Comprehensive Assessment for the Potential Environmental Impacts of the Grand Ethiopian Renaissance Dam on the Downstream Countries: Itaipu Dam in the Rearview Mirror

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Comprehensive Assessment for the Potential Environmental Impacts of the Grand Ethiopian Renaissance Dam on the Downstream Countries: Itaipu Dam in the Rearview Mirror

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ABSTRACT: This article provides a comparative environmental assessment for the Grand Ethiopian Renaissance Dam (GERD) learning from Itaipu dam experience. The article gives a full insight about the potential political and technical concerns that may affect the downstream countries as a result of the construction of GERD and proposed a solution and way forward for the negotiation based on joint collaboration perspective. Based on the analytical comparison conducted between GERD and Itaipu, the results showed that the total annual carbon dioxide (CO_2) emissions expected to be released from the GERD during the operation is 3,927 tCO_2eq, while other secondary emissions were estimated to be 16.17 tons, mainly of carbon monoxide and nitrogen oxides. Also, the ratio of power generation to reservoir capacity of the GERD was questionable, since Ethiopia has announced that the dam is built only for power generation and that there is no intention to utilize water from the dam reservoir. On the other side, the water quality - represented in turbidity, total suspended solids (TSS), dissolved oxygen (DO), total phosphorus (TP), and chemical oxygen demand (COD) - behind the GERD is expected to deteriorate dramatically. Also, an increase in total nitrogen (TN) is expected to occur depending on human activities. Accordingly, the article discussed thoughtfully the potential adverse impacts of the GERD on downstream countries and the possible mitigation options. The article also extended to discuss proposals for practical solutions that pave the road for joint collaboration between the three countries to achieve a transparent resolution and a fair resources utilization.

KEYWORDS: Environmental impacts, GERD, Itaipu dam, Nile River, mitigation options, proposal for joint administration

TYPE: Original Research

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Introduction

The Grand Ethiopian Renaissance Dam (GERD) is located on the Blue Nile, as shown in Figure 1, which is a major tributary of the Nile River contributing up to 85% of its water, despite the fact that its contribution is seasonal (Hamada, 2017). The Blue Nile originates at Lake Tana in north-western Ethiopian Highlands and runs for approximately 1,450 km to meet another major tributary the White Nile. The Grand Renaissance hydroelectric facility comprises a concrete gravity dam on the Blue Nile River with a storage capacity of 74 billion cubic meters (BCM) of water, one outdoor powerhouse on each bank of the river, three spillways, and a saddle dam.

The initial purpose of the Grand Ethiopian Renaissance Dam (GERD) is to produce from 5 to 6.4 GW hydroelectric power based on different designs (Kansara et al., 2021; Siddig et al., 2020). The latest negotiations between Egypt, Sudan, and Ethiopia that was halted for reaching a dead end in July 2020, which is around the period of filling the dam lake for the first year with 5 BCM (U.S. Department of the Treasury, 2020). Although, Egypt and Sudan are expected to face water scarcity challenges during the filling period (Abdeldayem et al., 2020), Ethiopia has continued their individual actions without reaching an abiding agreement with the downstream countries and filled the dam for the second year with around 2–3 BCM (Kansara et al., 2021) which empowers the downstream countries situation when Egypt jointly with Sudan took the GERD dispute file to the United Nation Security Council and shows how the situation is a matter of live for the downstream countries and how the Egypt and Sudan are concerned about such an individual action. Because decreasing the filling years means more reduction of the flow arriving to Sudan and Egypt (Abtew & Dessu, 2019; Borowski, 2020; Madson & Sheng, 2021). However, the filling period and possible political conflict is intensively dependent on climate change and the amount of the rainfall that are expected to fall during the filling period. Normally, the main rain season in Ethiopia starts proximally in June and finish in September (Borowski, 2017).

Alternatively, run-of-the-river dams could have provided Ethiopia with energy much sooner than the GERD will and without all the risks it has generated for the downstream countries. Moreover, Ethiopia's already excessive reliance on hydropower is risky due to uncertain projections of climate change for the rainfall patterns in East Africa (AbuZeid, 2021). According to the Intergovernmental Panel on Climate Change (IPCC), it is expected that the African horn (east Africa) will experience an increase in rainfall of December and January in the future, because of climate change effects, 90% of the models confirmed that (Wainwright et al., 2021). The same result was recorded by another study, which predicted that rain fall over the African horn will increase by more than 10 mm on average (Dunning et al., 2018). This is despite the fact that east Africa has experienced decreasing rainfall during the "long

Figure 1. The location of the GERD on the Blue Nile.

rains" season, recently (Rowell et al., 2015). Ethiopia's abundant solar power provides another alternative for peaceful energy sources (Sterl et al., 2021). It needs only 0.003% of its land to be covered with solar PV to satisfy its current electricity needs, and its average practical power potential is 4,695 KWh/KWp (The World Bank, 2020). Besides, if Ethiopia develops its massive geothermal resources, it would expand its energy security and alleviate the political tensions that the GERD has created.

It is very important to have Environmental and Social Impact Assessment (ESIA) studies for the GERD project, which are required by law and an obligation before a country develops any transboundary project that necessitates it (Morsy et al., 2020). Although it is quite straight forward to expect the various negative impacts of GERD on the environment in Ethiopia and the downstream countries, the magnitude of the effect is not very easy to determine due to multiple and complicated factors affecting them (Wheeler et al., 2020) such as the rainfall and discharge from the GERD during the filling period, how quickly Ethiopia is planning to fill the reservoir, how much Electric power is planned to be extracted from the dam, which depends on the extent of the grid development in

Ethiopia (Eldardiry & Hossain, 2021), how building the dam is going to affect Sudan withdrawal (Siddig et al., 2020), the water level in the High Aswan Dam (HAD) reservoir before GERD, and how HAD will be operated during the filling of GERD reservoir. Despite being complicated to measure, the environmental impacts can be a critical factor in the Egyptian Ethiopian negotiations on the GERD. The absence of ESIA is considered a breach to the international laws of the transboundary projects. Accordingly, this article is meant to emphasize on the importance of having an environmental impact assessment (EIA) study for the GERD. The convention in this kind of transboundary studies is to involve all the meant stakeholders. This is what happened in the case of Alqueva dam in Portugal, which required coordination between Spain and Portugal (Albergaria & Fidelis, 2006).

Although several hydraulic studies have been conducted on Grand Ethiopian Renaissance Dam (GERD), a comprehensive study associated with the environmental side has not been well explored. With the ever-growing concern about the current negotiations about the GERD, which take place between Egypt, Ethiopia, and Sudan since the construction started in 2011 (Borowski, 2021), the consideration of having an environmental impact assessment for such a project has revealed to be a key player and a main contributor in such negotiations worldwide. This article presented some of the direct and indirect potential environmental impacts of the GERD and its effect on the biological, physical, and chemical features of the Nile River. A comparative assessment for the GERD versus Itaipu dam was conducted to explore the environmental impacts of the dam. The dam impacts will extend to affect the following aspects with varying severity: water quality and physical properties; riverine ecosystem and biodiversity; evapotranspiration and climatic variability; fisheries; impacts on Aswan High Dam (AHD) and Lake Nasser; climate change and green-house-gas emissions; eutrophication and floating aquatic weeds; public health; and tourism and navigation. The possible mitigation options for those effects are discussed in this article. This article has presented the international laws for transboundary projects among international waterbodies and rivers which are considered the foundations and principals to the realization of human rights law such as Espoo Convention, Rio Declaration on Environment and Development in addition to the International Court of Justice. The article also extended to discuss proposals for practical solutions that pave the road for joint collaboration between the three countries to achieve a transparent resolution and a fair resources utilization.

International Laws and Obligations for Transboundary Projects

Based on the GERD's specifications and sensitive location, leading international agencies, such as the Food and Agriculture Organization (FAO), United Nation Development Program (UNDP), and World Bank (WB) would classify the GERD as high-risk infrastructure. It requires rigorous technical planning and implementation processes—woven around the human and environmental rights considerations—called PESTEL (political, ecological, social, technological, economical, legal) analysis for all parties the dam may impact, inside and outside Ethiopia, the host country (Borowski, 2019). The international environmental law principles are foundation to the realization of human rights law. Most of the world's countries recognize these laws' interdependence.

Espoo convention

In 1991, the European Espoo Convention (Convention on Environmental Impact Assessment in a Transboundary Context) has come into force to put principals for the EIA of transboundary projects. The Convention has put an obligation on the parties to give the public an opportunity to participate in the Environment Impact Assessment procedure for a proposed activity or project. In the process, the public of the affected country or states must be given equal opportunity as the public of the country or state where the project is proposed (United Nations Economic Commission for Europe, 1991).

Rio Declaration on Environment and Development

In 1992, the Rio Declaration on Environment and Development required parties to carry out an EIA for proposed transboundary activities and/or projects that are likely to have significant adverse impacts on the environment. It further required the countries to provide a prior and timely notification and relevant information to potentially affected countries or states on these activities/projects. Also, it emphasized to consult with those countries or states at an early stage and in good faith (United Nations, 1992).

International Court of Justice

The International Court of Justice (ICJ) has recognized environmental impact assessment as a practice that has become an obligation of general international law in similar cases. In 2010, it was the first occasion in which an international court held that prior assessment of transboundary impacts is not merely a treaty-based obligation but a requirement of general international law during the judgment of the Pulp Mills on the River Uruguay, even though, Uruguay was not a party to the 1991 Espoo Convention on Transboundary EIA.

Methodology

This study has considered reviewing and learning from dams with similar situations and cases in Europe and Latin America. Alqueva dam, located in Portugal, and Itaipu dam, located in Brazil, were both taken as references to explore the potential

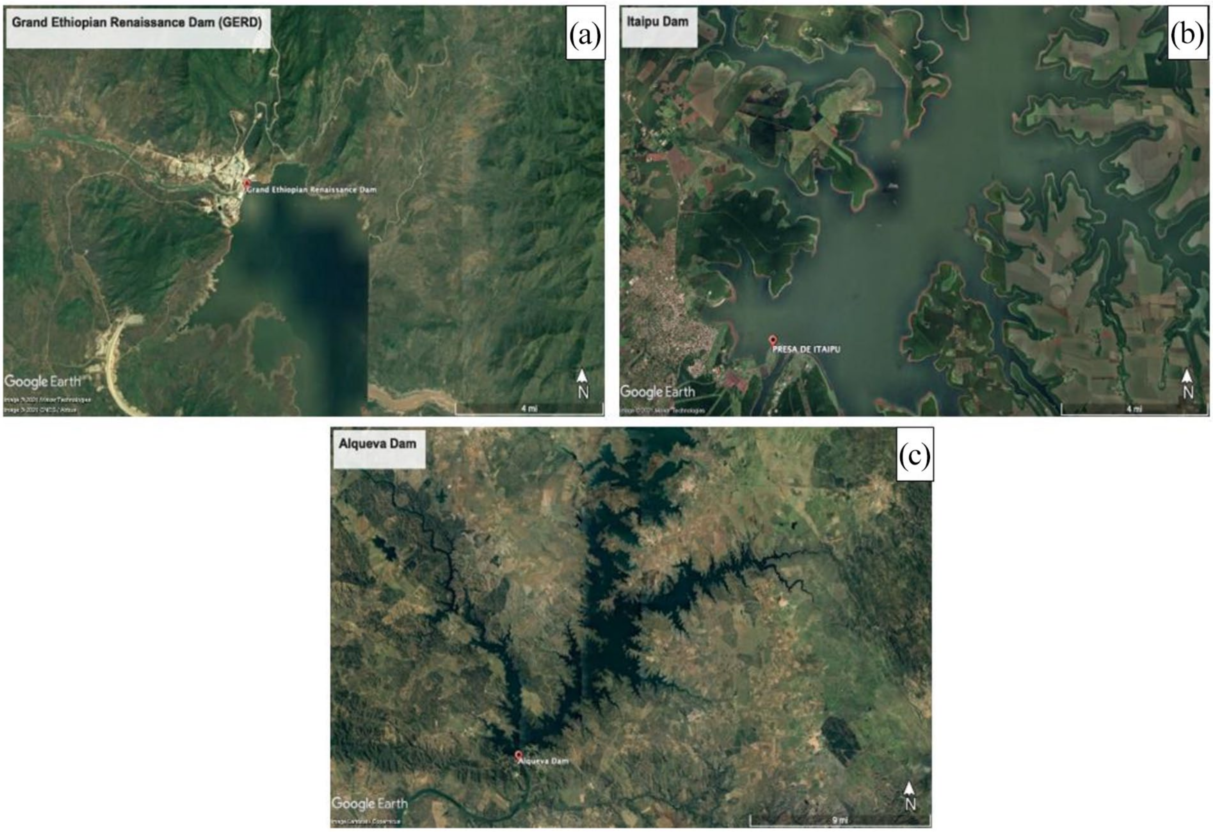

Figure 2. Satellite image for the three dams under consideration: (a) GERD, (b) Itaipu Dam, and (c) Alqueva Dam.

Table 1. Information About GERD, Itaipu, and Alqueva Dams.

	GERD	ITAIPU DAM	ALQUEVA DAM
Location	Borders of Ethiopia and Sudan	Borders of Brazil and Paraguay	Borders of Spain and Portugal
Dam height	145 m	196 m	96 m
Dam length	1,780 m	7,919 m	458 m
Reservoir total capacity	74 bn m^3	29 bn m^3	4.15 bn m^3
Power generation	6.35 GW	14 GW	520 MW

GERD: Grand Ethiopian Renaissance Dam.

environmental and social impacts, which are expected to happen as a result of GERD being in place. Figure 2 shows the satellite image for the three dams under consideration (GERD, Itaipu Dam, and Alqueva Dam).

The study extended to estimate the greenhouse gas emissions resulting from the GERD during operation based on experience and data from Itaipu dam. Greenhouse gases under consideration in this study include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_x), nitrous oxide (N_2O), sulfur oxide (SO_x), hydrocarbons (HC), particulate matter (PM), and aldehyde (CHO). The most governing parameter in the estimation process is the length of the dam where the trucks and equipment make their journeys through several times per day. As shown in Table 1, the length of GERD is 4 times bigger than the Alqueva dam and 5 time smaller than the Itaipu dam. Information about the size, reservoir capacity and power generation of the three dams were included in Table 1 (Structurae, 2021a, 2021b; Taye et al., 2016). In addition, this article explored the potential different physical parameters of the water quality for the Nile River after having GERD in operation. The studied parameters include turbidity, total suspended solids (TSS), dissolved oxygen (DO), total phosphorus (TP), chemical oxygen demand (COD), and total nitrogen (TN).

It is worth noting that Alqueva dam is considered as the largest dam in Western Europe with a reservoir capacity of 4.15 billion m^3. The dam is a transboundary project that required much coordination between Portugal and Spain. The dam impacts ranged from stream reprofiling, destruction of habitat, and introduction of invasive species to the surrounding

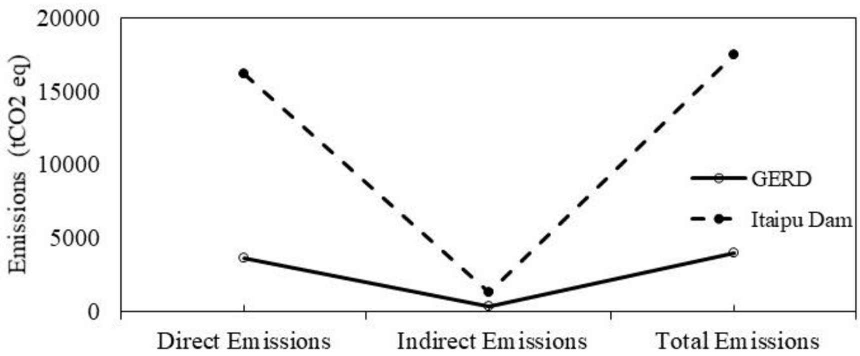

Figure 3. Carbon dioxide emissions of Itaipu Dam in 2009 versus Expected annual emissions of GERD.

ecosystem to increasing eutrophication effects in the still water of the reservoir (Radke et al., 2015). The dam also caused expansion in fertilizers usage, and agricultural expansion, which finally led to deterioration of water quality (Bettencourt & Grade, 2009). Also, Itaipu dam is the largest in Latin America and a transboundary dam on the borders between Brazil and Paraguay. The reservoir storage of the dam is 29 billion m^3. An environmental study on the impacts of dams in Brazil has mentioned that the negative impact of dams varied from changing the structure of aquatic lives, loss of fauna and flora, changes to the river slopes, and water quality alterations to eutrophication effects (Von Sperling, 2012).

Results and Discussion

Greenhouse gas emissions during operations

Data regarding the greenhouse gas emissions released from Itaipu dam during operation process after construction were collected. The operation process comprises the transportation of the trucks and equipment within the site of the dam, as well as the electricity required for simple domestic use within the dam site. An extrapolation was made to roughly estimate the greenhouse gas emissions that may release from GERD dam during operation. The most governing parameter in the estimation process is the length of the dam. Having said that the length of Itaipu dam is 7,919 m and the length of the GERD is 1,780 m, the greenhouse gas emissions for GERD were estimated from available data issued in the year 2009. The main greenhouse gas emissions addressed in this study are the carbon dioxide, nitrogen oxide, sulfur oxide, aldehyde, carbon monoxide, particulate matter, and hydrocarbons. Figure 3 presents the direct, indirect, and total carbon dioxide emissions from Itaipu and the estimated amounts for GERD. The estimated results showed that the total CO_2 emissions from GERD during operation process could reach 3,927 tCO_2eq (direct emissions: 3,639 tCO_2eq and indirect emissions: 288 tCO_2eq). Figure 4 presents the 3-year average of annual secondary greenhouse gases emission form Itaipu Dam and the expected annual emissions from GERD. The results showed that the total annual emissions that are expected to release from the GERD during the operation is about 16.17 ton which divides as following: 33.3% CO, 32.8% NOx, 16.9% N_2O, 8.7% SOx, 7.2% HC, 1.09% PM, and 0.03% CHO.

Power generation against reservoir capacity

Despite the length of Itaipu is almost 5 times that of GERD, yet, GERD was designed to store triple the amount of Itaipu and 17 times the amount of Alqueva. Although the main purpose behind building the GERD, as stated by the Ethiopian government, is to generate electricity (Jeuland et al., 2017), the expected amount of electricity that will be generated by the GERD is almost third of the amount of electricity generated by Itaipu. In addition, the ratio of power generation to reservoir capacity for Itaipu and Alqueva is about 48.3% and 12.5%, respectively, while the ratio for GERD does not exceed 9% (Figure 5). Thus, there is a big concern behind the design adopted in GERD which neither is optimal nor sustainable to fit the main purpose.

Water quality (physical and chemical parameters)

Water quality in large dams' reservoirs like GERD is not usually homogeneous over the whole reservoir body. Reservoirs can usually be split into three longitudinal zones that have distinctive hydrological, chemical and physical characteristics. These zones are the riverine, the transition, and the lacustrine zones. The riverine zone is the upstream part of the reservoir, where water still preserves a significant proportion of its velocity (Melo et al., 2018). The transitional zone is in the middle of the reservoir, and it has a lower velocity than the riverine zone. The lacustrine zone, which is the downstream part of the reservoir, and water at this part has the lowest velocity. This is important because water velocity affects the physical and chemical characteristics of water. In a study of water quality in Itaipu Dam reservoir, it was shown that turbidity and suspended solids was highest in riverine zone, then the transitional zone, and lowest in the lacustrine zone. The opposite is correct for transparency (Ribeiro Filho et al., 2011).

Water quality in three dams' reservoirs was tested, and the results showed that dissolved oxygen (DO) tends to be depleted

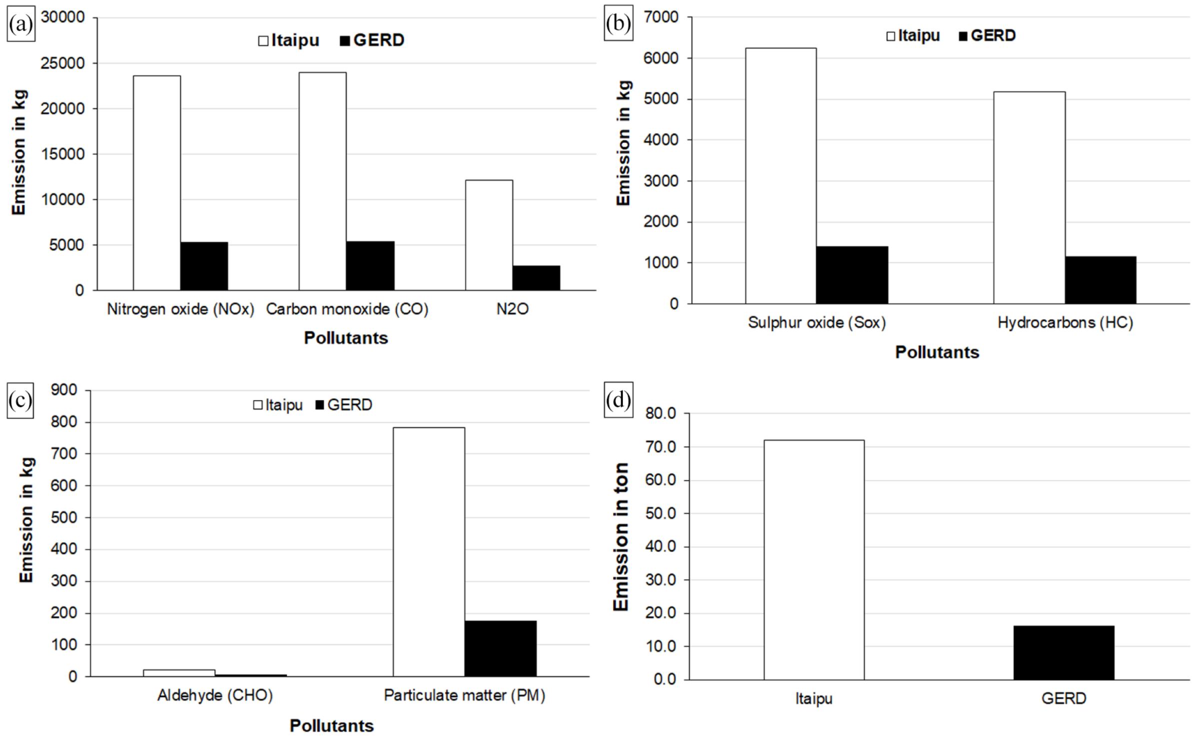

Figure 4. Three-year average of annual secondary greenhouse gases emission form Itaipu Dam versus Expected annual emissions from GERD. (a) NOx, CO & N2O, (b) SOx & HC, (c) CHO & PM and (d) Total secondary emissions in TCO2.

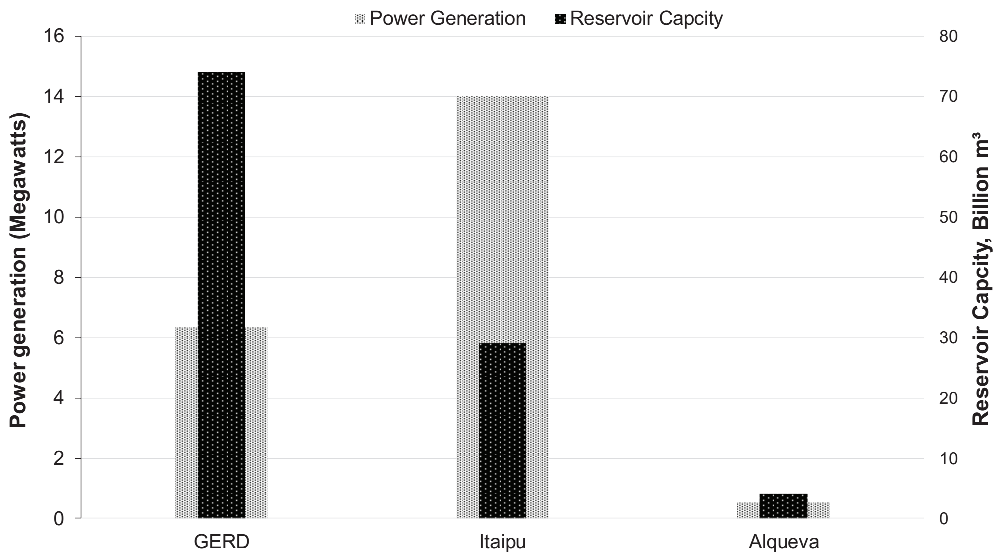

Figure 5. Power generation against reservoir capacity for GRED, Itaipu, and Alqueva Dams.

in the lower layers along the vertical profile of the reservoir due to stratification, and pH change slightly or does not change at all. The same pattern can be observed on the longitudinal profile (Sharman, 2015).

Water quality was also studied in the "Three Georges Reservoir" in China from 1996 to 2016, the largest reservoir in the world. The results showed that COD and TP decreases on the long run, and it was attributed to decreased stream velocity and sedimentation. On the other hand, TN increased over time due to intensified human activities, and it was not affected much by sedimentation (Li et al., 2019).

Water quality tests for Lake Nasser of HAD showed close results. pH, TN, and turbidity were in the permissible range according to the United Nations standards and Egyptian standards, while DO was below the permissible range, and this confirms the results shown above, and gives us a clearer picture about what to expect in GERD reservoir (Rashed & Younis, 2012). Hence, it is reasonable to expect similar patterns in GERD reservoir, in terms of decreasing suspended solids, turbidity, and increasing total nitrogen due to the expected expansion in human activity in this area after building the dam. These changes are summarized in Table 2.

Table 2. Expected Change in Water Quality Parameters in GERD Reservoir.

WATER PHYSICAL PARAMETERS	EXPECTED IMPACTS
Turbidity	Decrease
TSS	Decrease
DO	Decrease
TN	Increase (depending on human activity)
TP	Decrease
COD	Decrease

GERD: Grand Ethiopian Renaissance Dam; TSS: total suspended solids; DO: dissolved oxygen; TN: total nitrogen; TP: total phosphorus; COD: chemical oxygen demand.

Potential environmental and socio-economic impacts

The potential environmental impacts of the GERD comprise direct and indirect influences on the biological, physical, and chemical features of the Nile River. The items that have been addressed include (1) flooding of natural habitats, (2) loss of terrestrial wildlife, (3) involuntary displacement, (4) deterioration of water quality, (5) downstream-river hydrological changes, (6) water-related diseases, (7) fisheries and aquatic life, (8) eutrophication and floating aquatic vegetation, (9) loss of cultural property, tourism, and navigation, (10) greenhouse gases, (11) impacts on High Aswan Dam (HAD) and Lake Nasser, and (12) effect on crop patterns.

Flooding of natural habitats. It is expected that the GERD will permanently flood extensive natural habitats, with local and global extinctions of biodiversity species. The riverine forests and riparian ecosystems will be significantly affected as they naturally exist along rivers and water streams. From another viewpoint, conservation of the biodiversity is expected to occur due to changing the morphology of the river noting that the aquatic habitats created by the reservoir are less valuable than the terrestrial natural habitats lost to flooding (Elsanabary & Ahmed, 2019). The World Bank has issued a policy regarding the Natural Habitats, which states that the hydroelectric projects should not be located where they would cause a significant biodiversity conservation or degradation of precarious natural habitats that do not exist anywhere else (World Bank, 2004).

Mitigation option. One or more compensatory protected areas shall be created and managed under the scope of the GERD. The protected area under the GERD should be calculated and idyllically be of similar or greater in size and has the same ecological quality as the natural area lost due to the construction of the GERD.

Loss of terrestrial wildlife. The loss of terrestrial wildlife to flooding during GERD reservoir filling is a consequence to the flooding of natural habitats, though it is treated as a separate impact.

Mitigation option. The wildlife rescue efforts hardly succeed in restoring wild inhabitants. The most efficient way to minimize wildlife death in the GERD is to choose dam location with minimum effect on the wildlife habitat.

Involuntary displacement. Involuntary displacement of populations is the main adverse social impact of the GERD. It also has vital environmental implications by allowing the displacement of natural habitats to accommodate resettled rural populations.

Mitigation option. Resettlement of displaced populations is the major mitigation measure. This includes new housing and replacement lands similar to the resettlement of population and local habitats that was done during the construction of Alqueva dam. Success usually necessitates consultation and participation in decision-making by the resettled and host populations.

Deterioration of water quality. The GERD dam can cause serious deterioration for the water quality due to the reduction of oxygenation and dilution of pollutants the stagnant reservoir, inundating of biomass, and reservoir stratification. The changes in river morphology will accordingly results in changes in water temperature, chemical composition, dissolved oxygen, salinity, and the physical properties in which the adaptation of the existing biodiversity will become difficult. Serious water quality deterioration will occur due to the reduced oxygenation and dilution of pollutants by stationary water, flooding of biomass and resulting underwater decay due to reservoir stratification where deep waters lack oxygen (Ledec & Quintero, 2003). Many articles studied the effect of damming on water quality downstream and the consequences of water deterioration on health and quality of life. Several articles have mentioned that the effluent of large dams is usually very cool and depleted of dissolved oxygen, but rich in dissolved solids (FAO, 2021), while warm water promotes the growth of harmful algae, the cold water released through the turbines from the bottom of the reservoir contains high mineral concentrations. In a book by Asit Biswas (2012), it was reported that Aswan High Dam blocks almost 100% of sediments upstream the dam (Biswas & Tortajada, 2012), and it is quite fair to assume the same for GERD. These sediments are nutrient rich, and it is important for soil fertility. Since these sediments will be blocked by the GERD, the fertility of Sudan agricultural lands will decrease, and they will have to increase their fertilizers use like Egypt. The increase in fertilizers application will of course deteriorate the quality of the water reaching Lake Naser, which is considered the water bank of Egypt. However, Lake Naser works as a great clarifier for Egypt. So, determining the exact effects on water quality will require a water quality model to take all factors into consideration.

Mitigation option. Control measures of the water quality shall be adopted to improve reservoir water quality, where poor water quality may result from the decay of the biomass. As such, a selective forest clearing within the dam area should be finished previous to reservoir filling.

Downstream-river hydrological changes. Major destructions to the riparian ecosystems of the downstream-river hydrological changes based on the periodic natural flooding and intensify water pollution during low flow times, which may lead to an increase in saltwater intrusion near river estuaries. Reduced sediment and nutrient loads downstream-river of GERD will increase river edges, coastal erosion, and damage to the economic value and biological productivity of the Nile river (Negm et al., 2019). Drought of river downstream the GERD dam will accordingly kill fish as well as fauna and flora which are dependent on the river; it will also adversely affect the agriculture and human water supplies especially in Egypt and Sudan. Decreased flows would decrease the water applied to the fields, which may cause an increase in soil salinity and will decrease the water reaching underground aquifers.

Mitigation option. Joint management shall take place with the participation of the three parties. Proper study for the climatic variations and the rainy seasons shall be taken into consideration. Reference to Itaipu water management experience, Ethiopia shall take the liabilities of the agreement and coordination with the downstream countries to minimize the potential impacts on them.

Water-related diseases. Newly man-made waterbodies such as the GERD reservoir can cause water-related diseases that have a negative impact on the public health, such as malaria and bilharzia. Infectious diseases can spread in the areas of water reservoirs, especially in high temperatures and densely populated regions (Sanchez-Ribas et al., 2012). These diseases also can spread upstream and downstream the large dam projects (Lerer & Scudder, 1999).

Mitigation option. Awareness campaigns and prevention measures shall take place in addition to monitoring of the vectors and outbreaks of any disease. Meanwhile, the control of the floating aquatic weeds nearby the populated areas may reduce the risks of mosquito-borne diseases.

Fisheries and aquatic life. GERD project will have major negative impacts on aquatic life and fisheries. GERD blocks the upriver fish migrations, knowing that downriver passage through turbines or over spillways are often ineffective. Moreover, most of river-adapted aquatic species and fishes are not adapted to survive in artificial lakes; the major changes in downriver flow patterns, due to the presence of the GERD, adversely affect the aquatic life and surrounding ecosystem (Soliman et al., 2015). Also, deterioration of water quality within the reservoirs, such as having low oxygen levels and sometimes gas super-saturation, leads to fish mortality and aquatic habitats damage, especially because the freshwater biodiversity is more sensitive to changes due to their limited mobility (Ledec & Quintero, 2003).

Mitigation option. Management of water issues may be needed for the existence of fisheries, within and downstream the reservoir. Fish passage facilities are needed to allow mitigatory fishes to move past the dam. These facilities can be fish ladders, elevators, or trap-and-truck operations. However, these methods are usually ineffective for several reasons.

Eutrophication and floating aquatic vegetation. Eutrophication can easily occur in the reservoir due to the still water causing an increase of the floating aquatic vegetation, which results in the following:

- Destroying habitat for most species of fish and aquatic ecosystem;
- Better breeding grounds for mosquitoes, nuisance species, and disease vectors;
- Blocking of electro-mechanical equipment at dams; and
- Increased water loss from reservoirs.

According to a case study conducted on a polish rivers and reservoirs, the changes in physical, chemical and biological characteristics of a river due to construction of dams may deteriorate water quality and cause Eutrophication (Siuda et al., 2020). In addition, the Blue Nile is well known for being sediment rich, and that is the reason for fertility of the Egyptian lands that was well known over centuries (Abtew & Dessu, 2019). Blocking these sediments behind the dam will not only decrease the storage capacity but may also cause serious eutrophication problems.

Mitigation option. Pollution control and physical removal of containments is effective but enacts an expense for large reservoirs like the GERD. Where compatible with power generation objectives, occasional drawdown of reservoir water levels can be used to get rid of the aquatic weeds. Chemical poisoning of weeds or related insect pests requires much environmental caution.

Loss of cultural property, tourism, and navigation. Archeological, paleontological, historical, and religious sites can be destroyed by the reservoir and the associated quarries, borrow pits, roads, or any other works. The lower water levels that will be resulted from the GERD construction will have an adverse impact on tourism and sailing used for transportation of goods and trades downstream the river. GERD creates barrier for upstream-downstream navigation and migration of fish and other aquatic creatures. The Dam will substantially change the flow of water and transport of sediment, nutrients, and food materials that supply downstream aquatic ecosystems and estuaries, with influence extending for many kilometers downstream the Dam.

Mitigation option. Rescuing and displacement of the historical sites shall be carried out through careful physical relocation, scientific inventory, documentation, and storage in museums. However, loss and damage to unique sites especially with religious or ceremonial significance cannot be recovered.

Greenhouse gases. During filling the reservoir, the upstream forests will be flooded which eliminate their function as a carbon sink. In addition, the sank vegetation decomposes, decaying plants in the reservoir, in which methane gas will be released to the atmosphere making the reservoir a source of emissions (Cunha et al., 2016). It is estimated that the annual greenhouse gas emissions from dams amount to about a billion of tons, making it a significant global source (Fearnside, 2015). As a result of the changing climate, more frequent and extended drought will take place, which means that the GERD will capture less water, resulting in lower electricity production to Ethiopia and correspondingly will result in raising temperature that will affect the surrounding African neighbors in particular and the globe in general.

Mitigation option. Commercial timber and fuelwood can be utilized to reduce the greenhouse gas emissions from reservoirs, yet, due to (a) the high abstraction and transportation costs, (b) marketing restraints, or (c) political and economic pressures not to delay reservoir filling, these do not take place.

Impacts on High Aswan Dam (HAD) and Lake Nasser. GERD will have significant environmental impacts on HAD in terms of water levels in Naser Lake. It was predicted that the water in Nasser lake will reach the lowest level of 147 m by the end of the 5 years filling period, and they suggested that possible solutions could be decreasing the dam capacity or increasing filling years (Donia & Negm, 2019). Another study showed that the relationship between filling period and water levels at specific locations in Egypt and Sudan is not linear, and by holding 10%–25% of monthly flow behind the GERD produces a 6%–14% average reduction in flow reaching Lake Nasser during the first 5 years. The implications at the Gezira Scheme are even more severe, because no other tributaries reach this area (Zhang et al., 2015). Similar conclusions was reached by McCartney and Menker Girma (2012) as they found out that the flow at the Ethiopia-Sudan border will be reduced from 1661 m^3/s to 1301 m^3/s during the filling of GERD lake. It was also proved that the minimum level will be reached after 4 years of filling (Aziz et al., 2019). For the more permanent effects of GERD, the effect of GERD on water discharge was modeled using different scenarios for filling and operation, and for water levels at Nasser Lake. The study concluded that evaporation and infiltration from GERD reservoir will be the main reasons for losses from the Blue Nile (AbuZeid, 2019). Reduction in the water share to Egypt will accordingly result in a reduction in power generated at AHD. It is expected that hydroelectric power production will decrease by 20% of its original value (Ibrahim & Ibrahim, 2017). Infilling Lake Nasser with sediment, the amount of silt deposited is estimated to be 109 million cubic meters per year. The silt sedimentation can lead to the blockage of a large part of Lake Nasser, which may result in a significant loss of the stored water due to evaporation and leakage.

Mitigation option. Watershed management shall be in place to minimize sedimentation. Protected areas are established in upper catchments to reduce sediment flows into reservoirs, as for the Fortuna Dam in Panama and the Rio Amoya (Colombia) and Nam Theun II (Laos) projects. Aside from watershed management, other sediment management techniques shall be physically and economically feasible; they are including upstream check structures, protecting dam outlets, reservoir flushing, and mechanical removal.

Effect on crop patterns. The crop patterns are changed due to new policies in such areas to reduce the amount of water required for the agricultural sector, which in turn reduces the infiltrated amount of irrigation water to the shallow aquifer that comes from excess irrigation water, where water that exceeds the plant's needs infiltrates to the aquifer. Replacing crops that voraciously consume water with crops that consume less water is an obvious way to ameliorate the crisis of surface water shortage after the construction and operation of the GERD. However, changing crop patterns affects the soil's properties, particularly salinity. Crops that consume large amounts of water not only have economic benefits but are also cultivated to improve soil properties (Hanin et al., 2016). The large amounts of water consumed by these types leached into the soil, especially in areas near the Mediterranean Sea (North Egypt). Soil properties have a negative effect on reducing (or even preventing) the cultivation of these crops, as salinity could increase, leading to a deterioration in soil properties (Zörb et al., 2019). A case study was conducted to record the effect of changing water intensive crops like rice with less water consuming crops, and the results showed that this change caused the ground water level to decrease by 1.3 m. In addition, a simulation was run to predict the effect on soil salinity, and the results of the simulation showed that soil salinity will increase from 0.45 S/m to 0.48 S/m after 10 years of the crop change (Aziz et al., 2019).

Mitigation option. Crop management and selection are options. However, joint management shall take place with the participation of the three parties. Proper study for the climatic variations and the rainy seasons shall be taken into consideration. Reference to Itaipu water management experience, Ethiopia shall take the liabilities of the agreement and coordination with the downstream countries to minimize the potential impacts on them.

Practical Solutions

The urge for ESIAs

Environmental and Social Impact Assessments (ESIAs) are required by law for any transboundary project, such as the

GERD. Considering the GERD, a transboundary project, which necessitates on Ethiopia to obey multilateral techno-legal process in the implementation and operation of the dam to avoid human rights, environmental and security negative consequences. ESIAs are mandatory by law for the dam which shall be requested from Ethiopia with the engagement of Egypt and Sudan and under the supervision of international entities.

Besides, the Deceleration of Principals (DoPs) included in 2015 Pledge between Egypt, Ethiopia and Sudan has stipulated that ESIAs shall be conducted and utilized to show the processes of filling the Dam's reservoir and operation (State Information Service [SIS], 2017); however, no ESIAs have been presented yet and the construction works continued without having the required multilateral legal process in place (SIS, 2021). In fact, GERD is not an exception, most of the world dams did not have an Environmental impact assessment until early in the new millennium, and most of the EIAs for the average size dams did not manage to predict more than 40%–50% of the actual effects, and for the large size dams only 50%–75% of the effects were predicted (Biswas & Tortajada, 2012). However, at that point in time, the world was less environmentally aware like it is, now, and the negative effects of turning a blind eye to the social and environmental impacts for large projects like GERD is making it a necessity to push the process of having a real assessment of this project that will affect the lives and welfare of millions of people in Egypt and Sudan. The construction of the Ethiopian Dam necessitated to conduct transboundary ESIAs. Although the ESIAs usefulness decreases when employed later than prescribed by law, yet ESIAs are still vital and mandatory. ESIAs are important to avoid and/or mitigate any unforeseen environmental and social harm that may occur to any of the three countries.

Proposal for joint administration as a way forward

Referring to the international governance and the shared administration between Brazil and Paraguay with regard to managing and operating Itaipu dam, this article proposes establishing an entity or a corporate with representatives from the three countries Egypt, Ethiopia and Sudan to supervise, manage, and operate the dam. The joint administration will allow transparency, ethics true values, efficient management and respect for people and the environment to take place and will satisfy the needs of the three partners (Pemunta et al., 2021).

Learning from Itaipu dam case, the investment in social and environmental mitigation measures highlights two major aspects for the dam management: (1) Cooperation in transboundary projects should consider long-term plans for joint management, benefit sharing in addition to mitigation plans and not be limited to short-term compensation (Gebresenbet & Wondemagegnehu, 2021). (2) Managing and operating transboundary projects can play an important role in improving the governance network responsibility.

In detail, the following conclusions can be drawn from the Itaipu case (Itaipu Binacional, 2009):

1. *Agreements on basin-wide*: having agreements on the basin-wide can provide an encouraging framework transboundary project. La Plata Basin Treaty has provided a continuous forum and reference point for member states to make a resolution for any arisen debates (River Plate Basin Treaty, 1969). Thus, the treaty can be considered as a diplomatic success.
2. *Arrangements with affected states who are indirectly affected by the project*: close coordination regarding the water management between the shared river countries took place as Itaipu dam caused a threat to the operation of Yacyreta Dam. The three-party treaty with Argentina specifies water levels. This means that all upstream dams shall be operated in a way that follows to the treaty agreement. This ensures a minimum flow for hydropower stations in the downstream, such as Yacyreta Dam.
3. *Agreements for cost sharing and compensation for the accommodation of emerging developments*: since Itaipu Treaty does not specify the energy sales and compensation payments details, bilateral conflicts between Brazil and Paraguay over the arrangements have been solved through negotiation continuing the fruitful collaboration between the treaties.
4. *Agreements on programs to run the dam during operation*: Itaipu Binacional corporate is responsible to set programs for the dam during operation in order not to affect any of the river sharing members. This extended to cover the social responsibility practices, extensive environmental, and social mitigation programs.
5. *Agreements on the domestic benefit-sharing*: after 1988, Brazil's participating and revenue sharing practices improved the social aspects of the dam in specific, including the reservoir fisheries management and local income.

Conclusions

GERD filling and operation is going to have tremendous adverse impacts on the environment downstream and at the dam reservoir. These impacts will extend from blocking migration routes of fish, and alteration of the ecosystem and terrestrial life around the reservoir to deterioration of water quality, and sea water intrusion downstream in Egypt. The comparative analysis of GERD with Itaipu dam also showed that the dam reservoir will be a huge source of green house gas emission. The results showed that the total annual emissions that are expected to release from the GERD during the operation is about 16.17 ton which divides as following: 33.3% CO, 32.8% NOx, 16.9% N_2O, 8.7% SOx, 7.2% HC, 1.09% PM, and 0.03% CHO. Regarding the water quality in GERD reservoir, a decrease is expected to occur in turbidity, TSS, DO, TP, and COD. An increase in TN is expected to occur depending on human activities. All of these negative impacts direct our attention to the main conclusion of this article that there is a pressing need to perform a comprehensive EIA for this dam, where all the stakeholders' benefits are taken into consideration. Also having this vast reservoir of 74 BCM to produce only 6.4 GW is causing justified skepticism about the efficiency of the dam design, and that its only purpose is hydropower generation. The urge of having an EIA is not only justified by technical evidence, but it was also required by international law in more than one international convention and treaty like Espoo convention and Rio declaration on environment and development, which made EIAs an obligation for transboundary development projects, and gave the same rights of the project country public to the affected countries public in this case. From a practical perspective, the best solution for this situation is cooperation not unilateral action, because political instability is not in favor of any party or even the whole region, and its aspiration for development for decades. Therefore, it is strongly suggested that Ethiopia commit to the Declaration of Principles (DoP) signed by Egypt, Sudan, and Ethiopia in 2015, which indicated that filling and operation of the dam should be in full coordination with the downstream countries not to affect their water shares, and a clear plan for operation during water or climate emergencies should be in place.

Author's Note

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