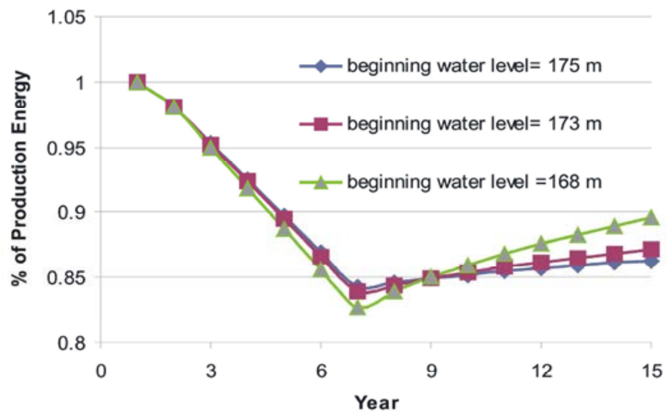

Fig. 9: Ratio of yearly energy production to the base year during and after GERD filling with reduction in inflow discharge.

filling period of GERD then begin to increase but slightly to nearly 0.9 of base year by the end of simulation period of 15 years.

CONCLUSIONS

This study evaluates the impact of GERD dam operation during and after the filling period on the water levels at Nasser Lake and energy production. It was found that the water levels in the lake will be affected severely by its initial water level at the beginning of operation. The best case to begin GERD reservoir filling when the water level at HAD reservoir equal to 178 at first of August and a filling period of not less than 5 years during the flood season only. The water level in Nasser Lake will return to original level, if there is no reduction occurs in inflow after the filling period. Moreover, the energy production from Aswan High Dam turbines will arrive its minimum value at the end of filling period and the reduction will be about 15% from the base year then begin to increase another if there is not decrease in the inflow discharge.The only advantage of GERD dam is the reduction of evaporation losses from Nasser lake.

Water management is thus one of the most important adaption actions. Adaptation of supply includes measures to improve rain harvesting techniques, increase abstraction of ground water, reuse of drainage and sewage water, desalinate water, improve its transportation and rationalize its use. Meanwhile, adaptation of demand requires minimizing the need for water and optimizing the economic return of its unit volume.

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