Assessment the Harm from the Grand Ethiopian Renaissance Dam on the Water Inflow to Egypt

Asmaa M. Kamel[1], Doaa M. Amin[2], Mohamed M. Nour Eldin[3]

[1]PhD Student, Assistant Researcher, Water Resources Research Institute (WRRI), National Water Research Center (NWRC), Ministry of Water Resources and Irrigation (MWRI), Egypt
[2]Researcher, Water Resources Research Institute (WRRI), National Water Research Center (NWRC), Ministry of Water Resources and Irrigation (MWRI), Egypt
[3]Professor, Irrigation and Hydraulic Department, Faculty of Engineering Ain Shams University, Egypt

---

Abstract - *The Nile River is the lifeline for Egypt as it covers about 95% of its demand. The natural flow at Aswan in Egypt is very sensitive to any change in the Blue Nile basin; this means that any upstream development in the Blue Nile Basin countries affects the inflow to Egypt. The Grand Ethiopian Renaissance Dam (GERD) is the most disputes between Ethiopia and downstream countries because of its unknown consequences. In this paper, the Eastern Nile Model (ENM) in RiverWare software was used to simulate the filling and operation of GERD reservoir during the period (2017-2060) for three scenarios and 115 ensembles of hydrological flow data with six years filling period. The results declares that the harm from GERD reservoir especially in the filling phase is catastrophic that could cause drought in Egypt. For instance, the probability of the High Aswan Dam (HAD) inflow less than 55.5 BCM would reach 70% and the probability of the shortage during the filling period bigger than 30 BCM reaches 8.7%. Finally, this article gives a qualitative analysis of the impact on the HAD reservoir from the GERD filling and operation.*

***Key Words*: River system modelling; Reservoir simulation; Transboundary Rivers; Eastern Nile; Riverware**

1. INTRODUCTION

The Nile River is the lifeline for Egypt as it covers about 95% of its demand. The Blue Nile contributes by about 60% of the inflow to Lake Nasser [1]; this means that any change in the hydrology of the Blue Nile affects the inflow to Egypt. In addition, the upstream developments in the Blue Nile Basin countries affect the water share of Egypt.

In few years ago, the government of Ethiopia is persisting their development plans by generating hydropower with a sequence of proposed dams. One of these dams is the Grand Ethiopian Renaissance Dam (GERD) with full storage over 74 BCM and installed hydropower capacity of 6000 MW. The GERD is in its last stage of construction and its filling is approaching. However, regional disputes are continuing due to its unforeseen impacts on downstream countries.

Building dams is a major hydraulic development that brings about many environmental, economic and social benefits to satisfy human needs, such as controlling floods, retaining sediments [2], providing water for irrigation, adjusting surface water quantity and quality, and generating hydropower. On the other hand, dams have several negative ecological impacts, including clearing/flooding large areas, increasing humidity of the nearby areas, provision of ideal habitat that leads to transmission [3]. In addition, the reservoir operation is a complex problem that involves many decision variables, multiple objectives as well as considerable risk and uncertainty [4].

Many efforts were done by many researchers to study the impact of Grand Ethiopian Renaissance Dam (GERD) construction on the inflow to Lake Nasser. The consequences of this dam could be catastrophic for Egypt. Ramadan et al. [5] studied the environmental impacts of GERD on the Egyptian water resources using MODSIM hydrological model. The study concluded decreasing in the Lake Nasser active storage by 37.263, 25.413, 13.287 BCM/year when the GERD impounded through two, three, six years respectively at the normal flow from the Blue Nile. At a minimum flow from the Blue Nile, the decrease of the active storage could be 55.138, 54.415, 44.398 BCM/year.

Zhang et al. [6] studied various filling policies of GERD. They found that impounding 10% (25%) of monthly streamflow behind the GERD produces a 6% (14%) average reduction in streamflow entering Lake Nasser. Twenty one different scenarios investigated the impact on High Aswan Dam (HAD) inflow by [7], where she found a reduction on hydropower production in Egypt. Ahmed, T. A. and Elsanabary [8] investigated the possibility of the GERD damage using HEC-RAC model, where they concluded that the best accepted scenario for constructing the dam is charging a reservoir with 10 BCM/year or less.

Mulat and Moges [1] modelled the Eastern Nile river basin using Mike Basin model that showed; 1- decreasing in HAD water level to 147m (the dead storage level), and 2- decreasing in the average annual inflow to HAD by 2%.

Thereafter, Wheeler et al. [9] compared the findings of 224 potential and practical filling strategies, using a river basin planning model (RiverWare) with a wide range of historical hydrological conditions (1900-2002). Wheeler found that the risks to Egyptian users and energy generation can be minimized through a basin-wide cooperative agreement that guarantee specific elevation for Lake Nasser.

Mobasher and Elabd [10] tested four different filling periods of (4, 5, 6, or 7) years, where they found that the smallest period the annual percentage of the inflow deduction could be 68.8% and could be reduce to 41.20% if the filling period increase to 7 years and the annual maximum violation would decrease from 40.07 BCM to 33.67 BCM in case of increasing the GERD filling period from 4 to 7 years.

This paper aims to study the impact of the GERD on inflow to HAD during the GERD filling and operation stages. The RiverWare software included the updated schematic of the Eastern Nile Model [11] was used. The influences on the operation of HAD from the GERD filling and operation will be analyzed and discussed to find out the minimum impacted scenario on the HAD inflow.

2. Study Region and Data Sets

2.1. The Eastern Nile Basin

The study area is the Eastern Nile basin showed in Figure 1. The Eastern Nile basin is located in the middle-east of the Nile Basin. It is geographically shared between Egypt, Sudan, South Sudan, and Ethiopia. The basin covers an area around 1,738,000 km^2 [12]. The Eastern Nile area starts from the Ethiopian plateau. The main sub-basins in the Eastern Nile Basin (ENB) are; the Blue Nile, Sobat River, and Atbara River (Figure 1). These three main sub-basins contribute with more than 85% to the total annual flow of the Nile.

In the Ethiopian highlands, the study area has steep slopes that receives heavy rainfall. In Sudanese part, the study area has mild slopes that receives less rainfall. Thus, the high portion of the flow in the Eastern Nile basin is coming from the Ethiopian highlands [13].

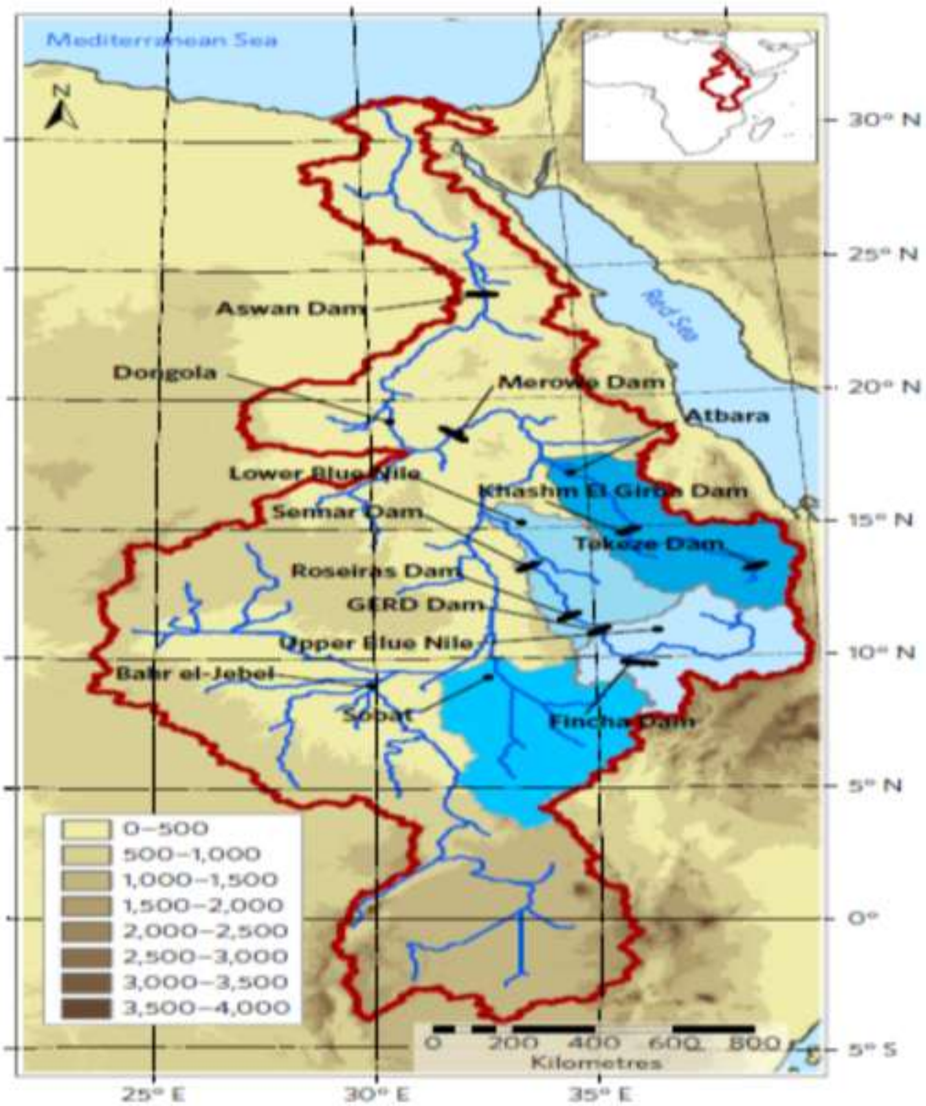


Figure 1: The Eastern Nile sub-basins within the Nile River basin in the topographic map [14]

2.2. The Data Sets

Many efforts were done to have the latest data about the GERD reservoir. Some of these data are old and not updated and there are many changes in the reservoir characteristics from year to year. It was decided to use the data from the Eastern Nile Technical Regional Office (ENTRO) for the physical characteristics of the GERD reservoir. Then, the data was updated through communications with Nile Water Sector (NWS). For the GERD reservoir characteristics, Table 1 shows the physical characteristics of GERD reservoirs. Figure 2 shows the Volume and Area – Stage Curve for the GERD reservoir.

Table 1: The Reservoir Characteristics, source: ENTRO Reservoir Profile Spreadsheet

Reservoir Characteristics	GERD
Dam Crest Level (masl)	645
Full Supply Level (masl)	640
Min. Operating Level (masl)	590
Storage @ FSL (BCM)	79
Active Storage (BCM)	59.22
Surface Area at FSL (km2)	1561
Power Capacity (MW)	6000

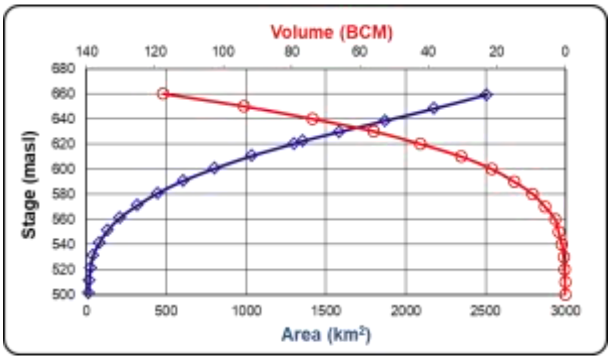


Figure 2: Volume and Area-stage curve for the GERD reservoir

3. Methodological Approach

The updated ENM [11] was used to assess the impacts from the GERD implementation on Egypt. Three scenarios were simulated by changing the HAD initial water level. The analysis were carried out by comparing the simulation outputs for the three scenarios. Examination of the GERD impacts on HAD was achieved through the analysis for the two stages (filling and operation) of the GERD reservoir.

The ENM was simulated in multiple run tool that is included in the RiverWare, where each scenario was executed using the 115 time series ensamples of hydrologic flow data as an input for expected flows from 2017 to 2060. This simulation is repeated for the three scenarios (initial HAD level 165, 170, 175 m). The outputs were analyzed and discussed in details.

3.1. Model Inputs and Assumptions

The Eastern Nile Model (ENM) was developed using RiverWare software [9,15]. Recently, Kamel et al. [11] updated the ENM for Reservoir Management. Their study concluded that the ENM is ready to evaluate the benefits and the impacts of any future development in the Nile basin.

In this paper, the ENM simulation was accomplished to study the effect from the GERD in the filling and operation phases. The simulated period starts from 2017 to 2060. The starting time of the simulation was controlled by the available input data, such as the initial water level for existing reservoirs. However, the filling of the GERD starts in July 2019.

The initial water level for all reservoirs exists in the system are shown in Table 2. The Sudanese dams' strategy was assumed to be ruled with its maximum capacity, where the Sudanese dams will receive more regulated flow due to the GERD implementation.

Table 2: The upstream initial water level for the existing reservoirs

Reservoir	Roseires	Sennar	Jebel Aluia	Khashm El Girba	Merowe	Upper Atbara and Setit	GERD
Water Level (m)	490.00	421.70	377.40	474.00	300.00	521.00	500

For the GERD reservoir, the start time of filling was assumed to be in July 2019. The initial water level for GERD was set to be 500 m. The GERD filling period was assumed to be finished in six years with three phases. The first phase was assumed in one-year with targets level 565 m, and corresponding storage 4.5 BCM. The second phase was assumed in one-year with targets level 595 m, and corresponding storage 18.0 BCM. Finally, the third phase was assumed to be fill in four years with targets level 640 m, where the filling volume during the third phase was distributed over the four years with the percentage 40%, 30%, 20% and 10% for the first, second, third and fourth year respectively. Table 3 indicated the target level and storage for each year in the filling period. In the GERD operation period, the GERD operation was set to target only the hydropower production.

Table 3: The target water level and storage volume for GERD reservoir

Year	1	2	3	4	5	6
Target elevation (m)	565	595	618	630	637	640
Target storage (BCM)	4.5	18.0	40.4	57.2	68.4	74.0

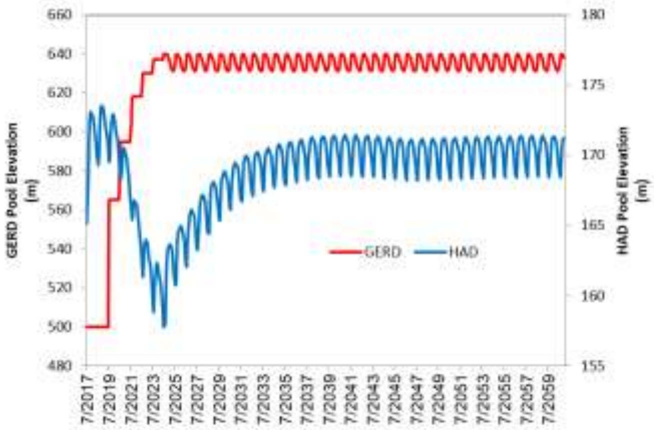
For the HAD reservoir, the initial water level was assumed to be 165 m, 170 m, and 175 m, which developing 3 different scenarios.

A series of 115 years of historical flow data (1900-2014) was used to develop stochastic hydrologic conditions by applying the index-sequential method [16]. This method applies the sequence of the historical hydrologic flows to produce series of future flow data with the similar sequence for the modelled period (2017–2060).

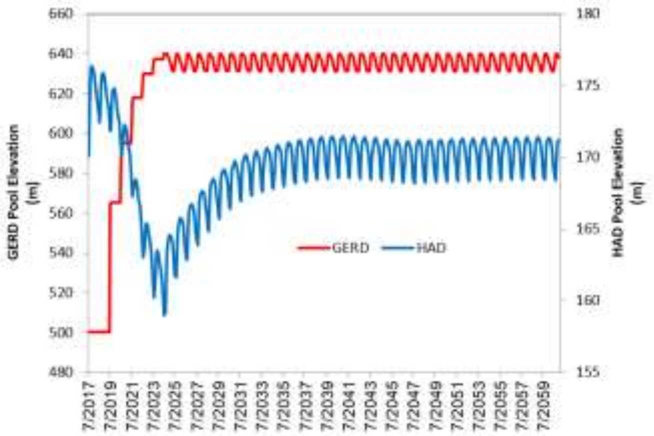
4. Results and Discussion

The analysis was carried out by comparing the simulation outputs for the three scenarios considering the two stages of filling and operation of GERD. Examination of the GERD impact on HAD was achieved through four main criteria. The first criteria was the probability of HAD water level less than 159 m and 147 m. The second criteria was the probability of the inflow entering HAD not exceeding 55.5 BCM. The third criteria was the 10%, 50%, and 90% probability of exceedance for HAD pool elevation. Finally, the fourth criteria was the probability of shortage percentage for the short term. These criteria were described below.

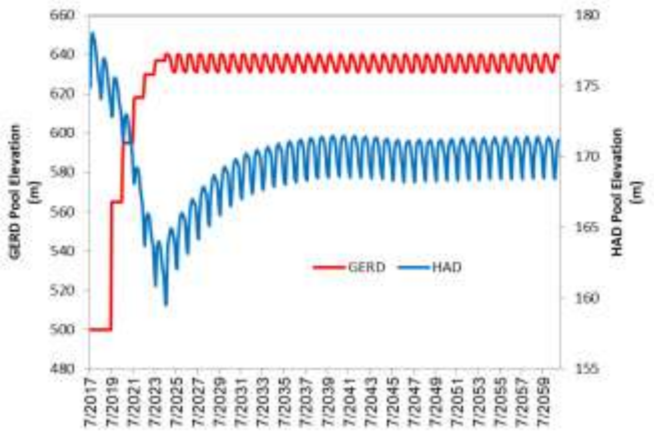
Figure 3 shows the average of the 115 ensembles for the pool elevation (the level of the month start day) for the GERD and HAD reservoirs during the simulation period (2017 to 2060) for the three scenarios. It appears from Figure 3 that HAD pool elevation drops to very low levels in the filling period of the GERD in all scenarios. The difference between the initial and the minimum value is around 7 m, 11 m, 15.5 m in the first, second, and third scenario respectively. After the filling, the HAD pool elevation rises and reach equilibrium between 168 to 171 m amsl.



(a)



(b)



(c)

Figure 3: The average of 115 ensembles for the monthly simulated pool elevation for GERD and HAD reservoirs: (a) HAD initial level = 165 m, (b) HAD initial level = 170 m, (c) HAD initial level = 175 m

The maximum probability of HAD water level less than or equal 159 m and 147 m was analyzed, where level 159 m is the minimum elevation for power generation from the HAD, and level 147 m is HAD dead storage level. The probability of HAD water level less than or equal 159 m equals to the probability of shutting down the HAD turbines, where the probability of HAD water level less than or equal 147 m equals to the probability of having zero outflow from HAD that causes catastrophically drought in Egypt.

The maximum probabilities of HAD water level less than or equal 159 m and 147 m were computed for the short term (2019-2024) and the long term (2025-2060) representing the filling and operation phases of GERD reservoir. The probability of HAD water level was expressed as:

$$P(L \leq 159) = n(L \leq 159) / n(L)$$

Where $P(L\leq159)$ is the probability of HAD water level occurrence less than or equal 159 m in each time step (monthly) for all hydrological ensembles (115), $n(L\leq159)$ is the number of occurrence less than or equal 159 m, and $n(L)$

is the total number of all possible HAD water level outcomes (115).

The maximum probability was calculated from the maximum of all probabilities for all time steps, this process was repeated for all scenarios and for HAD water level less than 159 m and 147 m in short and long terms, Figure 4 and Figure 5. The two figures confirmed that the max probability of HAD level less than or equal 159 m is higher than the max probability of HAD level less than or equal 147 m in all conditions. It was clear that the maximum probability of HAD level less than or equal 159 m and 147 m was decreasing by increasing the HAD initial water level in both short and long terms. The values of the maximum probability of HAD level less than or equal 159 m and 147 m are higher in the short term than in long terms. This was due to the effect of the GERD reservoir filling. Figure 4 indicates the Egypt harms from GERD filling, which was represented in the high probabilities of lowering HAD level, especially if HAD initial water level was low when the GERD filling starts. Additionally, this harm was decreasing in long term; however, the probability of HAD level to be less than 159 m and 147 m still exists in the operational phase of GERD (Figure 5).

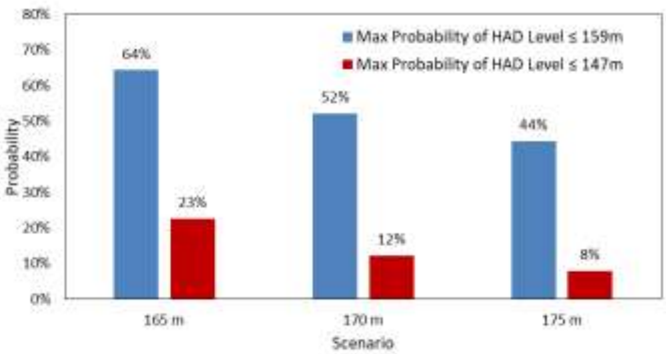


Figure 4: Maximum Probability of HAD level ≤ 159 m, ≤147 m in short term (2019-2024) for the three scenarios

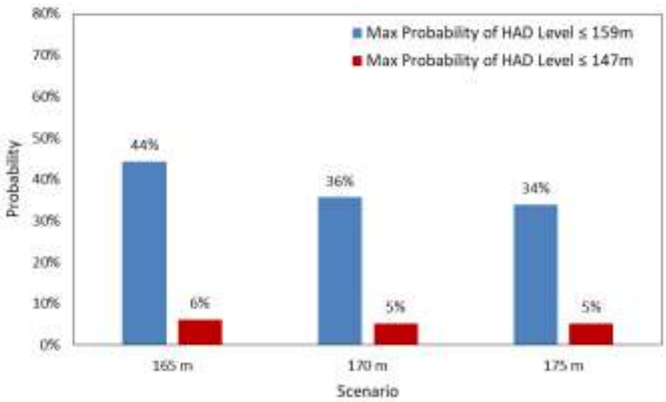


Figure 5: Maximum Probability of HAD level ≤ 159 m, ≤147 m in long term (2025-2060) for the three scenarios

The second criteria was check the probability of the HAD inflow to not cover the Egypt share 55.5 BCM. These probabilities were computed for the three scenarios. The probability of HAD inflow was expressed as:

P(I<55.5) = n(I<55.5) / n(I)

where P(I<55.5) is the inflow entering HAD not exceeding 55.5 BCM in each year for all hydrological ensembles (115), n(I<55.5) is the number of occurrence less than 55.5 BCM, and n(I) is the total number of all possible HAD water level outcomes (115). This process was repeated for all scenarios with different HAD initial water level. Finally, these probabilities were plotted in Figure 6 that shows the probability of the inflow entering HAD not exceeding 55.5 BCM for the three scenarios. It is obvious that the probability of the HAD inflow to be less than 55.5 BCM dramatically increases in the first six or seven years. In the other side, these probabilities were slightly increased in long term for all scenarios.

For the three scenarios, the probability of the HAD inflow less than 55.5 BCM reaches 70% during the GERD filling period. However, it decreases to 13% in the GERD operation period, (Figure 6). The probabilities in the three scenarios are similar all the time. This means that whatever the initial HAD level, Egypt won't receive its share (55.5 BCM) with 70% probability in the GERD filling period. Figure 6 exhibits that Egypt could suffer from drought when the GERD filling with high probabilities.

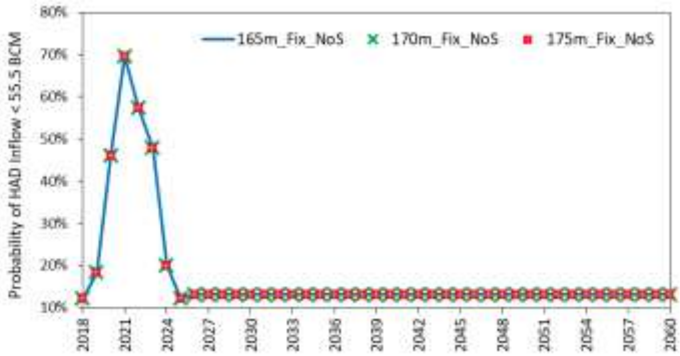
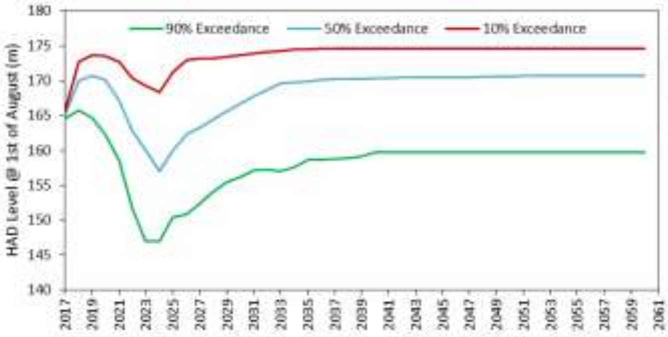


Figure 6: Probability of HAD Inflow < 55.5 BCM

The 10%, 50%, and 90% probability of exceedance for HAD pool elevation was analyzed to observe the changes in HAD water levels for all climatological ensamples. These probabilities were calculated from the HAD pool elevation at first of August for the three different scenarios. The 10%, 50%, and 90% probability of exceedance for HAD pool elevation were expressed from the 90th, 50th, and 10th percentile respectively, Figure 7.

Figure 7 (a, b, and c) shows the 10%, 50%, and 90% probability of exceedance for HAD pool elevation (at 1st of August) during the simulation period for the initial HAD level 165 m, 170 m, and 175 m respectively. The figure manifests the effect of GERD filling on HAD pool elevations in all scenarios. For instance, the 90% probability of exceedance for HAD pool elevation in the three scenarios looks similar. However, in the first scenario, the HAD level drop to its minimum elevation 147 m for two years during the GERD filling instead of dropping to its minimum elevation 147 m for one year only in the second and third scenarios. During GERD operation, the HAD pool elevation rises and reach equilibrium between 159.67, 170.69, and 174.63 m amsl for the 90%, 50%, and 10% probability of exceedance for all scenarios.



(a)

(b)

(c)

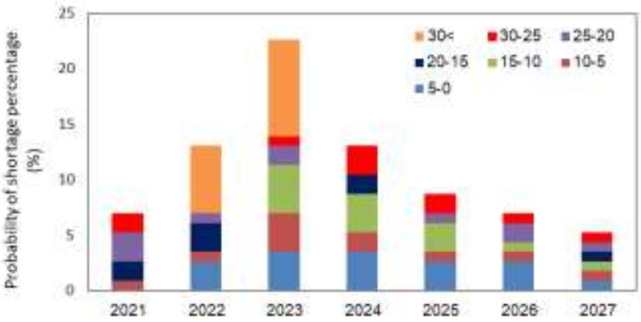
Figure 7: 10%, 50%, and 90% probability of exceedance for HAD pool elevation: (a) initial HAD level = 165 m, (b) initial HAD level = 170 m, (c) initial HAD level = 175 m

The probabilities of the depletion shortage percentages regarding the Egyptian demands were computed for each year in the short term (2019-2027) representing the filling phase of the GERD reservoir. The probabilities of shortage percentages were calculated according to seven specified intervals (0-5), (5-10), (10-15), (15-20), (20-25), (25-30), and (>30) BCM. This is to recognize the shortage problem in each year with the shortage value and its probabilities. These probabilities were computed for the three scenarios. The probability of shortage percentages for the specified intervals (0-5) was expressed as:

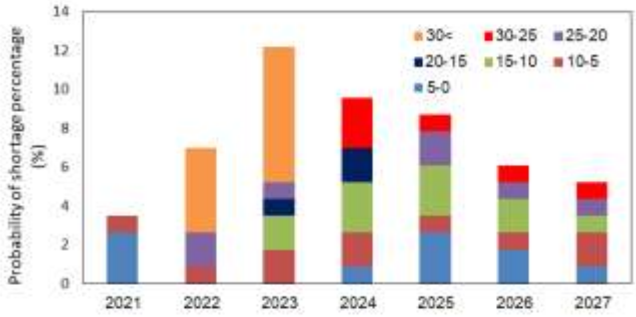
$$P(0<sh<5)= n(0<sh<5) / n(I)$$

where $P(0<sh<5)$ is the probability of shortage in each year in the short term (2019-2027), $n(0<sh<5)$ is the number of occurrence bigger than 0 BCM and less than 5 BCM, and $n(I)$ is the total number of all possible shortage outcomes (115). This process was repeated for the seven specified intervals (0-5), (5-10), (10-15), (15-20), (20-25), (25-30), and (>30). This process was repeated for all scenarios with different HAD initial water level.

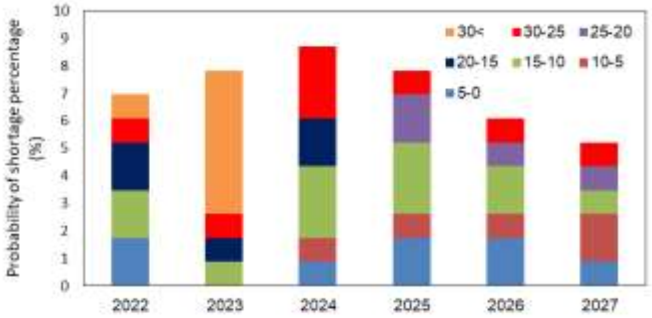
Figure 8 (a, b, and c) shows the probability of shortage percentage in short term (2019-2027) for the initial HAD level 165 m, 170 m, and 175 m respectively. The figure confirms the negative consequence from the GERD filling on Egypt. For example, in 2023, the probability of shortage bigger than 30 BCM reaches 8.7%, 7%, 5.2% for the initial HAD level 165 m, 170 m, and 175 m respectively. In other words, Egypt will suffer from severe drought in 2023 even with small probabilities due to the GERD filling regardless the initial HAD level. This could have serious consequences such as increasing pollution of surface water, dryness of agriculture lands, economic crisis, higher food production costs, lower energy production from hydro plants, depletion of water tourism and transport revenue, and problems with water supply for the energy sector and for technological processes in metallurgy, mining, the chemical, paper, wood, foodstuff industries etc.



(a)



(b)



(c)

Figure 8: Probability of shortage percentage in short term (2017-2027): (a) initial HAD level = 165 m, (b) initial HAD level = 170 m, (c) initial HAD level = 175 m

5. Conclusions

The updated ENM was used to simulate the filling and operation of GERD reservoir in RiverWare software. The ENM simulation was accomplished for three scenarios (initial HAD level 165, 170, 175 m). The number of the hydrological flow ensembles for each scenario was 115; the length of the ensemble was for the period (2017-2060).

The analysis was carried out through four main criteria (the probability of HAD water level occurrence less than 159 m and 147 m, the probability of the inflow entering HAD not exceeding 55.5 BCM, the third criteria is the 10%, 50%, and 90% probability of exceedance for HAD pool elevation, and the fourth criteria is the probability of shortage percentage).

From the results, the GERD may have very high impact on the water inflow to Egypt. The first harm indicator is represented in high probabilities (34% - 64%) of decreasing HAD level to less than 159m. This means high probabilities of shutting down the turbines and no hydropower generated from HAD. In addition, the probabilities (5% - 23%) of decreasing HAD level to less than 147 m, which means high probabilities of emptying the reservoir, this means that HAD will not be able to release water downstream HAD, which causes catastrophically drought in Egypt. The second harm indicator is represented in the probability of the HAD inflow less than 55.5 BCM, which reaches 70%, this means that the inflow to Egypt may be decrease to less than 25% of the mean annual inflow. The third harm indicator is represented by the 90% probability of exceedance that showed the HAD pool elevation drops to its minimum elevation 147 m. The fourth harm indicator is represented by the probability of shortage bigger than 30 BCM reaches 8.7% in 2023. Consequently, the harm from GERD reservoir especially in the filling phase is enormous that could cause drought in Egypt with high probabilities.

This article gives a qualitative analysis of the impact on the HAD reservoir from the GERD filling and operation. Egypt will suffer more from the construction of GERD especially in the filling period, where all sectors depend on water will be under risk during the filling period. Finally, the basin managements and cooperation between the Eastern Nile countries are essential and needed to avoid or reduce the harm from GERD on water inflow to Egypt. It is recommended to test other scenarios for changing the GERD filling policies to avoid or reduce the harm from the GERD implementation on Egypt.

REFERENCES

[1] Mulat AG, Moges SA. Assessment of the impact of the Grand Ethiopian Renaissance Dam on the performance of the high Aswan Dam. Water Resour Prot 2014;6:583–98. doi:10.1080/14703291003718950.

[2] Zhang W, Mu S, Zhang Y, Chen K. Temporal variation of suspended sediment load in the Pearl River due to human activities. Int J Sediment Res 2011;26:487–97. doi:10.1016/S1001-6279(12)60007-9.

[3] Alrajoula MT, Zayed IS Al, Elagib NA, Hamdi MR. Hydrological, socio-economic and reservoir alterations of Er Roseires Dam in Sudan. Sci Total Environ 2016;566–567:938–48.

[4] Oliveira R, Loucks DP. Operating rules for multireservoir systems. Water Resour Res 1997;33:839–52. doi:10.1029/96WR03745.

[5] Ramadan sayed M, Negm AM, Smanny M, Helmy A. Environmental Impacts Of Great Ethiopian Renaissance Dam On The Egyptian Water Resources Management And Security. Conf Pap 2013;55:1–14. doi:10.13140/2.1.2233.2483.

[6] Zhang Y, Block P, Hammond M, King A. Ethiopia's Grand Renaissance Dam: Implications for Downstream Riparian Countries. J Water Resour Plan Manag 2015;141:05015002. doi:10.1061/(ASCE)WR.1943-5452.0000520.

[7] Ismail SS. Flow Reduction Impacts along River Nile in Egypt. Seventeenth Int Water Technol Conf 2013:5–7.

[8] Ahmed, T. A. and Elsanabary MH. Hydrological and Environmental Impacts of Grand Ethiopian Renaissance Dam on The Nile River. Eighteenth Int. Water Technol. Conf. IWTC18, 2015, p. 336–347.

[9] Wheeler KG, Basheer M, Mekonnen ZT, Sami O, Mersha A, Abdo GM, et al. Cooperative filling approaches for the Grand Ethiopian Renaissance Dam 2016;8060:0–24. doi:10.1080/02508060.2016.1177698.

[10] Mobasher AM, Elabd SM. Impact Assessment of the Filling Period of the Grand Ethiopian Renaissance Dam Reservoir on the Nile Flow. Int J Water Resour Environ Manag 2016;7:1–14.

[11] Kamel AM, Amin D, Eldin MMN. Updating and assessment of the eastern nile model in riverware for reservoir management. Int J Appl Eng Res 2019;14:1772–81.

[12] Digna RF, Castro-Gama ME, van der Zaag P, Mohamed

YA, Corzo G, Uhlenbrook S. Optimal operation of the Eastern Nile System using Genetic Algorithm, and benefits distribution of water resources development. Water (Switzerland) 2018;10. doi:10.3390/w10070921.

[13] Amin DM, Kotb A. Assessment of the Skill of Seasonal Meteorological Forecasts in the Eastern Nile. Nile Water Sci Eng J 2015;8:31–40.

[14] Siam MS, Eltahir EAB. Climate change enhances interannual variability of the Nile river flow. Nat Clim Chang 2017;7:350–4. doi:10.1038/nclimate3273.

[15] Wheeler KG, Hall JW, Abdo GM, Dadson SJ, Kasprzyk JR, Smith R, et al. Exploring Cooperative Transboundary River Management Strategies for the Eastern Nile Basin. Water Resour Res 2018;54:9224–54. doi:10.1029/2017WR022149.

[16] Ouarda TBMJ, Labadie JW, Fontane DG. Indexed sequential hydrologic modeling for hydropower capacity estimation. J Am Water Resour Assoc 1997;33:1337–49. doi:10.1111/j.1752-1688.1997.tb03557.x.