Title

The Dam Problem: The Controversy of the Grand Ethiopian Renaissance Dam

Author

Hmoud, Sarah

Publication Date

2024

The Dam Problem: The Controversy of the Grand Ethiopian Renaissance Dam

Prepared by Sarah Hmoud

Master of Advanced Studies in Climate Science & Policy

Scripps Institution of Oceanography, UCSD

2024

Table of Contents

Capstone Committee

Corey Gabriel, PhD

Scripps Institution of Oceanography - University of California San Diego

Capstone Chair

Tarik Benmarhnia, PhD

Scripps Institution of Oceanography - University of California San Diego

Advisor

[redacted]

Ian Jones, PhD

New York University

Advisor

Lauren Prather, PhD

University of California San Diego

Advisor

Acknowledgements

I would like to begin by thanking my amazing chair, Corey, who presented the idea of this capstone to me after months of brainstorming and jumping from topic to topic. I was having trouble narrowing down my ideas and he was always so supportive while still reminding me to focus on a specific topic. So, thank you Corey for always being open minded and inspiring me to go outside more.

I would also like to thank my wonderful advisory committee Ian, Tarik, and Lauren who very graciously lent their expertise of human-environment interactions, environmental epidemiology/ climate change, and Middle East politics, respectively, without which I would still be floundering around without a clue of where to start my research. I truly cannot express how grateful I am to have such inspiring, accomplished committee members who I hope to continue working with in some capacity.

Finally, I must thank my friends and family for supporting me and believing in me throughout this crazy and exciting year. Probably the best thing I got out of this program were the friends I made from the cohort, who have quickly and somewhat unexpectedly become some of my favorite people I've had the good fortune to meet. And to Hannah, the heart and soul of this program, thank you for being so kind and helping me to conquer my fears, I'd still be lost and afraid if it weren't for you. To a particular friend outside of the cohort (you know who you are), thank you for pushing me to apply to this program and believing in my ability to be accepted and make it through to the end. I would not have had the confidence to complete this program if it weren't for you. And to my family, especially my parents, thank you for always being there to support me and help me in whatever endeavors I pursue. I say this less than I should but mean it more than you know: I love you.

List of Tables and Figures

Executive Summary

The countries within the Nile Basin have become increasingly water stressed with each passing year due to the intensification of climate change, and disagreements about water allocation rights between these countries only exacerbate the issue. For about a century, Ethiopia and Egypt have been quarrelling over rights to the Nile's waters with no resolution in sight. In 2011, Ethiopia began construction of the Grand Ethiopian Renaissance Dam (GERD), which increased tensions. As of 2023, the dam's construction was completed but negotiations have made no meaningful progress. The dam worsens political relations but impacts the environment, economy, and society in both positive and negative ways. Considering these impacts and the example of the demolition of the Klamath River dams, it was determined that dam demolition would be the most beneficial and equitable course of action, in the long run, for all the Nile River riparian countries. A policy memo was then constructed advocating for demolition of the GERD.

Introduction

With climate change increasing and intensifying water scarcity in the Middle East and North Africa at a catastrophic level, definitive water rights are more vital than ever. For this reason, the Grand Ethiopian Renaissance Dam (GERD), Africa's newest and largest dam whose construction began in April 2011 but whose final filling was completed in September 2023, has been a major source of controversy. The purpose of the dam according to Ethiopia, as one of the least economically developed countries in Africa, is "to generate power, contribute to economic development, promote cooperation beyond borders, and regional integration through generating clean sustainable energy that can be relied on" (Al-Anani, 2022). As of 2022, more than half of its population lacked access to electricity, but with the help of GERD the country plans to reach

100% electrification by 2025 (Al-Anani, 2022). By irrigating hundreds of thousands of acres of land, the dam is also meant to expand the country's agricultural sector. The storage capacity of the dam is far greater than what is needed to provide for its domestic needs, allowing it to become an electricity exporter. With this newly acquired capability, Ethiopia would be able to supply neighboring counties, such as Sudan, with power. Despite this, Sudan stands with Egypt in objecting to the dam's filling and operations claiming it is a "breach of Ethiopia's international legal commitments" and "a clear violation of the 2015 Declaration of Principles Agreement and a grave violation of the applicable rules of international law" (Al-Anani, 2022).

The two sides have a decades long history of mistrust. Ethiopia believes Egypt and Sudan have been utilizing the Nile River unfairly at the expense of upstream countries, itself included. In fact, Egypt's 1959 agreement allocated all the Nile River's waters to itself and Sudan, affording none to upstream riparian states from which most of the waters flow (Mbaku, 2020). To further reinforce Ethiopia's claims, the agreement also "granted Egypt veto power over future Nile River projects" (Mbaku, 2020). In this way, the construction of the GERD can be seen as an Ethiopian response to what it views as unjust water allocation treaties.

Egypt and Sudan are calling the dam an existential threat, believing it will significantly impact their economic and development needs since the Nile provides them with the majority of their fresh water, and Ethiopia supplies more than 85% of water that flows into the Nile (Mbaku, 2020). Because of its extensive diplomatic connections and 1929 and 1959 agreements, Egypt was able to "prevent the construction of any major infrastructure projects on the tributaries of the Nile" for years before Ethiopia began construction of the dam (Mbaku, 2020). Additionally, both countries are concerned that without a clear and binding agreement with Ethiopia, they will be left without sufficient water during droughts. For a decade now, Egypt and Sudan have been desperately trying to reach an agreement with Ethiopia regarding the dam but so far, all negotiations have ended in stalemates, even with other countries trying to mitigate the dispute. Sudan has actually warmed up to the idea of the dam, due to potential benefits it will provide the country, but are still concerned about the risks it poses to their own dams. These building tensions have the potential to lead to an all-out “water war”.

Relations between these countries must be improved if any sort of agreement is to be made. All riparian states involved must understand that because the Nile is a regional watercourse, “its management must be approached from a regional perspective” that takes into consideration how each state is affected by changes to its flow and discharge rates (Mbaku, 2020).

Objective

This paper will analyze the possible impacts of the Grand Ethiopian Renaissance Dam to the environments and economies of the riparian states that rely on the Nile as their main source of freshwater, with a focus on the two big players: Ethiopia and Egypt. Based on the impacts, a determination will be made on whether the construction of the dam was economically worth the cost Ethiopia spent and if it should be demolished. Because it is a relatively new dam and there is not much data to go on, the Klamath River dams will be used as examples to demonstrate how detrimental a dam can be for a region.

Some of the negative effects of the dam that will be explored include flooding, dislocation, ecosystem destruction, and methane emissions. Some studies have even found that dams exacerbate environmental health issues, particularly in a changing climate, like the potential to increase the spread of vector-borne diseases including malaria, which will be investigated as well. Additionally, how the dam fuels competition for resources, economic distress, and social discontent - how the wealthy benefit from the dam compared to the poor - will be analyzed.

International US military involvement is the cause of a plethora of climate issues worldwide and Egypt is one of the largest US military aid recipients (Khamis, 2021). Does this relationship of Egypt's with western powers play a role in the tensions between it and Ethiopia? The answer to this question and more will be sought after in this paper.

The arguments of the two main involved countries will be further studied as well as how solutions to each of their particular grievances can be worked into possible agreements. With this information, a comprehensive policy memo will be written that will hopefully satisfy the main parties of interest. And finally, the questions "Does the Grand Ethiopian Renaissance Dam cause more risks than benefits? And if so, what are the best ways to mitigate its detrimental impacts?"; "Should it be deconstructed and if so, what does that mean for Ethiopia?"; and "Is dam removal always a climate solution?" will be answered.

Background

The Nile River

Flowing through eleven countries, five of which are among the poorest in the world, the Nile is one of the world's longest rivers and comprises three main tributaries: the White Nile, the Blue Nile, and the Tekeze-Atbara, with more than 291 million people living within its basin (Attia & Saleh, 2021). Nearly all the Nile streamflow is consumed by the two most downstream riparian countries: Egypt and Sudan. The Nile streamflow provides around 90% of Egypt's freshwater consumption and 7% of its electricity supply through hydropower (Attia & Saleh, 2021). Despite the great importance of the river's land and water resources for the adjacent countries, it is badly managed and constantly under dispute.

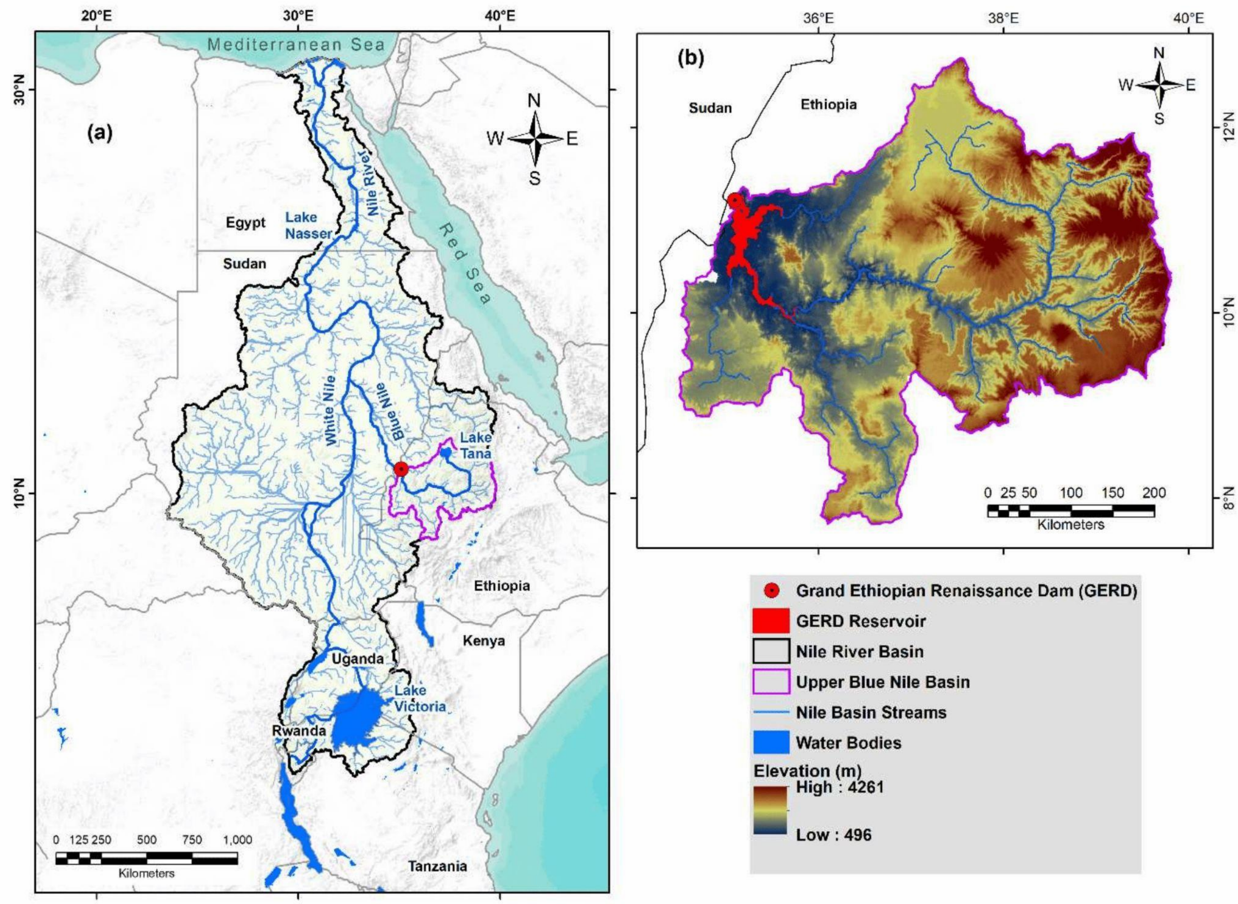

Figure 1. Map of the Nile River Basin (Kamara et al., 2022)

The Nile River is host to wetlands which cover ~ 10% of the Nile Basin land cover and provide resources for agricultural development and fisheries (Rebelo & McCartney, 2012). Wetlands must be noted as they are arguably one of the most valuable ecosystems. Although they make up only about 1% of the Earth's surface, they provide habitats for about 20% of species, especially those that are endangered and endemic (Wu et al., 2019). The construction of dams degrades these biodiversity hotspots and habitats. With over 300 giant dams and tens of thousands of smaller dams worldwide, over half of the global large rivers, and thus wetlands, have been left fragmented, leaving countless species without homes and at risk of extinction (Wu et al., 2019).

Climate vulnerability of the region

Egypt

As a desert country, Egypt has felt the impacts of climate change rather acutely. In the past thirty years alone, temperatures have been increasing by a dramatic 0.53°C per decade, and its average annual temperature is predicted to rise by a staggering 4.4°C by the close of the century if global emissions trends persist (Hamzawy et al., 2023). This projected trend is deeply troubling for Egypt's water scarcity. "Heat-related mortality is expected to increase by as much as forty-seven times by 2080" (Hamzawy et al., 2023). The country's densely populated cities will suffer disproportionately due to the heat-island effect, and as energy consumption increases for cooling, cities will become even warmer. This warming will be especially difficult for lower-income residents who are unable to afford energy costs. Livestock and crops will also suffer from heat stress, resulting in reduced crop yields and decreased dairy and meat production.

Rising temperatures also means reduced water supply. The amount of water lost to evapotranspiration across the Nile Basin has consistently surpassed the amount gained through precipitation for 90% of the time between 2009 and 2019 (Hamzawy et al., 2023).

For the economy, heat stress will mean declining productivity with up to 134,000 work hours wasted per year by 2030 (Hamzawy et al., 2023). Atmospheric warming is further expected to disrupt Egypt's domestic food supply chains as elevated temperatures influence the duration of crop-growing periods and alter the zones suitable for cultivating specific crops, curbing biodiversity and unsettling the country's food production. This leads to surges in food prices or supply shortages. Climate change and variability will also make Egypt's precipitation less predictable. In the past thirty years alone, Egypt's total annual rainfall decreased by about 22% and, if current trends persist, it could decline by a further 3 millimeters annually before the end of the century (Hamzawy et al., 2023). Economic inequalities in the agriculture sector will be amplified due to the decreased rainfall since vulnerable smallholders will be hit the hardest. By increasing evaporation and reducing groundwater recharge rates, higher temperatures and decreased rainfall could also predispose Egypt to more frequent and prolonged droughts and heat waves. Heat waves may be prolonged by nine to seventy-seven days, while dry spells could increase by 75 days in about 50 years (Hamzawy et al., 2023). In summary, Egypt's water scarcity and food production will suffer as a result of increasing heat stress.

Even without the effects of climate change, Egypt faces a dire water scarcity crisis. Since the late 1970s, Egypt's water demands have outstripped Nile water supply, which accounts for 98% of Egypt's renewable water supply (Hamzawy et al., 2023). Economic development and a growing population have substantially increased demand and exacerbated the country's water stress. Between 1989 and 2018 Egypt's population rose 2% and its GDP 4% annually, escalating water demand and consumption (Hamzawy et al., 2023).

Since the early 1990s, Egypt has been well below the Falkenmark threshold of water scarcity (1,000 cubic meters), but the country is now rapidly approaching the critical threshold of absolute water scarcity of 500 cubic meters per capita, possibly in the next five years (Hamzawy et al., 2023). In 2000, water stress, calculated as freshwater withdrawals over freshwater supply, amounted to 104%; in 2019, it climbed to a staggering 141%, excluding the vast amounts of freshwater imported to meet demands (Hamzawy et al., 2023). Even with its water reuse practices, Egypt's average consumption of the Nile between 1988 and 2017 amounted to some 62 cubic kilometers annually, supplemented by 40 cubic kilometers of annual freshwater imports since the 2010s (Hamzawy et al., 2023). By 2030, Egypt is projected to increase the volume of its freshwater imports so substantially that it may surpass the volume supplied from the Nile for the first time.

To make matters more dire, sea level rise and seawater intrusion into the Nile have begun to deplete the river's freshwater supply, while extreme temperatures and irregular precipitation will likely increase surface water evaporation across the country, thereby worsening droughts. Moreover, because the Nile is only about a meter above sea level, rising sea levels are causing the Nile to shrink at a shocking 3 to 5 millimeters per year. This means climate change could deplete up to one-third of the river's freshwater resources by the end of the century (Hamzawy et al., 2023).

Egypt's water usage/waste

Despite being home to the Nile River, Egypt is one of the world's most drought-stricken countries partly due to man-made practices such as unsustainable agriculture and urbanization, such as the construction of the Grand Ethiopian Renaissance Dam. Though Egypt's Aswan High Dam, constructed in the 1960s to mitigate flooding and droughts, was arguably a success, it did cause unintended negative impacts including an increase in soil salinity. Climate change is visibly exacerbating the crisis, as rising sea levels threaten to submerge low-lying areas of the Nile Delta and increase saltwater intrusion into fresh groundwater and raise soil salinity, decreasing its organic matter content and productive capacity. Decreased freshwater from the Nile due to the GERD upstream may also cause Egypt to rely more on wells but when wells are overpumped, aquifers may experience saltwater intrusion.

A joint study done by the Egyptian government and the United Nations Development Programme estimates that the country will suffer an 8 to 47 % decrease in agricultural output by

2060 (Arafat, 2023). In response, the Egyptian government has made efforts at building or improving infrastructure for water transport, irrigation, and wastewater treatment and reuse; smart farming and reducing food wastage; and exploiting groundwater (aquifers), desalination, and virtual water. However, these so-called solutions have exacerbated water scarcity. Egypt's construction of its New Administrative Capital highlights both the stark reality of water stress and the inefficient use of scarce funding in a country already suffering from acute economic and financial crises. Furthermore, the water megaprojects being built across the country are exhausting massive funds and are directed to serve only a small percentage of Egypt's population.

Successive governments have sought to rectify the growing shortfall in Egypt's water supply. The administration of President Abdel Fattah el-Sisi has sought to optimize the use of water for irrigation through two main tracks. The first was to replace outdated irrigation systems such as flood irrigation with more efficient systems such as drip and sprinkler irrigation. However, small-scale farmers were often reluctant to invest in these advanced, modern systems. Minister of Water Resources and Irrigation, Hani Sweilem, has acknowledged that the modern irrigation systems have medium- and long-term drawbacks, especially in the northern Nile Delta, where increasing salinity is degrading farmland, in part due to the Aswan High Dam, and forcing farmers to use flood irrigation to rinse out the soil. As a result, the spread of these modern irrigation methods has largely been confined to newly reclaimed desert lands. The second track in the government's plan sought to tackle the Nile Delta's annual loss of some 7 billion cubic meters of water due to seepage from canals and leaky piping, along with a further 2.5 billion cubic meters due to evaporation (Arafat, 2023) . In 2020, the Ministry of Water Resources and Irrigation released a plan to upgrade 7,000 kilometers (4,350 miles) of canals across the country, at an estimated cost of 90 billion Egyptian pounds (Arafat, 2023). Shortly before the first phase of the project was completed, the canal-lining project was criticized by Sweilem due to the lack of an environmental impact assessment and the removal of trees along the banks of refurbished canals. The project still proceeded as planned and access to water has improved in several provinces due to the concrete-sealed canals enabling a rapid flow and ensuring supply to farmers farthest along the canals. However, in much of the northern Delta region, the seepage of fresh water from irrigation canals into the surrounding soil had previously helped reserve salinity, which was increasing due to the use of artificial fertilizers and pesticides as well as the growing encroachment of salt water from the Mediterranean Sea. In addition, canal-lining using concrete, coupled with high temperatures, has increased evaporation rates significantly, further contributing to rising salinity of both soil and groundwater.

As of 2020, agriculture accounted for the majority of Egypt's water consumption (Arafat, 2023). To mitigate this, the government sought to boost the use of sewage and wastewater for agricultural and manufacturing purposes. Current plans to treat and reuse wastewater aim to recover 3 billion cubic meters a year of agricultural drainage water, two-thirds of which can be used for farming or manufacturing. However, recovering sewage on this scale requires a vast network of pipes and other infrastructure which is costly and poses potential risks for public health and the environment such as exacerbating soil salinity. Given its low average rainfall, Egypt's alternative water resources are limited, but groundwater may be a possibility. The country sits atop six aquifers one of which it shares with Sudan, Libya, and Chad. Dozens of private land reclamation companies dig unregistered, illegal wells for farming and grow water intensive export crops. Consequently, growing consumption and uncontrolled extraction of desert groundwater has significantly lowered the water table in various areas and exacerbated soil salinity.

Egypt has made use of virtual water, the indirect water used to produce other goods, by exporting and importing agricultural products. Imports consist of up to 40 billion cubic meters of virtual water (Arafat, 2023)[1].

The National Water Resources Plan 2020–2050 envisages quadrupling desalination capacity to 2.8 million cubic meters per day in five years (Arafat, 2023). Desalinating seawater offers a means of providing remote areas with drinking water rather than transporting it from elsewhere and reduces agricultural reliance on the Nile, but it is extremely costly. Egypt already has eighty-one desalination plants with eleven more under construction, and with nearly 2,400 kilometers (1,491 miles) of coastline on the Red and Mediterranean Seas, there is considerable potential (Arafat, 2023). However, the government needs to focus on improving desalination technologies and developing clean sources of energy (the amounts of which are needed are immense) to power the process. Use of desalinated water in agriculture will only become viable if the economic value of water outweighs the costs of the desalination process. Furthermore, the environmental footprint of waste from the desalination process and its impact on marine ecosystems must be considered, especially given the country's unique Red Sea coral reefs and distinctive marine ecosystems already being impacted by toxic by-products from Saudi desalination plants.

[1] In theory, the country can amplify its available natural water resources and arable land by balancing exporting high-value, water-efficient crops and importing low-value, water-intensive crops without compromising its food security. For example, water-intensive crops should only be grown in areas that have plenty of water and high soil salinity since flood irrigation can decrease soil salinity.

Despite efforts to limit agricultural water wastage, indirect waste of water through food wastage has not been examined by the Egyptian government. Some 16% of food was wasted annually between 2015 and 2019, according to the Central Agency for Public Mobilization and Statistics (Arafat, 2023). Food waste was estimated to be equivalent to nearly 5 billion cubic meters of water, or 4.4% of Egypt's annual water consumption in 2021 (Arafat, 2023).

In the government's attempt to solve the country's water scarcity issue, it has more often aggravated the situation instead, via massive water-intensive construction and land reclamation projects that require billions of dollars for water extraction and transport infrastructure. A prime example of this is the rerouting of their scarce water resources from Cairo neighborhoods and other satellite cities to the New Administrative Capital being built to the east of Cairo at a cost of 1 billion Egyptian pounds ($32 million), on top of electricity and transportation fuel costs (Arafat, 2023). Three pipelines were also extended to draw water directly from the Nile, adding a further 10 billion Egyptian pounds ($323 million) to the overall cost (Arafat, 2023). The new capital is only one (albeit the largest) of the twenty-two new cities built so far with another twenty or so planned.

Ethiopia

The effects of climate change on Ethiopia are exacerbated because of its geographic location and relatively low socioeconomic status. Firstly, substantial reliance on agriculture exposes its communities harshly to disruptions in rainfall patterns, more frequent and severe droughts, and soil degradation, all of which lead to reduced agricultural productivity. Consequently, food scarcity, susceptibility to hunger, and malnutrition rises. Second, climate change affects water availability and access, causing irregular rainfall patterns and extended droughts that diminish vital freshwater resources. This water scarcity affects drinking, sanitation, and irrigation, impacting rural communities struggling daily to secure sufficient and safe water.

In Ethiopia's highlands, agriculture is the primary source of livelihood and shifts in precipitation and temperature impact crop yields. In contrast, pastoral communities in the arid lowlands face challenges like dwindling water resources and the loss of grazing lands. Thus, agriculture is a main sector in Ethiopia, and climate change can significantly impact farmers' livelihoods via altering rainfall patterns and increasing temperatures.

Escalating temperatures from climate change also contribute to health risks such as the spread of malaria, while droughts and water scarcity exacerbate inadequate hygiene and elevate waterborne diseases (Sinore & Wang, 2024). Ethiopia's mean annual temperature has increased by 1.3°C between 1960 and 2006, an average rate of 0.28°C per decade (Simane et al., 2016). According to the Ethiopian Climate Resilient Green Economy document, the health impacts of climate change will be made evident by morbidity and mortality from extreme temperature, an increase in vector-borne and weather condition-related diseases, problems due to poor air quality, mortality due to floods and storms, and malnutrition due to shortage of food and water supply.

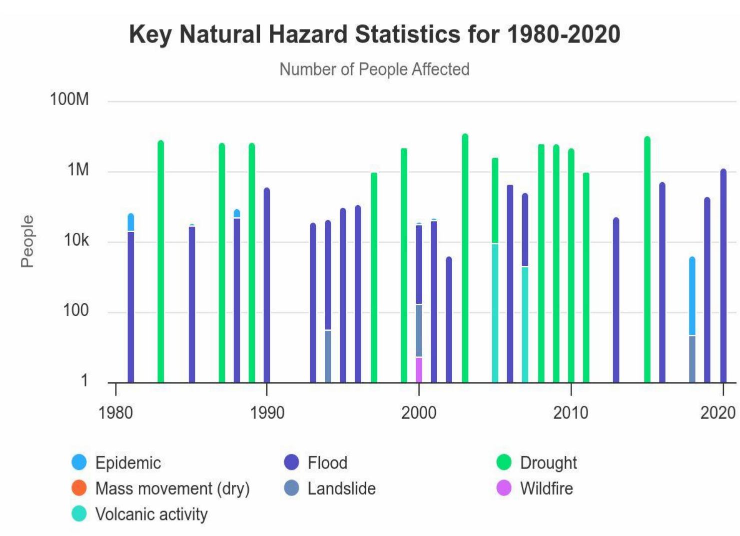

Figure 2. Key Natural Hazard Statistics for Ethiopia from 1980-2020 (World Bank Group, n.d.)

The impact of climate change on agriculture and its related aspects in Ethiopia.

Sectors	Descriptions
Agriculture	• The agriculture sector includes; cropping and livestock sectors which highly need suitable rainfall to be productive. • Variability of climate leads to failure of crops, yield reduction, poor livestock productivity, loss of forage production and quality, and • hence the carrying capacity of rangelands all these lead to mortality of animals and human.
Environment	• The environment includes water bodies, vegetation, and soil components. • Changing climate has significant impacts on these resources • for instance; severe soil erosion, shortages of water, drying of streams and rivers, increased deforestation, drying of vegetation, soil fertility decline, and other associated problems.
Society	• Reducing the adaptive capacity of the farmers decreases the income of smallholder farmers, • hence increasing poverty and loss of human life.

Table 1. The impact of climate change on agriculture and its related aspects in Ethiopia (Sinore & Wang, 2024)

Climate change impact adaptation strategies in Ethiopia.

Major adaptation strategies	Descriptions
Mixed farming.	• application of improved crop varieties, • use of improved livestock breeds, • mixed cropping, early and late planting, • drought tolerant variety so on.
Land management practices.	• Soil and water conservation, • agroforestry practices, • integrated soil fertility management practices, and • small-scale irrigation practices.
Livelihood diversification.	• Income-generating activities, • off/on-farm activities, and so on.
Practicing both mixed farming and land management practices together.	• Using the integration of mixed cropping and • land management practices together.
Practicing both mixed farming and livelihood diversification together.	• Using the integration of mixed cropping and • livelihood diversification practices together.
Practicing more than two practices.	• Practicing mixed farming, • land management, and • livelihood diversification together and so on.

Table 2. Climate change impact adaptation strategies in Ethiopia (Sinore & Wang, 2024)

Why building the dam was the best option for Ethiopia

According to the Ethiopian Embassy the GERD was meant as a development project that supports Africa's green transition. Ethiopia generates 86% of the Nile flow with an average annual flow of 77 billion cubic meters. For Ethiopia, accessing and utilizing its water resources is imperative to its continued existence. The purpose of the GERD is to lift millions of people out of poverty and provide access to affordable electricity to more than 60 million Ethiopians. It will increase Ethiopian Hydroelectric power generation by 15,692 GWh/year on average, will significantly contribute to the economic and social development of the country, and will replace fossil fuels and reduce CO_2 emissions. Not only will it benefit Ethiopia, but neighboring countries as well by storing 74 billion cubic meters (bcm) of water that can benefit Egypt, Sudan and Ethiopia during droughts. The GERD will also regulate flow which will help downstream countries better manage their reservoirs. Negative impacts of climate change such as recurrent floods will be less of a risk with the GERD in place and 90 % of sediment will be captured which will protect irrigation canals and equipment from sedimentation related damages.

Furthermore, the GERD will improve dam efficiency and water use optimization downstream. With more regular flows, Sudan hydropower energy generation will be uplifted by more than 2,657 GWh/year. Regulating the flows of the Blue Nile will eliminate the risk of the High Aswan Dam (HAD) in Egypt overtopping. And, as stated by the Ethiopian Embassy, with GERD operating upstream, average annual HAD evaporation losses will be tremendously reduced, [since it will receive less water].

Impacts

Socio-Economic Impacts

Since the inception of hydropower dams in the late 1800s humans have been able to harness the power of water, store rainwater to mitigate the impacts of drought, promote economic growth and alleviate poverty, ensure food security, increase resilience in the face of climate variability, and prevent floods. Large dams, those higher than 15 meters that impound more than 3 million m^3, in particular have been used to regulate river flows, aiding countries to fulfill water and energy needs. Indeed, 16% of global surface water resources are stored via dams (Perera & North, 2021). Furthermore, "irrigated agriculture ensured largely by dams, contributes about 40% of world agricultural production, while hydropower dams generate around 20% of global electricity production" and 70% of renewable energy generation (Basheer et al., 2021; Perera & North, 2021).

However, this "clean” power source may not be so clean after all. “Clean energy” is usually defined as energy that comes from renewable sources, does not emit greenhouse gases or other pollutants, and does minimal or no damage to the environment. Based on this definition, hydropower dams should not be considered clean energy sources.

Dams convert dynamic rivers into static reservoirs, altering the hydrography and morphology of the rivers, consequently destroying ecosystems and decreasing biodiversity. Dams also cause major anthropogenic disturbances to the biogeochemical nutrient cycles and often result in human rights violations (mainly of indigenous people who rely on the rivers' ecosystems for survival). Large hydropower dams alone have displaced up to 80 million people and upheaved 472 million livelihoods (International Rivers, 2023). As with many things, the temperature and precipitation impacts of climate change may exacerbate these negative effects to irreversible extents.

The GERD, Africa’s newest and largest hydroelectric dam, is considered a giant dam at 509 feet tall, which is approximately 155 meters (USGS). It has 13 turbines that are expected to produce about 16,000 GWh of electricity annually, which will double Ethiopia’s previous output of electricity and provide power to 60% of the country’s population (USGS). The project, which cost roughly $5 billion to construct, is expected to bring employment and business opportunities and thus improve Ethiopians’ living standards and initiate and maintain their sustainable development.

Based on growth rate projections by the World Bank, "implementing GERD in a 3-year span would contribute to losses in Egypt's Gross Domestic Product (GDP) per capita by approximately 8%, and to a rise in the national unemployment rate by about 11 percentage points" (Kamara et al., 2022). Given the GERD reservoir volume of 74 km^3, losses in Egypt's annual water allocation were estimated to be around 51%, 25% and 19% for 3, 7 and 10-year filling scenarios, respectively. These values then translated into projected annual losses in agricultural land of about 53%, 28%, and 23% relative to the baseline scenario. Under the 3-year filling scenario, these losses lead to an average annual decline in food production of approximately 38%, leading to a rise in food import by roughly 9% and a corresponding decline in food export of 17%. With regards to overall agricultural sector output, the losses are projected to be 18% annually for the 3-year filling period. Moreover, the decline in the supply of food and other agricultural raw materials leads to a rise in the overall cost of living (CPI inflation) by 9 percentage points above the baseline. Furthermore, with GERD, employment in the agricultural sector is projected to drop drastically, with a total decline of 18 percentage points in the agricultural sector, which would contribute to a rise in the national unemployment rate of 11 percentage points. Moreover, the projected annual losses in real GDP per capita were estimated to be 8%, 4%, and 3% for the 3, 7, and 10-year scenarios, respectively. These translate into annual losses in Egypt's real GDP of $26 billion, $16 billion, and $13 billion, respectively, leading to overall welfare losses. These estimates represent the worst-case scenario in terms of losses generated by GERD. It was also assumed that the GERD reservoir would be filled gradually under a constant filling rate every year when in reality Ethiopia fills the reservoir using "phase" mechanisms, with each phase filling at a rate that might not be constant from year to year. (Kamara et al., 2022)

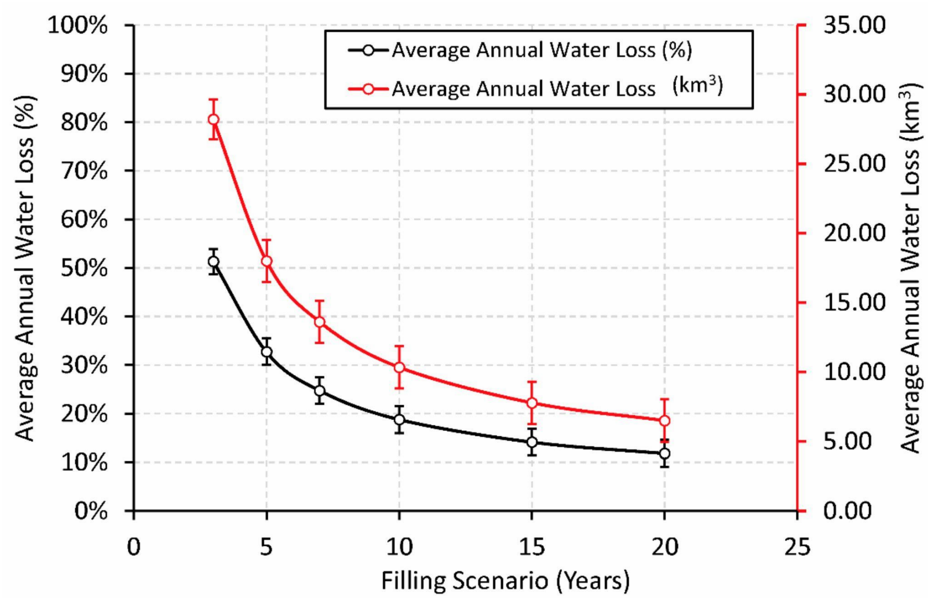

Figure 3. Average annual water loss in Egypt for various filling scenarios (Kamara et al., 2022)

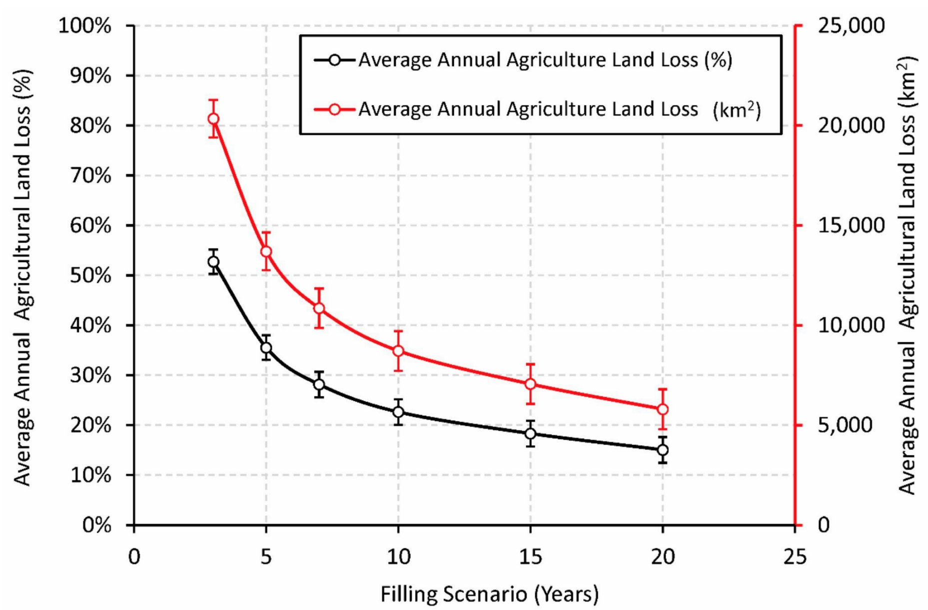

Figure 4. Annual agricultural land loss in Egypt for filling scenarios (Kamara et al., 2022)

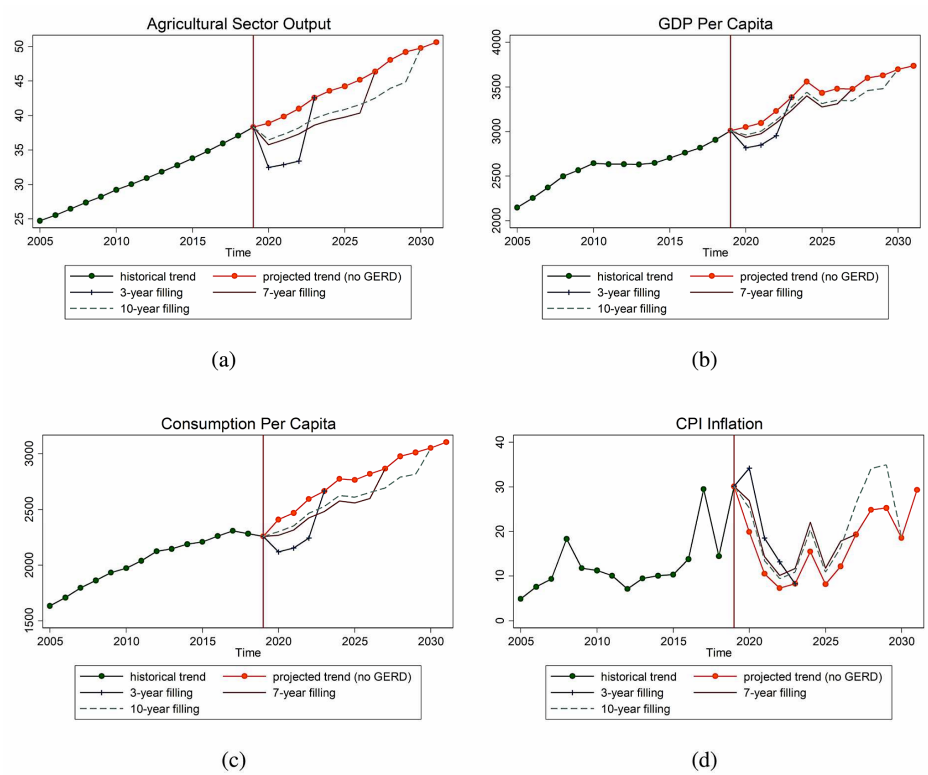

Figure 5. Projected impacts the GERD has on the Egyptian economy (Kamara et al., 2022)

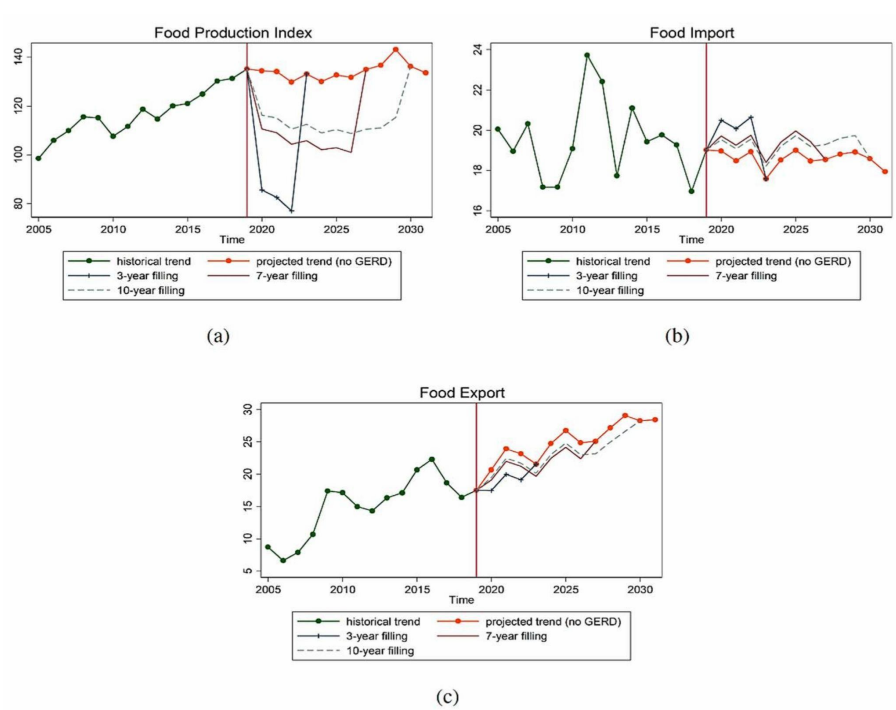

Figure 6. Projected impacts the GERD has on Egypt's food sector (Kamara et al., 2022)

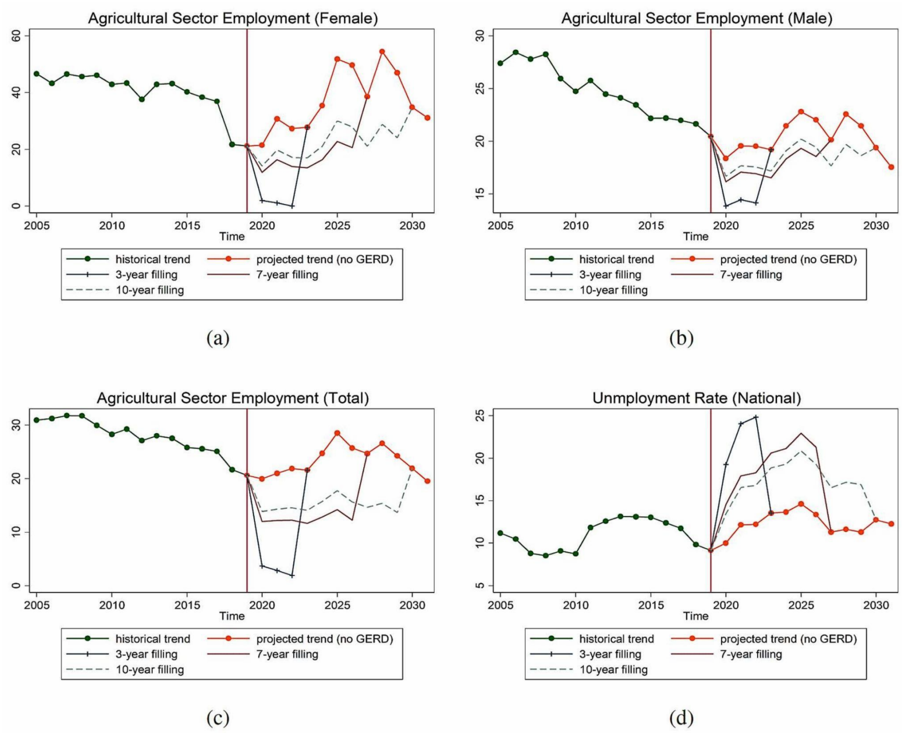

Figure 7. Projected impacts the GERD has on Egypt’s agricultural sector and unemployment (Kamara et al., 2022)

Public Health Impacts

Sub-Saharan Africa has the lowest per-capita water withdrawals in the world, which is why the governments of those countries believe dams are the solution to ensure water security for sustainable development and why hundreds of large dams are under construction that will accelerate the region's economic development. However, dam construction could lead to negative environmental, ecological and public health consequences, such as malaria outbreaks, which will be the main vector-borne disease discussed in this paper because it is one of the most common and well-known, but it is certainly not the only one.

Climate change has played an important role in exacerbating malaria in the eastern African region. According to the World Health Organization (WHO), 68% of Ethiopians are living in areas at risk of malaria (Simane et al., 2016). Changes in climate are likely to lengthen the transmission period of major vector-borne diseases and alter their geographic range, such as the projected encroachment of malaria from lower altitudes to higher altitudes in the Tigray and the Amhara regions of Ethiopia. Conditions for malarial transmission in the Ethiopian highlands are feared to become highly suitable by the 2080s (Simane et al., 2016).

Nearly 75% of the population of Sub-Saharan Africa resides in malarious areas (Kibret et al., 2019). African dams have been shown to cause at least 1.1 million malaria cases each year. The population at risk of malaria around these dams is estimated to be 15 million which is projected to increase to 25–26 million by the 2050s as a result of population growth and climate change; the number of malaria cases associated with reservoirs, specifically, is projected to rise to 2.1–2.9 million by the 2050s (Kibret, 2018). This rise in cases with the increase in dams is because damming rivers slows down the water flow and creates large impoundments that provide ideal breeding habitats for malaria-causing mosquitoes. Communities living close to reservoirs are thus at greater risk of contracting malaria than those living further away. In water-stressed areas like sub-Saharan Africa, people tend to relocate closer to water infrastructures to more easily access water for domestic use and irrigation. Therefore, dams should be established in non-malaria-endemic areas. Another solution would be to establish a buffer zone to prevent people from living too close to the dams and minimize the risk and spread of malaria. If a dam must be placed in a malaria-endemic area, the shoreline areas should be altered to be less favorable for mosquito breeding, such as a faster water level drawdown to discourage mosquito larval habitats from forming (Kibret, 2018).

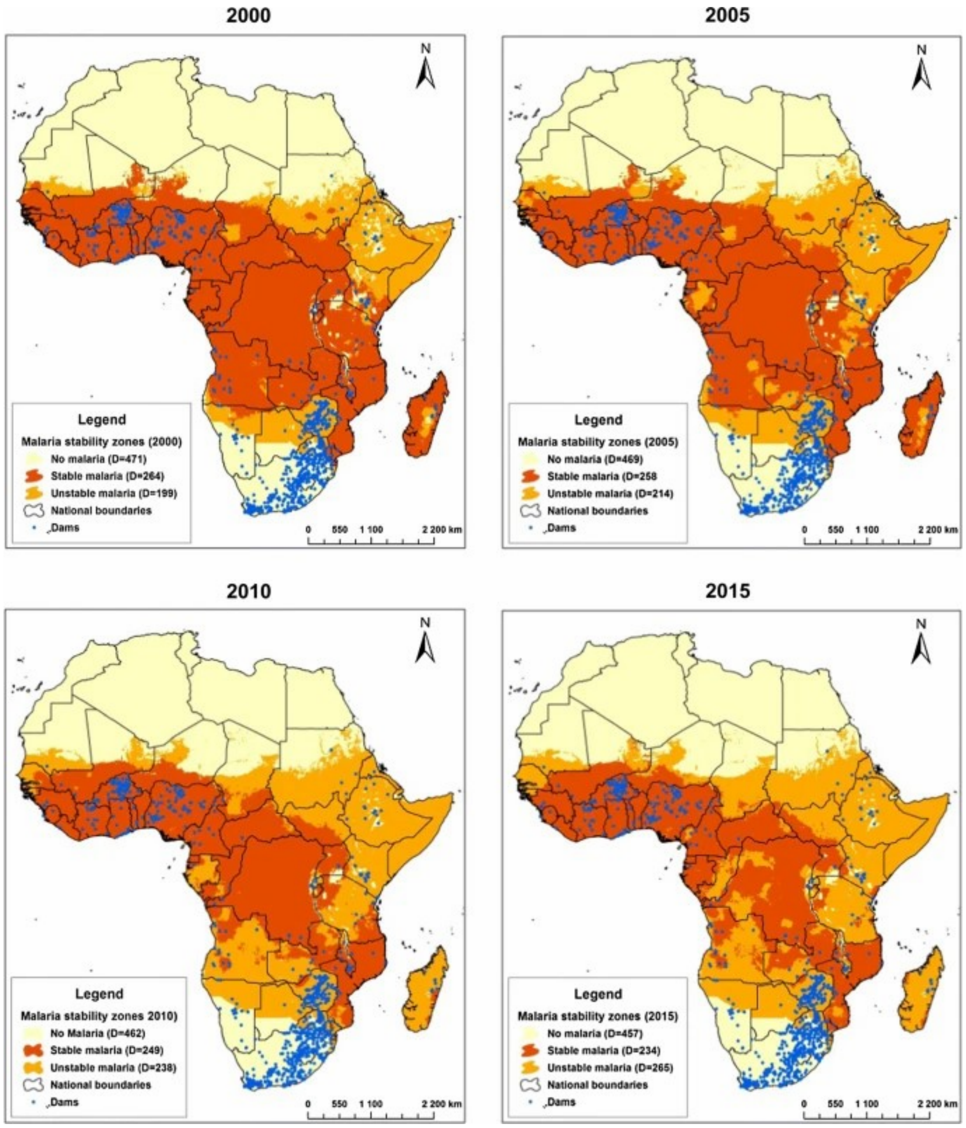

Figure 8. How dams affect malaria risk in sub-Sahara Africa (Kibret et al., 2019)

Large dams in areas of stable transmission, which are areas where infections occur often and so usually exhibit high immunity, tend to be located in more densely populated regions, resulting in a greater population at risk. From 2005 - 2015, a trend was made evident: 679,000 cases were reported in 2005, 798,000 in 2010, and 1.2 million in 2015 (Kibret et al., 2019). Thus, malaria cases in Sub-Saharan Africa are on the rise due to the unfortunate combination of intensifying climate change and the rapid increase of dam construction. Most cases were found around dams in stable areas (Kibret et al., 2019). As global malaria distribution shrinks, dam associated reservoirs in sub-Saharan Africa will continue to offer foci for malaria transmission.

Political Impacts

When the construction of the GERD was announced by Ethiopia in April 2011 a cumbersome negotiations process began over the filling and operation of the dam that has now lasted over a decade. The International Panel of Experts (IPoE), a panel consisting of members from Sudan, Ethiopia, and Egypt, was tasked with identifying the negative impact of the GERD and ways to mitigate it (Attia & Saleh, 2021). No fundamental flaws of the GERD's construction were reported, yet studies of its impact on Egypt and Sudan were recommended. In 2014, the Tripartite National Council (TNC) failed to improve relations due to disagreements on selecting international consultants to conduct the IPoE recommended studies (Attia & Saleh, 2021). Egypt demanded the construction of the dam be halted until the studies were completed. Ethiopia rejected this demand. The following year, the Declaration of Principles (DoP) committed the three states to peacefully resolve conflict by emphasizing the need to recognize Egypt's and Sudan's water needs. It also committed the parties to equitably and reasonably utilize Nile waters and in doing so, avoid harm.

The National Independent Research Scientific Group (NIRSG) was created in 2018 to select international consultancy groups to conduct the IPoE studies (Attia & Saleh, 2021). The NIRSG made significant progress in discussing the procedures for the first filling but did not agree on baseline scenarios for the studies, due to Egypt insisting its current water (at the time) be used as a baseline. The three main parties were also unable to reach a compromise on the long-term operation and coordination mechanisms of the dam. A year later, in 2019, Egypt invited the United States and the World Bank to observe the negotiations process of the

Washington Round (Attia & Saleh, 2021). Ethiopia withdrew from the process in 2020 and refused to sign the US proposed agreement drafted in its absence which lays out the technicalities of the filling and the operations of the dam based on the positions of the three parties. Ethiopia later claimed it was technically impracticable and would severely limit the energy-generation capacity of the GERD.

After Egypt brought the dam issue to the United Nations Security Council (UNSC) in 2020 and Ethiopia proceeded with the first filling despite a lack of agreement, the African Union (AU) led negotiations between the three parties, which ended in a deadlock in 2021 (Attia & Saleh, 2021). This process repeated in the second half of 2021 when Egypt re-presented the issue to the UNSC and Ethiopia unilaterally proceeded with the second filling, during which the IPoE studies were still not conducted. Ethiopia seemingly prolonged negotiations in an effort to gain time to conduct the filling prior to being restricted by any agreement that may have been reached, "thereby imposing a fait accompli on the downstream countries" (Attia & Saleh, 2021). Ethiopia rejected Egypt's request to postpone the dam's filling until an agreement could be reached, further diminishing trust between the two countries and making the likelihood of an agreement even smaller.

As Egypt's most important ally, the US has asserted its support for Egypt's water security. However, the US also has a close relationship with Ethiopia and is not generally involved in the Nile water issues, but the Trump administration put pressure on Ethiopia to accept their proposal by partially halting aid and even warning that Egypt had the right to blow up the dam if an agreement was not reached. These threats all but dissolved the US' role as a mediator of the GERD dispute. Following this, the US stepped back, and the issue was returned to the African Union. While the Biden administration continues to support Egypt's water security, it has adopted a more neutral stance than the previous administration. It took Saudi Arabia almost 11 years to officially back Egypt's position on the GERD in June 2022, likely resulting from its growing competition with the United Arab Emirates (UAE) for influence in Egypt (Darwisheh, 2022). Saudi Arabia stated that Egypt's water security is integral to Arab water security. However, Saudi Arabia also maintains political and economic relations with Ethiopia whose large population makes it a potentially large market for Saudi Arabia and the UAE's oil and commodity products. Ethiopia is also influential in the Horn of Africa and, unlike Egypt, is endowed with a substantial amount of freshwater (12 major river basins and 11 large lakes) as well as renewable energy resources with huge potential for hydro, solar, wind, and geothermal power (Darwisheh, 2022). Being entirely dependent on imported food, Saudi Arabia and other Gulf Cooperation Council (GCC) countries would gain much from investing in Ethiopia's water resources and agricultural and livestock development to ensure their own food security. In addition, the presence of Saudi Arabia and UAE in the Horn of Africa allow them to extend their power into a region that has some of the world's major trade sea lanes and land routes. The GCC's political and economic influence may allow them to bring Egypt, Sudan, and Ethiopia to conclude a binding agreement, which would simultaneously serve their wider geopolitical interests. Meanwhile, Russia is vying for political and economic influence in the Horn of Africa while China supports the principle of "African solutions to African problems" stating that "through joint efforts, the completion of GERD can become a tripartite development project to enhance mutual trust and win-win cooperation" (Darwisheh, 2022). China has close relationships with all involved parties and has thus been directly involved in the dam by financing its power lines and infrastructure. "This noninterference policy is crucial for China to protect its ever-growing economic investments in Africa, particularly in Ethiopia, one of China's largest African trade partners" (Darwisheh, 2022).

Egypt depends on the Nile more than any other riparian state, because it is not only its main source of surface water but also an integral part of its civilization and culture. Egypt's historical and acquired rights to Nile waters go back to the 1929 agreement it made with Great Britain (on behalf of its colonies) that gave Egypt veto power over any construction project on the Nile's banks. Ethiopia, however, does not recognize the agreement, naming it a colonial-era design meant to promote Egypt's interests. On top of the 1929 agreement, the 1959 agreement between Egypt and Sudan divided the Nile's downstream flow of water between the two, allocating 55.5 billion cubic meters (bcm) to Egypt and 18.5 bcm to Sudan (Attia & Saleh, 2021). This was the legal basis for Egypt's construction of the Aswan High Dam (AHD) and Sudan's construction of the Roseires Dam on the Blue Nile.

Egypt's complete dependency on the Nile, has shaped the country's foreign policy of the Nile Basin for decades. Egypt was part of the Nile Basin Initiative (NBI), an intergovernmental framework of cooperation established in 1999 to facilitate the implementation of basin-wide projects in the Eastern Nile and Equatorial Lakes (Attia & Saleh, 2021).

The construction of the GERD raises concerns of water shortages, artificial droughts, and a decreased resilience of the AHD for Egypt. However, Egypt's position has shifted from complete opposition to a willingness to make concessions, suggesting the GERD and AHD work as part of a multi reservoir operation (Attia & Saleh, 2021). It agreed that the filling and hydropower generation process should continue even in the most severe drought periods and accepted reductions in hydropower generation at the AHD in all cases as well as acknowledged Ethiopia's right to utilize the Nile for its development. Now that the GERD has become a reality, Egypt's options to mitigate the risks are limited, which explains why it is seeking international pressure on Ethiopia.

Like Egypt, Sudan depends heavily on the Nile, especially considering the frequent drought seasons and variability of rainfall it endures. Nearly 43% of the Nile Basin lies within its territories hence why before the secession of South Sudan, the country was named Africa's breadbasket with the largest irrigated area in sub-Saharan Africa (Attia & Saleh, 2021). Sudan and Egypt have, for the most part, always seen eye to eye on Nile water issues, and so, like Egypt, Sudan declared its strong opposition to the GERD. The discourse in Sudan shifted towards the potential benefits of the GERD, when Sudanese president Omar al Bashir began strengthening economic ties with Ethiopia, including electricity imports, flood prevention, and the entrapment of sediments carried by the Blue Nile (Attia & Saleh, 2021). But since the deposition of al-Bashir in 2019, and the subsequent aggression of Ethiopian militias on the Sudanese border, Sudan has reasserted its initial stance on the GERD and opposed any unilateral action by Ethiopia. The construction of the dam may, however, be beneficial for Sudan, which is why it has not signed onto any Egyptian-led initiatives. Sudan's concerns primarily center on the dam's safety and the difficulty of trusting Ethiopia given their troubling history.

In contrast to Egypt and Sudan, Ethiopia's surface water resource potential is impressive, but relatively underdeveloped. The country's economy is mostly based on agriculture primarily dependent on rainfall. Ethiopia is currently heavily reliant on hydropower for electricity generation with its many reservoir dams constructed for just that reason as well as irrigation and drinking water supply. It is estimated that nearly 30% of the population lives in poverty and only 48.3% of the population have access to electricity which explains why Ethiopia is eager to develop its hydro-resources, accelerate electrification, and expand access to electricity (Attia & Saleh, 2021).

Ethiopia's claims to the Nile date back to the 1902 demarcation agreement between Ethiopia and Great Britain on behalf of Anglo-Egyptian Sudan which restricts Ethiopia's right to construct projects on the Nile (Attia & Saleh, 2021). Ethiopia thus refers to both the 1902 and 1929 agreements as colonial agreements with no legitimacy. Ethiopia also does not recognize the 1959 agreement, arguing that it grants Egypt and Sudan full utilization and control over the river. But Ethiopia also has a growing population it must provide for and changing economic needs, and therefore, also possess a natural right to utilize the waters for its development. The unilateral construction of the GERD was the country's first serious move to undermine Egypt's hegemony over the Nile, using the dam's construction not only as a national project central to Ethiopia's hope of becoming a middle-income country but also as a tool to alter power dynamics in the Nile Basin. While Ethiopia joined the negotiation process and proposed trilateral committees and signed the DoP, it insists on its sovereign right to utilize Nile waters and to operate the dam. In this vein, it has only addressed the first two years of the filling and did not provide any information for future plans of the operation.

The GERD is located in an area rich in natural resources, which attracts affluent countries looking for resource extraction and those looking to cultivate water intensive crops for their growing populations in external territories, such as China, India, Saudi Arabia, Qatar, and the United States, who all have large-scale agricultural projects in the region. But the unstable political climate of the region fosters mistrust as previously illustrated. The Red Sea region also hosts external armed forces from over a dozen countries, including the United States, China, France, and Germany. Egypt's Abdel Fattah el-Sisi pledged that bargaining over Egypt's share of water would be a “red line”. This strongly resonates with the Egyptian public considering that approximately 96% of the Egyptian population is concentrated around the Nile (Attia & Saleh, 2021). For Ethiopia, the financing of the GERD was presented as a nation building project that would allow the country to achieve energy self-sufficiency, socio economic development, and technical advancement. After the World Bank refused to finance its construction and external funding proved difficult to acquire without Egypt’s endorsement, the majority of GERD financing came from the Ethiopian people, making it a symbol of Ethiopian nationalism. This conflict between the riparian states could result in international dilemmas if tensions escalate any further. Egypt and Ethiopia are crucial regional players and two key partners of the United States and a number of EU countries with interests in the southern Mediterranean and the Horn of Africa. Egypt warned that any harm to its water would result in “inconceivable instability” in the region and has strengthened ties with Sudan, most recently conducting a joint military drill called “Guardians of the Nile” in May 2021 in a symbolic move vis à vis Ethiopia (Attia & Saleh, 2021).

Environmental Impacts

On top of the political unrest the GERD has contributed to, it, like all dams, has environmental consequences. While dam construction is declining in most parts of the world, planned dam projects in Africa are on the rise to aid economic development. Though the African economies will reflect the positive changes made by dams, it is of the utmost importance to acknowledge how hydropower, which is widely known as a green source of energy, in truth “represents a false climate solution" (International Rivers, 2023). Even before dam construction begins, manufacturing the concrete and steel for them requires equipment that may produce emissions if fossil fuels are used in the process. Once the dams are built, greenhouse gasses

(GHG) such as carbon dioxide and methane form in the resulting reservoirs as a result of the aerobic and anaerobic decomposition of biomass in the water (U.S. Energy Information Administration, 2022). In fact, “reservoirs contribute 22 million tons of methane per year” (Turns, 2024). In this way, dams indirectly contribute to global warming. “While reservoirs are often thought of as ‘green’ or carbon-neutral sources of energy […] their role as greenhouse gas sources [has been documented]” (Arora, 2024). Reservoirs collectively contribute 1.3% of the world’s annual GHG emissions, equal to that of Canada (Arora, 2024).

Furthermore, dams fragment rivers and destroy surrounding forests, thus eliminating valuable carbon sinks. This fragmentation alters the natural flow of rivers, fracturing the migratory routes of most fish and preventing them from spawning. This disturbance is felt up the food chain as predator species that depend on the river ecosystems for survival are indirectly impacted. In addition to impeding the flow of rivers, dams also deter the flow of vital nutrients (i.e. carbon, nitrogen, silicon, and phosphorus) via sedimentation. Sedimentation in reservoirs leads to increased nutrient retention upstream while simultaneously depriving the downstream areas of nutrient-rich sediment. A disruption in the flow of carbon between continental and oceanic carbon could have disastrous results. For instance, at the start of the 21st century, in-reservoir sedimentation wiped out 13% of the total riverine export of carbon to the oceans, and that number is expected to rise to 19% by 2030 (Arora, 2024). As downstream areas receive fewer nutrients, the soil gradually loses fertility and ability to support life. Moreover, as less of these nutrients flow into the ocean, algae, which are major carbon sinks, fail to bloom, meaning that this is yet another way dams indirectly aggravate climate change. Because dams and reservoirs have a much greater surface area than average rivers and the nutrient-rich water in the reservoirs promotes plant growth, increased transpiration due to increased sun exposure speeds up the process of evaporation, leading to immense losses of the very resource dams are meant to store. The global average of water lost to evaporation from reservoirs every year amounts to about 170 cubic kilometers, the equivalent of 7% of all freshwater used by humans (Arora, 2024). Thus, the belief that dams help in the preservation of water is in fact false, as is the belief that hydroelectricity is clean. To boot, dam breaches are quite frequent during which toxic metals often seep into the soil, thereby undermining the utility of the dam (Arora, 2024).

As dams age, they become more expensive to repair and maintain and increasingly prone to failure. In general, dams have an average lifespan of 50 to 100 years, hence many dams built in the last century are being considered for removal because the cost of management may not be worth it (Perera & North, 2021). However, the cost of repair vs cost of removal, socio-economic impacts, public safety risks, environmental impacts, and government water policies, energy, and food production must be considered before formally deciding whether a dam should be removed.

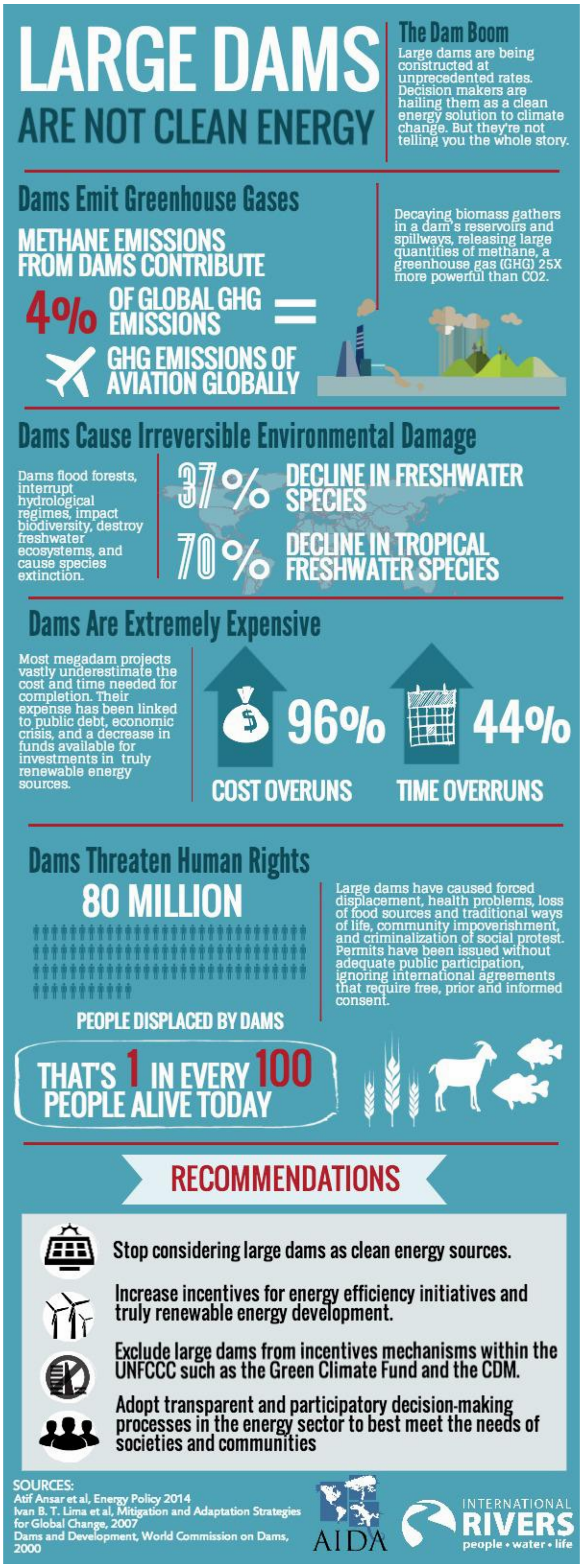

Figure 9. Negative impacts of dams and recommendations of how to reduce them (International Rivers, n.d.)

Methodology

The process of conducting research for this paper began by comparing the views Egypt and Ethiopia have on the Grand Ethiopian Renaissance Dam Project. A comprehensive literature review was conducted using Google and Google Scholar search engines.

The types of literature reviewed included scholarly articles, government reports, climate reports, news articles, dam demolition project reports, and climate statistics databases. Irrelevant articles were sorted out by utilizing critical reading skills and evaluating abstracts. Biased information leaning towards one country or another's interests was also filtered out. After an extensive review of the available literature, trends, patterns, contradictions, and informational gaps were identified.

Recommendations

Dam Demolition

Based on the findings in this paper, the negatives of the GERD far outweigh the positives, especially when considering potential future impacts; accordingly, it should be considered for demolition. As the wealthier country and the one that seems to have the most at stake, Egypt should, at least partly, reimburse Ethiopia for this massive economic loss. The cost of demolition for a large dam is in the tens of millions of dollars. The management costs that would be required year after year, however, on top of the potential flood damage costs, would likely add up to be far greater.

As dams age, they pose a threat to public safety and could impact both the economy and the environment dramatically. By 2050, most of the predicted world population will reside downstream of large dams primarily constructed in the 20th or early 21st century (Perera &

North, 2021). The three potential solutions to manage aging dams are repair, re-operationalization (which modifies the original dam operation to recover social and ecological benefits), or dam removal.

On top of being a solution to managing aging infrastructure, dam removal also restores the health of riverine ecosystems. Out of the roughly 57,000 large dams worldwide, about 10,000 have been demolished (International Rivers; WWF, 2023). While dam repair preserves dam function, maintenance is often expensive and can be 10 - 30 times costlier than removal (Perera & North, 2021). Similarly, while re-operationalization has been proven to improve the ecological and social impacts of dams, it is a complex process, and many dams no longer provide the benefits that once justified their development. Alternatively, dam removal involves the full or partial removal of dam infrastructure and may be a feasible alternative if economic, social, and practical limitations prevent the dam from being renovated. However, dam removal can have consequences as well. Functionally, there may be a loss of services provided by the dam, such as hydropower generation, irrigation, or flood control, which may need to be replaced. Therefore, removal may not be advantageous for some countries, communities, and individuals that rely on dam services. In these cases, repair or re-operationalization is likely a more suitable option to maintain safe dam functioning.

Damming rivers may cause significant losses of riverine fish harvests. Therefore, dam removal may be beneficial to increase fishery yields. In the US, restoring rivers has significantly improved the quality and quantity of fish habitat and salmon migration. Indeed, several studies point to an increase in fish population after dam removal. Since dam removal restores terrestrial and aquatic ecological functioning, it is likely that river fisheries are more sustainable and provide higher yields than reservoir fisheries. However, this may not be the case in more arid regions where agriculture without irrigation can be impossible, particularly for countries with emerging economies (i.e. Ethiopia) where dams, irrigation systems, and hydropower play a critical role in fighting poverty because more irrigable land will produce more food. Therefore, in regions that rely on dams to supply water for irrigation, removal could have detrimental consequences to the surrounding communities.

Twenty percent of the world's electricity is generated by hydropower, the primary renewable energy source. However, nearly one billion people still lack access to electricity, predominantly in Africa and South Asia, and hydropower dams may be integral to closing the electricity access gap and improving livelihoods in those regions. Therefore, dam removal may have far-reaching negative consequences and may not be a feasible alternative to overcome the issue of aging dams, especially in developing countries.

Perhaps the most compelling reason for dam removal is disaster avoidance. Even when structurally sound, large dams are considered "high hazard" forms of infrastructure because of the possible loss of human life resulting from failure. Urban development downstream of dams is persistent and thus elevates the magnitude of dam failure. Dam failures may result from seepage, cracking, overtopping or structural failure. Several failures have occurred in dams over 50 years old. When combined with poor maintenance and infrequent inspection, older dams present a high risk to public safety. Dam failure can lead to extensive loss of life and property damage. Removing aging dams that are vulnerable to failure is an effective and proactive way to prevent loss of life and to protect property.

Dams are critical infrastructure for low-income countries for water supply, irrigation, and electricity generation. In these cases, dam removal may be impractical and not a viable option. As the climate becomes hotter and drier, increased pressure is placed on governments to supply water to growing populations. The global population is expected to increase to between 9.4 and 10 billion by 2050, with most of the growth occurring in Africa and Asia (Perera & North, 2021). Therefore, finding ways to provide safe, sufficient water to regions that are particularly vulnerable to climate change will be of the utmost importance. For the successful management of aging dams, the dam removal process and its potential impacts, both positive and negative, should be incorporated as an essential component in a dam's planning phase.

Undamming the Klamath

An example of an entire river system being destroyed by damming projects but then revived via dam demolition is the Klamath River which flows through Oregon and Northern California. In early 2024, operators opened the floodgates on the 49-meter-high dam that blocks the Klamath, allowing the more than 50 million tons of water it impounds to begin to drain (Cornwall, 2023). Once drained, the structure will be completely dismantled. All that will remain of the 11-kilometer-long reservoir that filled the valley for 60 years will be steep-sided slopes coated in gray mud, split once again by a free-flowing river (Cornwall, 2023). Within months that sediment will be covered with a fine, green carpet, and eventually the native trees and other vegetation will return to line the banks of the river. Beneath their boughs, salmon that last migrated through this valley more than a century ago will return.

For nearly 100 years, dams on the Klamath River have blocked salmon and steelhead trout from reaching more than 400 miles of historic spawning habitat upstream, encroached on Indigenous culture, and harmed water quality for people and wildlife (American Rivers, n.d.). The Klamath was once a fabled source of salmon, the third most productive in the western United States. As many as 1 million salmon journeyed each year up the 420-kilometer-long waterway, which flows from the dry plains of eastern Oregon to the Pacific Ocean. The yearly salmon runs were once the lifeblood, as an important source of sustenance, for the Yurok, Karuk, Klamath, and other tribes. Then, in 1918, a 36-meter-tall concrete dam was erected in a narrow canyon 325 kilometers upriver, walling off some 560 kilometers of habitat for migratory fish. It was the first of the six dams that now choke the Klamath River (See Figure 10). Four of those dams – J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate – built between 1908 and 1962, have been demolished (American Rivers, n.d.). This river restoration project will have lasting benefits for the river, salmon, and communities throughout the Klamath Basin. The four dams didn't provide flood control or irrigation, they only generated a small amount of hydropower, which will be replaced using renewables and efficiency measures, and thus removing the dams did not affect any water rights. Those blockages led to severe declines in salmon populations, with two whole species being eliminated, which now number at less than 5% of pre-dam levels (Cornwall, 2023). The dams also trapped nutrient rich waters in shallow reservoirs which resulted in massive blooms of toxic blue-green algae that posed a threat to wildlife and human health (See Figure 11). The algae blooms also trapped heat and depleted oxygen, further degrading water quality. Restoring the river will eliminate the reservoirs associated with algae blooms and improve water quality.

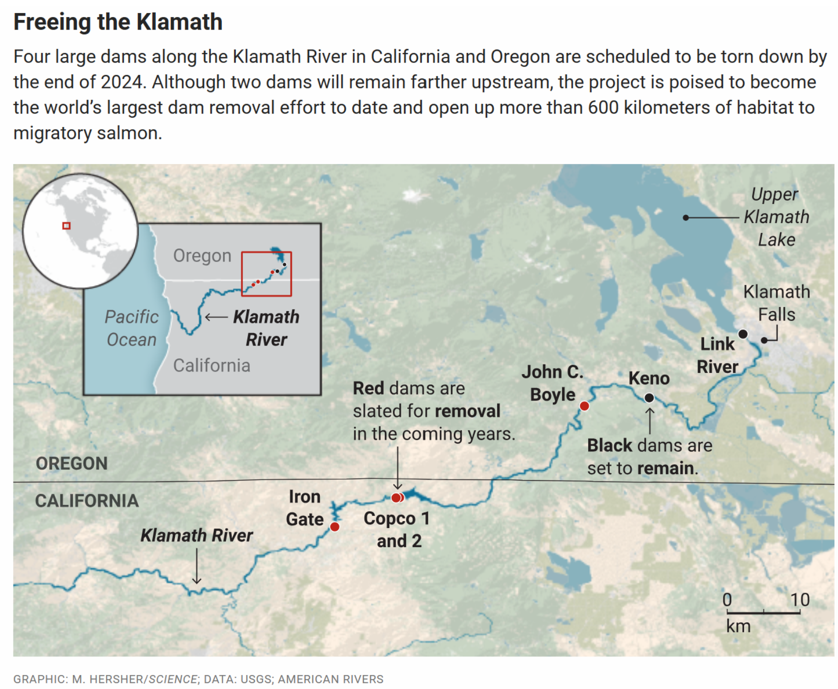

Figure 10. Map of the dams that clogged the Klamath River (Cornwall, 2023)

Figure 11. Algal bloom caused by Klamath River Dam (Cornwall, 2023)

In the early 2000s, under pressure from tribes, environmentalists, and anglers, the Federal Energy Regulatory Commission decided that before the dams' licenses could be renewed, the dams would need to be renovated to help fish get upstream. Facing hundreds of millions of dollars in construction costs, the owner—PacifiCorp—agreed in 2010 to allow them to be torn down instead, in what has become the world's largest dam removal project of $450 million to $500 million (Cornwall, 2023). Never before have four dams of this size been removed at once. Copco 2 was fully removed in October 2023 and as of February 16, 2024 the Copco 1, JC Boyle, and Iron Gate dams have fully completed the drawdown process, which refers to the draining of each dams' reservoir (American Rivers, n.d.). These dams inundated many miles of habitat (4 square miles and 15 miles of river length) and blocked access to more than 400 miles of habitat for salmon and other species. The four Klamath dams removed ranged in height from 33 feet to 172 feet (See Table 3), and their associated reservoirs covered approximately 1,300 acres, which will be revegetated and restored to provide critical riparian habitat for wildlife in the Klamath basin (American Rivers, n.d.).

Dam	System Components	Year Built	Electrical Capacity Avg Production/Year	Max Area of Reservoir	Reservoir Capacity	Dam Type	Dam Height Dam Length
JC Boyle	Reservoir, dam, fish ladder, power canal, two turbines, and powerhouse	1958	98 MW 329,000 MWh	420 acres	3,495 AF (total) 1,724 AF (active)	Earthfill	68 ft 693 ft
Copco 1	Reservoir, dam, two turbines, and powerhouse	1918	20 MW 106,000 MWh	1,000 acres	46,900 AF (total) 6,235 (active)	Concrete	126 ft 415 ft
Copco 2	Division dam, small impoundment, two turbines, and powerhouse	1925	27 MW 135,000 MWh	40 acres	73 AF (total) negligible (active)	Concrete	33 ft 278 ft
Iron Gate	Reservoir, dam, one turbine, powerhouse and fish hatchery	1962	18 MW 116,000 MWh	944 acres	58,800 AF (total) 3,790 AF (active)	Earthfill	173 ft 740 ft

Table 3. Specifics of the four recently removed Klamath dams (Klamath River Renewal Corporation, n.d.)

After a reservoir is drained, the soil transforms from a mixture of saturated mud and rough gravel to dry ground within a year, however, this newly exposed earth differs from what was there historically because dams trap fine silt, sand, and rocks. The revegetation of landscape that was formerly underwater in reservoirs involves seed collection and strategic dispersal of native plant species. The next steps will target water quality improvements in the tributaries and upper watershed to continue the Klamath River's recovery following the removal of the dams.

Removal of the four hydroelectric dams is the first crucial step to restore the health of the Klamath River and the communities that depend upon it. Long term, healthy salmon runs would add an estimated 450 jobs in the fishing industries in Oregon and California (Klamath River Renewal Corporation, n.d.). Klamath salmon support commercial fisheries worth $150 million per year and a local recreation industry that contributes millions to the Klamath Basin economy (Klamath River Renewal Corporation, n.d.). Water quality and fisheries improvements will substantially reduce the risk of fishery disasters.

The removal project benefits the public by reducing public spending on disaster relief. Over the past ten years, hundreds of millions in public dollars have been spent on emergency measures in response to Klamath crises (Klamath River Renewal Corporation, n.d.). Decommissioning will also prevent stagnant reservoirs from increasing water temperatures in the summer and help alleviate the poor habitat conditions that contribute to fish diseases below the dams. Furthermore, there is a direct correlation between the health of the Klamath River and health of the indigenous people who have depended on the river since time immemorial, but, in recent years, poor river conditions have led to the diminished harvest allocations and fish kills. Overall, restoration of the river will improve the lives, health, and economic well-being of those dependent on the river. Before the Nile reaches such a point of degradation that the Klamath did, the powers now vying for control of its waters must consider the full implications of damming them. Restoring the Nile back to its natural, original glory via demolition would be enormously beneficial to environment and countries downstream but is an extreme step for Ethiopia to take. Egypt's proposition that the GERD and AHD work as part of a multi reservoir operation may be a better resolution to the Egypt-Ethiopia political conflict since out-right declaring Ethiopia demolish their $5 million economic bolstering dam would undoubtedly cause even more strife. Another potential solution would be to suggest the demolition all dams on the Nile or that an extensive study be done to determine which Nile dams are most detrimental and that those be removed first.

Discussion

Ultimately, the political relationship between Egypt and Ethiopia has been a major player and aggravator in the controversy of the Grand Ethiopian Renaissance Dam. Ethiopia is wary of trusting Egypt because of its so-called "colonial agreements", while Egypt believes Ethiopia is breaking international law by filling the dam without its say-so. When observing the situation objectively, it is hard to definitively say whether the Grand Ethiopian Renaissance Dam causes more harm than good because it depends on the country. However, environmentally speaking, hydropower dams do cause more harm, especially in the long run. Economically, it depends not only on the country, but also the distance one is from the dam. The best, most logical way to mitigate its detrimental impacts, both current and future, is through demolition. This will restore the environment and ecosystems, as witnessed at the Klamath River, and ensure that there will be no future disasters, such as floods, that will occur due to the dam. In a way, the dam's construction has caused more political tensions *and* has been a result of political tensions; it is a bilateral relationship. Beginning with the 1929 agreement between Egypt and Great Britain, the rights of the Nile's waters have been a source of contention for Ethiopia. With the construction of the GERD, Ethiopia was able to gain some control of the Nile's waters and give Egypt a taste of their own medicine. Egypt is now taking Ethiopia more seriously and in desperation has proposed the GERD work together with their AHD, but after nearly a century of being excluded by Egypt in their plans of allocating the Nile's waters, Ethiopia is not interested in making concessions with Egypt.

If it does end up being deconstructed, Ethiopia will suffer economically due to the high cost of the project. But in the long run, the country will be saving money, the environment, and (potentially) lives. Conclusively, dam removal is always a climate solution but not always the best solution, especially when the lives of many are improved by its services, but in this case, as previously determined, it is the most reasonable solution.

Future Projections

There is still much to research and study regarding the Grand Ethiopian Renaissance Dam. First and foremost, gathering data directly from the Nile River Basin to compare flow rates, water quality, and wetland extent/health before and after the construction of the dam. Having a more detailed understanding of the effect that dam is having on the population of Ethiopia (based on social status, class, urban vs rural, etc.) would provide additional credibility to the study and recommendation that the dam should undergo demolition. Comparing the impacts of the GERD with those of the AHD would also be beneficial in settling the Egypt-Ethiopia disputes and because the Klamath Dam Removal Project left the two upstream dams intact, would removing all Nile dams downstream of the GERD but leaving it as is a better solution? How do impacts of upstream vs downstream dams differ?

In terms of continuing research on the impact of dams in general, finding ways to construct dams in ways that are less detrimental to the environment would be the primary focus, whether that be through altering the materials used to build the dams or inventing damming methods that aren't so permanent. Comparisons of the emissions and other environmental damage of dams to alternate hydropower plants would also be useful information to gather. A cost benefit analysis of hydropower dams vs desalination plants and possible ways to make the desalination process more cost effective could also be beneficial to coastal countries dealing with water scarcity.

References

Al-Anani, K. (2022, September 16). The Grand Ethiopian Renaissance Dam: Limited options for a resolution. Arab Center Washington DC. https://arabcenterdc.org/resource/the-grand-ethiopian-renaissance-dam-limited-options-for-a-resolution/

Ali, A. K., & Asfaw, D. M. (2023). Nexus between inflation, income inequality, and economic growth in Ethiopia. PLOS ONE, 18(11), e0294454. https://doi.org/10.1371/journal.pone.0294454

Amer, I. M. (2023, May 11). The Government of Egypt and the United Nations sign the United Nations Sustainable Development Cooperation Framework 2023-27. United Nations. https://egypt.un.org/en/231452-government-egypt-and-united-nations-sign-united-nations-sustainable-development-cooperation

Arafat, N. (2023, December 5). *Why addressing water scarcity in Egypt must be a priority - meeting Egypt's environmental challenges*. Carnegie Middle East Center. https://carnegie-mec.org/2023/12/05/why-addressing-water-scarcity-in-egypt-must-be-priority-pub-90721

Arora, A. (2024, January 18). *The Environmental Impacts of dams.* Earth.Org. https://earth.org/dams-economic-assets-or-ecological-liabilities/

Attia, H., & Saleh, M. (2021). *The political deadlock on the Grand Ethiopian Renaissance Dam*. https://nbn-resolving.org/urn:nbn:de:0168-ssoar-74082-8

Basheer, M., Nechifor, V., Calzadilla, A., Siddig, K., Etichia, M., Whittington, D., Hulme, D., & Harou, J. J. (2021). Collaborative management of the Grand Ethiopian Renaissance Dam increases economic benefits and resilience. Nature Communications, 12(1). https://doi.org/10.1038/s41467-021-25877-w

Bountry, J., Tullos, D., Duda, J., Randle, T., Jansen, A., McKay, K., Jumani, S., & Bailey, S. (n.d.). *Cost estimating dam removal: databases and drivers* [Slide show]. Federal Emergency Management Agency (FEMA). https://www.fema.gov/sites/default/files/documents/fema_dam-removal-cost-drivers_022023.pdf

Chibani, A. (2022, August 31). Confronting water scarcity in North Africa. Arab Center Washington DC. https://arabcenterdc.org/resource/confronting-water-scarcity-in-north-africa/

Climate risks to African hydropower – Climate Impacts on African Hydropower – Analysis - IEA. (n.d.). IEA. https://www.iea.org/reports/climate-impacts-on-african-hydropower/climate-risks-to-african-hydropower

Cornwall, W. (2023, October 19). After the Flood. Science. https://www.science.org/content/article/historic-dam-removal-poses-challenge-of-restoring-both-river-and-landscape

Dam no more: The truth about large dams. (2018, May 16). Interamerican Association for Environmental Defense (AIDA). https://aida-americas.org/en/dam-no-more-truth-about-large-dams

Dam removal on the Klamath River. (n.d.). American Rivers. https://www.americanrivers.org/dam-removal-on-the-klamath-river/

Darwisheh, H. (2022). *Egypt and the Politics of the Grand Ethiopian Renaissance Dam: An Update* (No. 173). Institute of Developing Economies - Japan External Trade Organization (IDE-JETRO). https://www.ide.go.jp/library/Japanese/Publish/Reports/AjikenPolicyBrief/pdf/173.pdf

El-Askary, H., Fawzy, A., Thomas, R., Li, W., LaHaye, N., Linstead, E., Piechota, T. C., Struppa, D. C., & Sayed, M. A. (2021). Assessing the Vertical Displacement of the Grand Ethiopian Renaissance Dam during Its Filling Using DInSAR Technology and Its Potential Acute Consequences on the Downstream Countries. Remote Sensing, 13(21), 4287. https://doi.org/10.3390/rs13214287

Embassy of Ethiopia. (2021, February 21). The Grand Ethiopian Renaissance Dam Project (GERDP) (February 15, 2021) - Embassy of Ethiopia. *Embassy of Ethiopia* -. https://ethiopianembassy.org/the-grand-ethiopian-renaissance-dam-project-gerdp/

Grand Ethiopian Renaissance Dam, Ethiopia | EROS. (n.d.). USGS. https://eros.usgs.gov/earthshots/grand-ethiopian-renaissance-dam-ethiopia

Hamzawy, A., Al-Mailam, M., & Arkeh, J. (2023, October 26). Climate change in Egypt: opportunities and obstacles. Carnegie Endowment for International Peace. https://carnegieendowment.org/2023/10/26/climate-change-in-egypt-opportunities-and-obstacles-pub-90854

Hoffman, J. (2023, July 3). Ten Years After Coup, the U.S. Still Supports Tyranny in Egypt. Cato Institute. https://www.cato.org/commentary/ten-years-after-coup-us-still-supports-tyranny-egypt

Kamara, A., Ahmed, M., & Benavides, A. (2022). Environmental and economic impacts of the Grand Ethiopian Renaissance Dam in Africa. Water, 14(3), 312. https://doi.org/10.3390/w14030312

Khamis, S. (2021, December 2). Agreements and tensions in US-Egyptian relations. Arab Center Washington DC. https://arabcenterdc.org/resource/agreements-and-tensions-in-us-egyptian-relations/

Kibret, S. (2018). Time to revisit how dams are affecting malaria transmission. The Lancet Planetary Health, 2(9), e378–e379. https://doi.org/10.1016/s2542-5196(18)30184-0

Kibret, S., Lautze, J., McCartney, M., Nhamo, L., & Yan, G. (2019). Malaria around large dams in Africa: effect of environmental and transmission endemicity factors. Malaria Journal, 18(1). https://doi.org/10.1186/s12936-019-2933-5

Klamath River Renewal. (n.d.). https://klamathrenewal.org/

MAP: Hydropower Dams in Sub-Saharan Africa. (2023, November 21). International Rivers. https://www.internationalrivers.org/news/map-hydropower-dams-in-sub-saharan-africa/

Mbaku, J. M. (2020, August 5). The controversy over the Grand Ethiopian Renaissance Dam. Brookings. https://www.brookings.edu/articles/the-controversy-over-the-grand-ethiopian-renaissance-dam/

Perera, D., & North, T. A. (2021). The Socio-Economic Impacts of Aged-Dam Removal: A review. *Journal of Geoscience and Environment Protection*, 09(10), 62–78. https://doi.org/10.4236/gep.2021.910005

Power Generation | EROS. (n.d.). https://eros.usgs.gov/earthshots/power-generation

Questions and answers about large dams. (n.d.). International Rivers. https://archive.internationalrivers.org/questions-and-answers-about-large-dams

Rebelo, L.-M., & McCartney, M. P. (2012). Wetlands of the Nile Basin. In *The Nile River Basin* (1st ed., pp. 212–226). https://www.iwmi.cgiar.org/Publications/Books/PDF/H045318.pdf

Removing dams, restoring rivers. (2023, February 28). WWF. https://wwf.panda.org/wwf_news/?7866466/Removing-dams-restoring-rivers

Simane, B., Beyene, H., Deressa, W., Kumie, A., Berhane, K., & Samet, J. (2016). Review of Climate Change and Health in Ethiopia: Status and Gap Analysis. *The Ethiopian journal of health development = Ya'Ityopya tena lemat mashet*, *30*(1 Spec Iss), 28–41.

Sinore, T., & Wang, F. (2024). Impact of climate change on agriculture and adaptation strategies in Ethiopia: A meta-analysis. Heliyon, 10(4), e26103. https://doi.org/10.1016/j.heliyon.2024.e26103

Turns, A. (2024, March 27). *Hydroelectricity is a hidden source of methane emissions. These people want to solve that*. https://www.bbc.com/future/article/20240326-how-hydroelectric-dams-are-a-hidden-source-of-carbon-emissions

Wheeler, K., Jeuland, M., Hall, J. W., Zagona, E., & Whittington, D. (2020). Understanding and managing new risks on the Nile with the Grand Ethiopian Renaissance Dam. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-19089-x

Wheeler, K., Jeuland, M., Strzepek, K., Hall, J. W., Zagona, E., Abdo, G., Basson, T., Blackmore, D., Block, P., & Whittington, D. (2022). Comment on 'Egypt's water budget deficit and suggested mitigation policies for the Grand Ethiopian Renaissance Dam filling scenarios.' Environmental Research Letters, 17(8), 088003. https://doi.org/10.1088/1748-9326/ac7e5e

World Bank Climate Change Knowledge Portal. (n.d.). https://climateknowledgeportal.worldbank.org/country/ethiopia/vulnerability

Wu, H., Chen, J., Xu, J., Zeng, G., Lian-Hai, S., Liu, Q., Zheng-Jie, Y., Dai, J., Yin, D., Liang, J., & Ye, S. (2019). Effects of dam construction on biodiversity: A review. *Journal of Cleaner Production*, *221*, 480–489. https://doi.org/10.1016/j.jclepro.2019.03.001

Appendix A: Policy Memo

Policy Memo

Date: May 2024

To: Nile Basin Initiative & UN Environment Programme

From: Sarah Hmoud, Master of Climate Science & Policy at the Scripps Institute of Oceanography, UCSD

Subject: The Controversy of the Grand Ethiopian Renaissance Dam (GERD)

Executive Summary

As you should be well aware, the Nile River Basin is a vital source of water for the over 290 million people living within it. With climate change on the rise, and its effects being felt most acutely by desert countries with less frequent rainfall and more frequent and intense droughts, it is now more imperative than ever to ensure that all those living within these parched regions have access to safe drinking water. However, the ever increasing construction of dams along the river for economic development is restricting the flow of that most vital resource from those downstream. Africa's newest and largest hydropower dam is the subject of a great controversy for that very reason. This is why collective action must be taken by all countries affected by this dam to develop a concrete plan for water allocation rights in which every country is provided sufficient fresh water for their population's needs.

Background

The greatest hurdle in regards to this controversy is the contentious relationship between Ethiopia and Egypt, the latter being the largest consumer of the Nile's water. According to Egypt's "colonial-era" agreement made with Great Britain, the Grand Ethiopian Renaissance Dam should never have been constructed, let alone filled. The fact that Ethiopia went ahead and did both without Egypt's approval has caused Egypt, who sees itself (arguably) as the Nile's owner, to become desperate. Ethiopia, meanwhile, thinks it only fair that they, with their growing population and underdeveloped economy, can harbor their own share of the Nile's water and power. That leaves Sudan, a country with water needs of its own, caught in the middle. While Sudan usually sides with Egypt on Nile River issues and does indeed agree that the dam breaches Ethiopia's international legal commitments, it does also benefit from the hydropower created by the dam. Therefore, despite its history of conflict with Ethiopia, Sudan has not signed any of Egypt's proposed agreements. While efforts have been made by international committees to solve this dilemma, Ethiopia has so far avoided agreeing to concessions.

Recommendation

Before tensions escalate any further, a neutral power must step in and convince Ethiopia that the GERD is not the best solution to their socio-economic problems. A comprehensive breakdown of the plethora of negative impacts dams have towards the environment, economy, and society should be presented to the Ethiopian government to help them see sense.

While the upstream riparian states must recognize Egypt's vulnerability due to its near total dependence on the Nile River's waters, Egypt must also abandon the idea of its so-called "natural historical rights" to the water. Egypt should also focus more on its diplomatic relations with the other riparian states rather than western entities who intervene on its behalf. On Ethiopia's part, it must cooperate with the other riparian states to develop an effective drought mitigation protocol as well as a dispute resolution mechanism.

The example of the Klamath River dams is a lesson to be learned by all countries who have or plan to construct dams. The common belief that hydroelectric dams are prime sources of clean energy is a misconception; in actuality, they are extremely detrimental to riparian and river ecosystems and exacerbate climate change rather than mitigate it. Additionally, in the long run, they are harmful economically due to maintenance costs and costs to repair damage caused by potential floods which would significantly harm the society living near and relying on the dam. Given Ethiopia's geographic location in a malaria risk zone, the potential increase in malarial cases due to the stagnant water of the dam's reservoir is another harmful factor for the Ethiopian government to consider. While dam demolition would cost tens of millions of dollars, it is nothing when compared to the potential costs that will result from the environmental damage and maintenance that will eventually be required. In the event that demolition is agreed upon, Ethiopia should be partially compensated for this economic loss by Egypt, who has the most to gain from the dam's removal.

Conclusion

Like with all climate related issues, political disputes should take a backseat because the well-being of the planet should be of the utmost importance to us all. While saying to demolish a dam is far easier than actually accomplishing it, it is not a novel idea. Is it truly worth it to keep it running until it destroys the entire river's ecosystem or deteriorates to the point of collapse, causing a devastating flood that kills hundreds and cripples the economy? Let the Nile River run free; it has provided civilization after civilization with fresh water, protect it and it will continue to do so in return. That being said, the Grand Ethiopian Renaissance Dam is not the only dam on the Nile that should be considered for demolition. However, in order to declare more definitively which dams are causing the most detrimental impacts, an in-depth cost-benefit analysis should be made for each dam, starting with Egypt's Aswan High Dam. Additionally, comparing how upstream versus downstream dams effect rivers and the societies relying on them would be extremely useful in determining which dams are most damaging to the Nile, and thus which should be critically assessed for demolition.