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Egypt's Water Budget under the Impact of the Filling Stages of the Grand Ethiopian Renaissance Dam

El Sayed Mokhtar Ramadan , Gamal Mohamed Mostafa Abd-Elaal, Maha Rashad Fahmy, Samar Mohamed Abd-ElHak Hassan*, Ismail Abd-Elaty

Department of Water and Water Structures Engineering, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt

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ABSTRACT

Now days, the gap existence between the supply and demand water is the significant challenges in Egypt, so intensive efforts are being made to overcome the dilemma. Nile River is a key resource of Egypt, as it supplies by 93% of its all fresh water. Any change and development in the hydrology of Blue Nile Basin result in influences to natural inflow of Egypt, whereas Blue Nile is the biggest contributes of the River Nile supplies. For that reason Egypt's concerns and fears regarding the implementation of the Grand Ethiopian Renaissance Dam (GERD) and its filling stages have increased. The paper objectives was to calculate Egypt's water budget within period (2010-2026), then investigate and evaluate the influence of GERD's filling stages on Egypt's water budget. The paper conducted based on geo-statistics data collection for Egypt's water budget during the concerned period according to the annual reports to Ministry of Water Resources and Irrigation (MWRI) and Central Agency for Public Mobilization and Statistics (CAPMAS). Results revealed that filling stages have negative impacts on water budget by decreasing especially in 2023 and 2024. As, Ethiopia impounded more quantity of water than was at the prior filling stages, so that the lack was more. Therefore It is recommended to reduce amount of water filling stages, in addition to apply reutilizing water through several appropriate approaches, reorganizing the distribution of water, and improve water transportations and eliminating its losses, construct water condensers next to severe evaporation regions, apply crop pattern, apply Modern and economical irrigation policy application, increasing abstraction of groundwater but take into account the necessary precautions.

1. Introduction

Recently, Egypt water resources are exposed to tremendous pressure represented in population growth, developments and economic activities, and climate changes [1, 2], thus Egypt entails to apply a new management strategies for achieving water sustainability and availability addition to diminish water shortage.

As stated in Ministry of Water Resources and Irrigation (MWRI) Report (2017)[3] that water resources in Egypt involves to the Nile River 55.5 billion cubic meter/year (BCM/y), groundwater (9.6 BCM/y), rainwater 1.3 BCM/y, sea water desalination (0.35 BCM/y), and reuse of agriculture drainage water (13.5 BCM/y). Nile River provides about 93% of the annual renewable water resources

* Corresponding author. Tel.: +2-01225200946
E-mail address: s.abdelhak.y.1989@gmail.com

in Egypt, as the Nile water agreement in 1959 allocated share of (55.5 BCM/y) to Egypt [3].

Water budget (water balance) (WB) is a principal activity for proper management of water resources. Actually 'WB' is an accounting of water inputs, outputs and storage of water e.g. in lithosphere, atmosphere and oceans during certain period. Hence, WB means the balance between the available water in the country and the water under use. Hence, it is balance between the accessible water and the water underutilization. It can be applied to any area with volume varied from local scale areas to regional scale areas or from any drainage basin to the whole land [4] .

The estimation and evaluation of all WB components have efficient role in regional management and development of water resources, mitigation hazardous flow events, and optimizing surface water and groundwater resources. According to the precious role of water on humanity, a numerous researches have attentive investigation of water budget. Thus it entails to understand the interactions between water in and out flow system and their ecological influences on lake [4] .

Water challenges in Egypt exert further stresses of Egypt's relatively fixed water resources. Todays, the significant and pioneer challenge is the Grand Ethiopian Renaissance Dam (GERD). In April 2011, Ethiopia started on the implementation of GERD or the millennium dam (i.e. El-Nahda dam) on the Blue Nile in which it have significant tributaries of River Nile, which supplies the Nile with 59%.of its all fresh water supplies.

GERD located in the Benishangul-Gummz Region of Ethiopia, at about 45 km east borders with Sudan. Ethiopian government planned to complete the dam by 2017, once completion of the dam construction it will be the largest hydroelectric power plant in Africa at 6000 Mega Watt (MW)[5-7]. GERD designed with dimensions up to 145 m high and 1800 m long. The reservoir of GERD covers an area around 1874 km^2 with storage capacity of 74 BCM and height of 50 meters and power plant capacity of 6000 MW to be generating electricity in 2014 as shown in

Figure 1 [8].

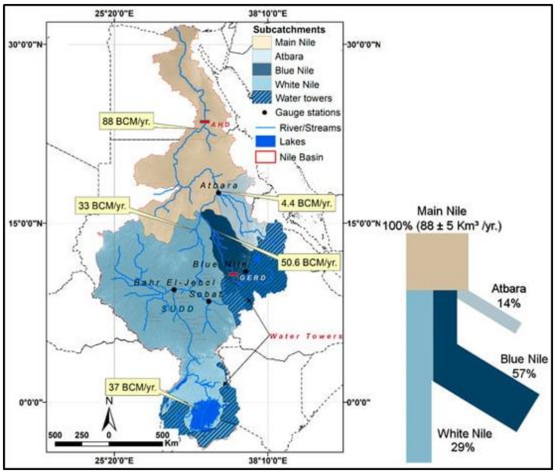

Figure 1 : Location map of GERD showing annual contribution of the major tributaries to the Nile River Basin (NRB) waters [9].

These storage values are approximations of the annual discharge figures. The storage values adapted from [10].

Ramadan et al. [11] implemented different mathematical scenarios to evaluate the expected negative effects of building the GERD on Egypt water resources. The results revealed that the evaporation losses will be increased to be 5.9% which affect the Nile River water quantity and quality at downstream of dam by increasing the Nile water salinity. The impounding of GRED at normal flow through 6, 3, 2 years will cause consequently reduction in the lake Nasser storage by 13.3, 25.4, 37.3 BCM per year. Tesfa [5] known that electricity generation was the target and exposed benefit to Ethiopia of GERD. The study identified the significant benefits of GERD on Sudan and Egypt are: it will benefit Egypt and Sudan with elimination of silt and sedimentation up to 86%. It regulates helpfully the steady water flow through the year, and it will avoid un-expected flooding to downstream countries. It will also preserve water in Ethiopian plain from evaporation. Nada and Fathy [12] conducted different scenarios of filling dam to investigate the impacts on water levels and discharges downstream of AHD. The results were a reduction in water levels from 0.40 m to 0.75 m when decreased recharge from 90% to 80% at maximum outflow. Mulat and Moges [13] using simulation model using mike basin river simulation model to evaluate the expected impact of the dam on the performance of AHD during filling and operation stages. The results indicated the proposed scenario 6 year time is enough to reservoir dam to be filled with little effect on the present water supplies to irrigation from AHD in Egypt without any proposed management precautions. Ibrahim [14] illustrated impacts of dam on Egypt will be included that Ethiopia became totally empowered and dominated of the Blue Nile flow path. The electricity power production of the High Dam and Aswan Reservoir would reduce by 20%. The Nile River would be posed water deficit with an average annual inflow by 10 BCM. Egypt will faces many severe environmental, economic and social problems as lack of cultivated irrigated pelvic area and wasted millions acres of agriculture lands and thus reclamation programs in Egypt affected. Environmental degradation and a rising in pollution occurs an imbalance in the natural system of life in North Lakes. Threatening Groundwater quality and increasing salinity in coastal aquifers in North Delta, due to rise in sea water intrusion. Navigation and Nile cruises will be affected by the reduction in water level in Nile, thus its branches and canals. Gad [15] stated that a crisis in water resources sustainability and management is facing Egypt as a developing country. Increasing of water demand is not the only way to occurrence the water shortage problem, but also to poor infrastructure that it is required urgent upgrading, limited funding and management procedures. Preservation water resources is required applying all means including rationalize the consumption, minimize the waste and posing strict laws governing the process of industrial wastewater pumping on water resources, also improve the quality of sewage treatment to reduce pollution as well as find alternative sources of water. Armanuos et al. [16]conducted 3d model for simulated the Nile delta aquifer by using MODFLOW program to study the expected impact of reduction in water head in canals networks system in Nile delta as a result of GERD and increasing the pumping discharges on ground water level the canals networks system were included for more accurate simulation of groundwater recharge. Calibration model for hydraulic conductivity of first and second layer was run using the observed head by RIGW, Morsy (2009) [17]. This study was considering three scenarios (1) was reduction of water depth in canals as a result of GERD. (2) Increasing pumping discharges of groundwater wells, and (3) combination between the first and second scenario. Results revealed that increasing the pumping discharges is more significant than the impact of reduction in water canals network depth compare with the state in 2008. It was found that drawdown of groundwater levels increases from north to south in studied domain. With reduction of water depth by (25%) this leads to drawdown of 0.30 m, 0.5 m and 0.2 m in average values in the western part, central region and eastern parts of Nile delta. more drawdown is expected by 0.6 m, 0.7 m and 0.4 m at scenario reduction water canal level with (50%). at scenario increasing pumping discharges by (25%) result to drawdown of 0.35 m, 1.0 m and 0.5 m in regular in the western, central part and eastern regions on Nile delta while scenario (50%) reveled more drawdown by 0.7 m, 1.5 m and 1.27 m in average. And the third scenario presented the worst case. El-Nashar and El Yamany [18] In this paper risk management is used to evaluate risks of GERD on Egypt. The work conducted assumed that the GRED reservoir will complete filling after 3 years and that is the worst scenario for Egypt. For identifying risks of GERD on Egypt used brainstorming technique. Using Delphi technique to defined the risks qualitatively and identified the probability and impact of risks, then assessed risks quantitatively using Expected value to determine risk magnitude, in order to eliminate risks and conserve and manage fresh water supplies in Egypt it must adopted the proposed management procedures and strategies. Thus the expected quantity of rescued water using these proposed strategies to be 40BCM which exceeds loses arising from GERD by 27.91 BCM. The impletion of all proposed strategies or a combination of them could eliminate the effect of dam. Most of these proposed strategies entail time to impletion as a design of development irrigation and progress surface irrigation system. Mohamed [19] evaluated the impact of GRED operation during and after filling stages on water level in Nasser Lake and power generation. Results revealed that water level in Lake Nasser will be affected at the beginning of operation and the best level in lake to begin GRED filling is 178 at the binging of August and filling period 5 years. The power generation from Aswan high dam (AHD) turbines will record lowest value at the end of filling period and the reduction will be about 15% from the base year. The only advantage of the dam, that it reduced evaporation losses from the lake. Nour El Din [20] applied the developed Eastern Nile Model by using RiverWare software to simulate the filling and operation of dam. The simulation was conducted for three scenarios (165, 170, 175 m) initial length of AHD at period 2017-2060, hydrological flow ensembles for each scenario was 115. The analysis was carried out through four main stages the first one was the probability occurrence of AHD water level less than 159 m, its result was decreasing in level with percentage 34%-64% lead to shutting down the turbines and no hydropower generated from dam. Also the probabilities by 5% - 23% of decreasing AHD level to less than 147 m, it revealed to emptying the reservoir and not release water downstream. The second probabilities of the AHD inflow less than 55.5 by 70% it means that decreasing in inflow to Egypt by 25%. The third was probability 90% of exceedance result in drops in AHD reservoir by 147 m its minimum level the last stages was the probability of shortage bigger than 30 BCM leads 8.7 % in 2023. Thus during filling dam is significant harmful to Egypt's inflow which could cause drought in Egypt. Abd-Elaty et al. [21] evaluated the water budget and salinity result in the sea level rise and expected decreasing inflow of Nile River consequence of GERD numerically by using SEAWAT code. The study was developed by three scenarios involved of the storage filling stages of dam in which 17 BCM at 600 m level, 37.30 BCM at 621 m, and 74 BCM at 645 m. Those past scenarios was combined with sea level rise to be 25 m, and increasing in an abstraction rates from Nile Delta Aquifer by 25%, 75%, and 100%. The results indicated that filling stages result in reduction in inflow of Aswan High Dam for three scenarios by 38.5 BCM, 35.20 BCM, and 18.50 BCM compared with base case 55.5 BCM before filling stages of dam. Total inflow and outflow increased in three scenarios due to over pumping and consequently raised inflow at the north from Mediterranean Sea result in increased sea water intrusion to the aquifer. Hereby the GRED filling will increase the aquifer salinity. The aquifer salt mass recorded 4.47%, 11.48%, and 29.99% respectively.

2. Methodology

In this paper the proposed methodology mainly involves collecting water budget data based on annual reports of Central Agency for Public Mobilization and Statistics (CAPMAS) and MWRI regards to Egypt's water budget at period (2010-2022) as illustrated as follows:

- Data collection for water budget data within available period from (2010-2022), then by replace inflow Nile River in water budget with inflow after filling dam for period from (2021-2022) to period (2025-2026) with assumption that inflow data is constant after 2021-2022 to the end of filling stages.
- According to outflow data collection at (2021-2022) and assumption that outflow will be constant to the end of filling stages.
- Data collection for filling stages of dam as shown in Table 3.
- Calculated the expected decrease value of inflow of Nile River.
- Calculated ΔS for Egypt's water budget with filling stages of dam.
- Evaluated and analysis the expected results.
- Stated several Recommendation and solutions.

2.1. Study Area and Data Sets

Egypt has been selected as study area; it is located on the northeast corner of Africa continent between latitudes 21° and 31° north and longitudes 25° and 35° east with total area 1.00*10^6 km^2. Egypt borders represents in the costal line of Mediterranean Sea at north, in the east by Red Sea, Sudan at south, and in the west by Libya. Egypt consists of four major physical regions as: Nile Valley and Delta, Sinai Peninsula, eastern desert, and Western Desert as visible in

Figure 2

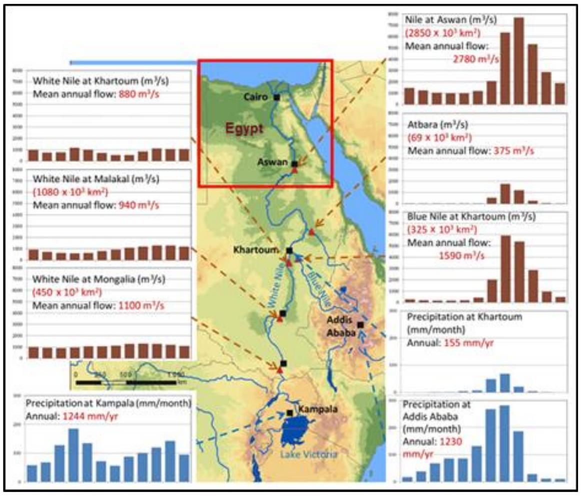

Figure 2 Nile River hydrology [22]

2.2. Surface water budget

through calculation and evaluation of the hydrological cycle, hydrologists take into account opened system based on water balance with time(ds/dt) as the following equations [4] :

$$\Delta S = inflow - outflow \quad (1)$$

$$P + Q_{in} = E_T + \Delta S + Q_{out} \quad (2)$$

P is precipitation, Q_{in} is in flow to hydrological system, E_T is evapotranspiration, ∆S is changes in system storage, and Q_{out} is out flow water of the hydrological system.

2.3. Data set for Egypt surface hydrology

According to annual report census of population by CAPMAS, in 2023 Egypt's population reached about 105 million individuals, on the 3 rd. of June 2023 with 43% living in urban areas and 57% in rural areas. Population distribution by regions: Lower Egypt houses the largest population in Egypt by 42.9% of the total population. It is followed by Upper Egypt with a percentage of 38.9%, then the urban areas with 16.7%, whereas the frontier cites by less than 2% of the total population.
The data has been collected based on annual reports of (CAPMAS) and MWRI regards to Egypt's water budget at period (2010-2022) which involves water resources supplies of Egypt as inflow resources as shown in Table 1

Table 1 Egypt's water resources supplies (inflow) after dam (2010-2026)

Year	Nile flow (BCM)	Groundwater (BCM)	Reuse wastewater (BCM)	Rainfall water (BCM)	Seawater desalination (BCM)	Total Inflow (BCM)
2009-2010	55.5	6.5	9.80	1.30	0.06	73.16
2010-2011	55.5	6.3	7.10	1.30	0.06	70.26
2011-2012	55.5	7.5	6.50	0.97	0.06	70.53
2012-2013	55.5	6.70	12.37	0.93	0.06	75.92
2013-2014	55.5	6.70	12.60	0.90	0.10	76.2
2014-2015	55.5	6.90	13.00	0.90	0.10	76.8
2015-2016	55.5	9.49	13.50	1.30	0.21	80
2016-2017	55.5	9.45	13.50	1.30	0.25	80
2017-2018	55.5	9.60	13.50	1.30	0.35	80.25
2018-2019	55.5	9.45	13.65	1.30	0.35	80.25
2019-2020	55.5	10.73	13.51	1.30	0.38	81.42
2020-2021	53.05	10.85	13.40	1.30	0.38	78.98
2021-2022	53.95	8.83	15.36	1.30	0.38	79.82
2022-2023	51	8.83	15.36	1.30	0.38	76.87
2023-2024	43.5	8.83	15.36	1.30	0.38	69.37
2024-2025	44	8.83	15.36	1.30	0.38	69.87
2025-2026	50.5	8.83	15.36	1.30	0.38	76.37

Then data for water resources demands as outflow, which include Agriculture Uses, Loss by Evaporation, Household uses, industrial uses, Rivers navigations, and take into consideration as MWRI opened Toshka depression twice in the year 2023. With estimated water requirements needed for reclaiming and cultivating540 thousand feddans are nearly from 4 to 5 BCM/Year of fresh Nile water [23]as shown in Table 2

Table 2 Egypt’s water demands after GRED (2010-2026)

Year	Agriculture (BCM)	Evaporation (BCM)	Household Use (BCM)	Industrial (BCM)	Rivers Navigations (BCM)	Toshka Project (BCM)	Total Out (BCM)
2009-2010	60.5	2.1	8.5	1.35	0.1	0.0	72.55
2010-2011	60.9	2.1	9.5	1.2	0	0.0	73.7
2011-2012	62.1	2.5	9.7	1.2	0	0.0	75.5
2012-2013	62	2.4	9.9	1.2	0	0.0	75.5
2013-2014	62.35	2.5	9.95	1.2	0	0.0	76
2014-2015	62.35	2.5	10.35	1.2	0	0.0	76.4
2015-2016	61.45	2.5	10.65	5.4	0	0.0	80
2016-2017	61.45	2.5	10.65	5.4	0	0.0	80
2017-2018	61.65	2.5	10.7	5.4	0	0.0	80.25
2018-2019	61.65	2.5	10.7	5.4	0	0.0	80.25
2019-2020	61.63	2.5	11.53	5.4	0	0.0	81.06
2020-2021	62.01	2.5	11.52	5.4	0	0.0	81.43
2021-2022	61.87	2.5	11.48	5.4	0	0.0	81.25
2022-2023	61.87	2.5	11.48	5.4	0	0.0	81.25
2023-2024	53.49	2.16	9.93	4.67	0	11	81.25
2024-2025	53.49	2.16	9.93	4.67	0	11	81.25
2025-2026	53.49	2.16	9.93	4.67	0	11	81.25

3. Results

3.1. Impact of GERD storage on Egypt surface water share

According to annual reports of GRED’S filling phases by Egyptian water expert Abbas Sharaqi, the data was collected in Table 3, in which illustrated that filling stages of dam began at 2020 with storage 4.9 BCM at level 565 reached to storage cumulative 24 BCM at level 625 m in current year with expected storage for residual years to be 23 and 10 respectively.

Figure 3 presents the relation via the cumulative storages of GRED and corresponding reduction in inflow of Nile River reveals that the dam achieves its aims of proper filling stages, but there are reduction rates in storages of Nile River inflow, which entails to apply new strategies to overcome this reduction

Table 3 filling phases of GRED and corresponding reduction in River Nile inflow

Year	level	storage	storage	filling loss	50% filling loss	total volume	Egypt share
	(m)	(BCM)					
Base	500	0	0	0	0	84	55.5
2020	565	4.9	4.9	4.9	2.45	79.1	53.05
2021	575	3.1	8	3.1	1.55	80.9	53.95
2022	600	9	17	9	4.5	75	51
2023	625	24	41	24	12	60	43.5
2024	640	23	64	23	11.5	61	44
2025	645	10	74	10	5	74	50.5

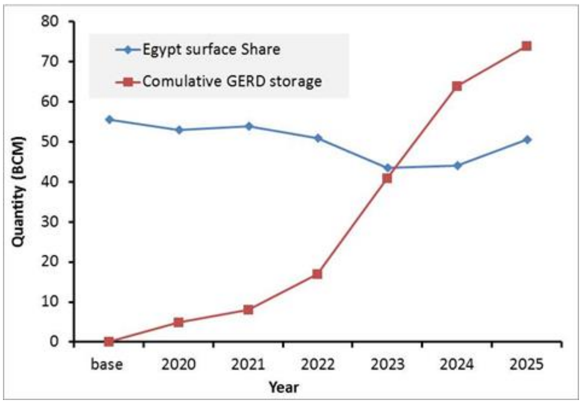

Figure 3 : Storage curve for stages filling GERD via Egypt share after filling dam

3.2. Impact of GERD storage on Egypt surface water storage

Water budget for Egypt water resources at period (2010-2026) shown in
Figure 4, then calculated ΔS as shown in
Figure 5 noticed that there are mild variation in values but in (2010 and 2011) there is clear decline.
Evaluation water budget under the filling stages revealed that the filling stages decrease the river inflow by (2.45, 1.43, 4.38, 11.88, 11.38, 4.88) respectively and consequently decreasing in all resources as the key depending on the Nile by 93% consequent of the dry climate of Egypt and rare scattered rainwater.

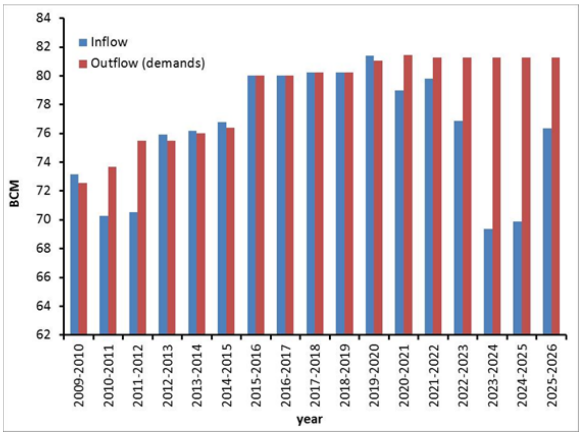

Figure 4 Egypt's water budget

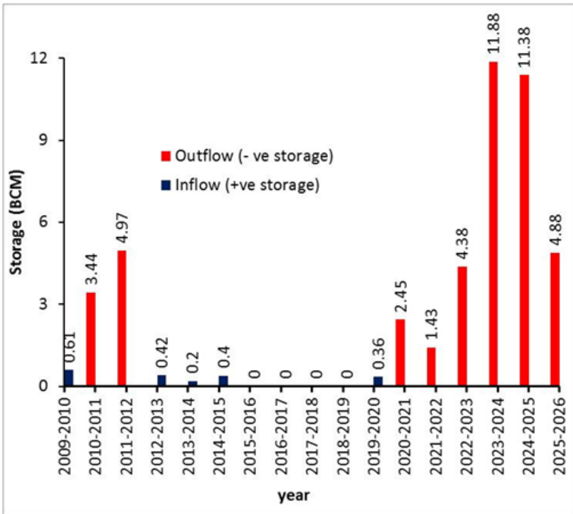

Figure 5 : Egypt Surface water Budget with Filling GRED

4. Conclusion and recommendations

Blue Nile represents the significant tributary of the River Nile, thus any alters in the hydrology of the Blue Nile Basin results in influences on inflow of Nile River. Consequently, it augmented Egypt's concerns and fears about its share of the Nile Water budget. So that, this paper was conducted to investigate the impacts of down stream's development in addition to construction and filling stages of GRED on Egypt's water budget. The study conducted through available data collection of Egypt's water budget at certain period (2010-2022) based on the annual reports to Ministry of Water Resources and Irrigation and Central Agency for Public Mobilization and Statistics. Results clarified that the filling stages of GRED effect on water budget of Egypt by obvious reduction, so the government must take into account to apply a necessarily procedures and measures to empower for a proper management this dilemma as follows. It is recommended to apply reutilizing water through several approaches, reorganizing the distribution of water, and eliminating water losses by apply crop pattern, apply Modern and economical irrigation policy application.

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