https://erjm.journals.ekb.eg
ISSN: 1110-1180

DOI: ---------

ERJ
Engineering Research Journal
Faculty of Engineering
Menoufia University

The Grand Ethiopian Renaissance Dam: Common Interests of Upstream and Downstream Countries

Ali E. Hassaballa

Civil and Architectural Engineering Department, College of Engineering and Computer Science, Jazan University, Jazan 45142, KSA
email: ahassaballa@jazanu.edu.sa

Abstract

The Grand Ethiopian Renaissance Dam (GERD) is a large hydroelectric project located on the Blue Nile River in Ethiopia, about 14 km eastern border with Sudan. It is one of the largest infrastructure projects in Africa, and it has been under construction since 2011. The purpose of the dam construction, as declared by Ethiopia, is to produce electricity. This paper attempts to identify the most significant disputes between upstream and downstream countries regarding the issues related to GERD. Many previous research and studies related to the Renaissance Dam were reviewed regarding its location, design, and method of filling in accordance with the agreements signed between these countries. Through the results of this study, the points of disagreement between the riparian countries were identified, and conclusions were drawn to contribute to developing solutions for the remaining operations of filling and managing the Nile water to benefit all the peoples of the Nile Valley. Furthermore, the study recommends that the riparian countries return to the agreements signed between them to manage the remaining filling operations and the rational management of the Nile water, so that the downstream countries are not harmed.

Keywords: Grand Ethiopian Renaissance Dam; upstream and downstream countries; filling operation; conflict.

1. Introduction

The Grand Ethiopian Renaissance Dam (GERD) is a massive hydroelectric dam on the Blue Nile River in Ethiopia's Benishangul-Gumuz region. GERD aims to boost Ethiopia's energy production and economic development while also serving as a regional power hub. However, it has sparked tensions with downstream countries (Egypt and Sudan) due to concerns over water flow and Nile water rights. The conflict over the GERD between upstream (Ethiopia) and downstream countries mainly revolves around water rights, national security, economic interests and filling and operation of the dam. The main objective of this study is to investigate the nature and causes of the conflict. To fulfil this objective, the study used a methodology including: collecting data from various sources regarding GERD, conducting an extensive literature review, obtaining results and discussion, drawing conclusion and recommendations.

2. Background

The main dam is assigned to be a roller-compacted concrete dam, while the saddle dam is composed of traditional embankment dams. A dam failure might cause a flood surge that is as deep as tens of meters and travels along the river at extremely high speeds [1]. According to this study, which used a one-dimensional analysis model to examine the downstream effects of GERD failure, Sudan, particularly the Roseires, Sennar, Merowe dams and Khartoum City, could suffer catastrophically. According to the research, the failure of the GERD and the subsequent failure of the Sudanese dams could put the Aswan high dam at unnecessary risk [1]. The saddle dam, with a height of 55 m, has a capacity of 60 BCM. The International Commission on Major Dams classified the two GERD components as huge since they were taller than 15 m and once the construction of GERD is finished, it will be the fourth-highest dam in Africa [2].

Although GERD is intended to be used in the hydropower industry, it is anticipated to have several downstream effects, similar to other major dams. As a result, built communities downstream could suffer extremely destructive effects. Generally speaking, Sudanese dams and cities, including Khartoum, located on the banks of Blue Nile will suffer many losses due to flood waves from regular dam breaks. As a result, it is crucial to look into the various what-if possibilities about the dam breaking due to unforeseen events. Mohamed al. [3] conducted a remote sensing analysis of the GERD to evaluate potential risks and environmental impacts. According to the analysis's findings, approximately 667,228 km^2 along the Blue Nile River was the largest region in the Sudanese flooding area that would be in great danger in the event of a GERD flood based on a flood basin model. When the groundwater table drops 5 m below sea level, the findings indicate that seawater intrusions will affect one third of the Nile Delta. Hazem et al. [4] used the GERD failure as a case study in a work on flood propagation modeling. This study recommended using a two-dimensional model under different failure scenarios. The study examined several global dam collapses starting in 1928 for various reasons. According to the study's findings, in certain residential locations, like Khartoum, flow depths might range from 3 to 10 meters in the event of a catastrophic breakdown. In addition, in the event of a dam breach involving a fully stored GERD reservoir, the water surface height in Lake Nasser may rise to 184 meters above mean sea level. Furthermore, the highest flow would surpass 21.5 times the dam spillway total capacity at 325,928 m^3 /sec. Lastly, the article results can help policymakers create other strategies to address the risks associated with GERD break.

A review paper on the main earthquake source elements related to the Ethiopian rift was published by Alemayehu et al. [5]. According to the study, the distribution of earthquakes in the rift floor is linked to strike-slip and normal faulting events. The Danakil microplate's counterclockwise motion may be connected to the strike-slip components observed in the region. However, normal faulting mechanisms are consistent with notable plate divergence. Due to this activity, the Nubian plate and the Danakil microplate may experience oblique-slip deformation. The dangers of flood wave and GERD dam failure for the nations downstream were assessed in a distinct study by Eldeeb et al. [6]. HEC-RAS investigated how a dam failure might affect the nations downstream. The study also subjected the output results to a sensitivity examination against breach parameters. The study concluded that Khartoum would become a lake in approximately ten days and that some residential areas would flood with water deeper than eleven meters.

Additionally, the flood surges crested the Sennar, Merowe, and Roseires dams by 20, 7, and 11 meters, respectively. Furthermore, Lake Nasser's level would rise to 188 meters above sea level, and the Aswan Dam would be in danger. While the event of Mw 5.0 contains a strong component of strike-slip at the center part of the major Ethiopian rift, the focal mechanism for the Mw 5.1 event, calculated from the moment tensor inversion, indicates dominant normal faulting along the western margin of Afar accompanied by a modest strike-slip component. Furthermore, most of the earthquake hypocenters were noticed in the upper crust. For example, moment tensor inversion was used to identify the focus of 9.7 km for the 2017 (Mw 5.0) event. Numerous lower crust earthquakes are also present, such as the 2018 event (Mw 5.1), which AHD a hypocenter of 20.2 km. The discovery in the international database of earthquakes with depths within the upper mantle increased seismic activity along the major Ethiopian rift.

Gala looked into the GERD triggers' susceptibility to seismic hazards [7]. This paper is a response to Egypt's justifiable concerns regarding the claim that GERD causes or exposes seismic hazards. The International Disaster - Emergency Events Database (EM-DAT) of the European Commission served as the basis for this study, which examined the geographical distribution of seismic vulnerability in Ethiopia as well as earthquake occurrences spatial distribution in Ethiopian areas and the Horn of Africa, as well as the spatial distribution of seismic risk and seismic hazard. These findings are displayed in Figures (1-4). The study concluded that the EM-DAT data gathered between 1900 and 2013 was used to assess GERD exposure and triggers to seismic risks and susceptibility. Furthermore, the GERD location is far from any seismically active region in Ethiopia. Furthermore, the dam is not located in seismic danger zones classified as Degree VI, VII, and VII, which are strong, very strong, and destructive, respectively. Lastly, GERD is situated in a region with an extremely low level of vulnerability, despite the fact that 46% of the population of these countries live in moderately sensitive areas of the environment, physical, social, and economic. Mohamed et al. studied potential effects on countries downstream of the Ethiopian Dam failure [8]. The two GERD failure scenarios assumed in the study were miss-guided dam operation due to a misleading flood signature and Dam Break (DB). The study's primary conclusion is that the model's predicted flood peak discharge at Khartoum under the DB scenario would be far higher than the devastating flood of 1946 (10,000 m^3/s at Khartoum). In contrast, the Gezira Plain, which is heavily farmed, would be submerged to an average depth, engulfing more productive farmlands, animals, people, and infrastructure. The Aswan High Dam (AHD) will eventually be approached by flood flows under a miss-guided dam operation situation, which will fill it for two and a half months and require emergency releases for over five months. The consequence would not affect the Gezira Plain. The report concluded that evaluating and modifying the operational parameters for the GERD and the AHD is necessary.

A comprehensive investigation into assessing the vertical movement of the Ethiopian dam during the filling process using DInSAR technology and its potential adverse impacts on neighboring countries was conducted by al-Askary et al. [9]. The approach taken to evaluate the deformation patterns associated with various segments of the Main Dam (an RCC dam construction) and the Saddle Dam (an embankment dam) GERD included the examination of Sentinel-1 satellite images. The researchers employed the Differential Synthetic Aperture Radar Interferometry method to examine 109 descending mode images from Sentinel-1 SAR taken between December 2016 and July 2021. They showcased the deformation patterns of the Main and Saddle Dam of the GERD. From December 2016 to July 2021, 109 descending mode scenes captured by Sentinel-1 SAR images were analyzed employing the Differential Synthetic Aperture Radar Interferometry technique. The goal was to depict the deformation patterns of the Main and Saddle Dams. The findings of the study revealed displacements at the dam's top that were recorded and varied from 10 to 90 mm. Furthermore, it was noted that the Saddle Dam underwent a total displacement of roughly 380 mm (~85 mm/year) during the same timeframe as the Main Dam, which saw a maximum displacement of about 90 mm over the course of the study (~20 mm/year).

Kansara et al. [10] conducted a study to determine how the GERD filling process affected the downstream countries. The study examined the filling process of the dam by analyzing satellite imagery from several sources. In light of the dam's quick filling, this article suggests trilateral strategies for managing the Blue Nile River's flow to ensure fair water allocation to Egypt and Sudan. Furthermore, the study suggests that the relationship between GERD filling and potential drought in the downstream countries should be considered during the upcoming dry spells in the Blue Nile River Basin. Engineering realities should be considered when filling Africa's largest hydropower dam. A paper by Basheer at al. [11] reported the GERD project's beginnings, the water requirements of nations that border rivers, and the discussions between Ethiopia, Sudan, and Egypt on the reservoir's initial filling. This study makes the case that any potential effects of the GERD's engineering limitations should be considered and handled cooperatively. The study focused on Ethiopia's GERD design and construction, which was finished before an agreement was reached with downstream countries Sudan and Egypt about the operation of the long duration of the dam and the filling of the initial reservoir. This investigation improved the everyday model of water balance for GERD. The need for operation and inflow of river to the dam operated as the model's driving forces. Utilizing the river flow record at Eldiem Gage dam, situated close to the Ethiopian-Sudan border, the model produced river flow sequences using the data from 1983 to 2017. The model was used to keep the river diversion outlets closed if the capacity of other dam outlets was sufficient for releases downstream. In Figure 1-B and 1-C), the GERD's outflow activities are depicted. Five distinct types of outlets can release water downstream from the GERD. Along with the percentage contributions of each dam departure, Figures (2-A, 2-C) show the chronological history of the GERD storage outflow. When these limitations are removed, the predicted discharges are calculated, and Figures (2-D and 2-I) show how the hydraulic limits of the GERD affect these discharges.

Chiu [12] suggested collaboration and resolving disputes on the Ethiopian Dam to develop a solution that would meet everyone's demands. A summary of the GERD collaboration problem, previous attempts at reconciliation, the negative effects of non-cooperation, and cooperative recommendations were presented at the outset of this work. Overall, the report argued that cooperation on the GERD would simultaneously foster local and regional economic growth and avert confrontation between Ethiopia, Egypt, and Sudan. Because the dam is being built in a region susceptible to earthquakes and there have been indications of fundamental fractures, Sudan and Egypt, countries that rely significantly on the Nile River for their water needs, are especially worried about the safety and stability of the dam itself. Additionally, water that would have otherwise gone to the AHD reservoir may be stored in the GERD's reservoir, leading to less hydroelectric power generated by the AHD once it is completed [13].

The three nations can ultimately reach a win-win deal to improve the region's general economic well-being, Gross Domestic Product (GDP) per capita, irrigation availability, and industrial development. Ngambouk et al. [14] have reviewed a dispute over the GERD project and the waters of the Nile. Different regions around the basin of the Nile have different demands when it comes to utilizing the Nile waters. There has long been disagreement and conflict between sovereign interests over the best use of the Nile waters. The Nile is important to Egypt, Uganda, South Sudan, Ethiopia, and Sudan. Tanzania, Kenya, Burundi, and Rwanda are considered to have small stakes in the Nile. In contrast, countries such as Eritrea and the Democratic Republic of the Congo are supposed to have negligible ownership [15, 16]. Ethiopia sources 86% of the Nile flow overall [15]. However, nearly the whole Nile flow is under the jurisdiction of Egypt and Sudan. Although Egypt has been using more than 55.5 BCM of the Nile water, the 1959 Nile Agreement only permits Sudan to consume 18.5 BCM.

These disputes resulted from the Nile Colony Treaty [15, 17], which deprived Ethiopia of its socioeconomic development in favor of giving Egypt more authority and exclusive control over the Nile resources. Figure (1) shows the GERD and Nile basin: (A) The Eastern Nile Basin's dams and irrigated land, (B) A general three-dimensional representation of the outflow functions of the GERD. The dashed rectangle represents the low-block spillway, which is gradually constructed and utilized to transfer surplus floodwater throughout the first and second years of reservoir filling. Once the dam is built, the low-block spillway will serve as the emergency spillway and (C) A broad cross-sectional representation of how the GERD outflow functions. Figure (2) illustrates a range of potentially realistic hydrologic scenarios: (A and C) are analyzed to determine the implications of the GERD's outflow capabilities with the first reservoir filling. The continuous line and the stacked areas are represented by vertical axes on the left and right, respectively. (D–F) displays the annual absolute divergence of the outflow from uncontrolled releases. The annual outflow of unrestricted releases is a percentage deviation (G–I) [11].

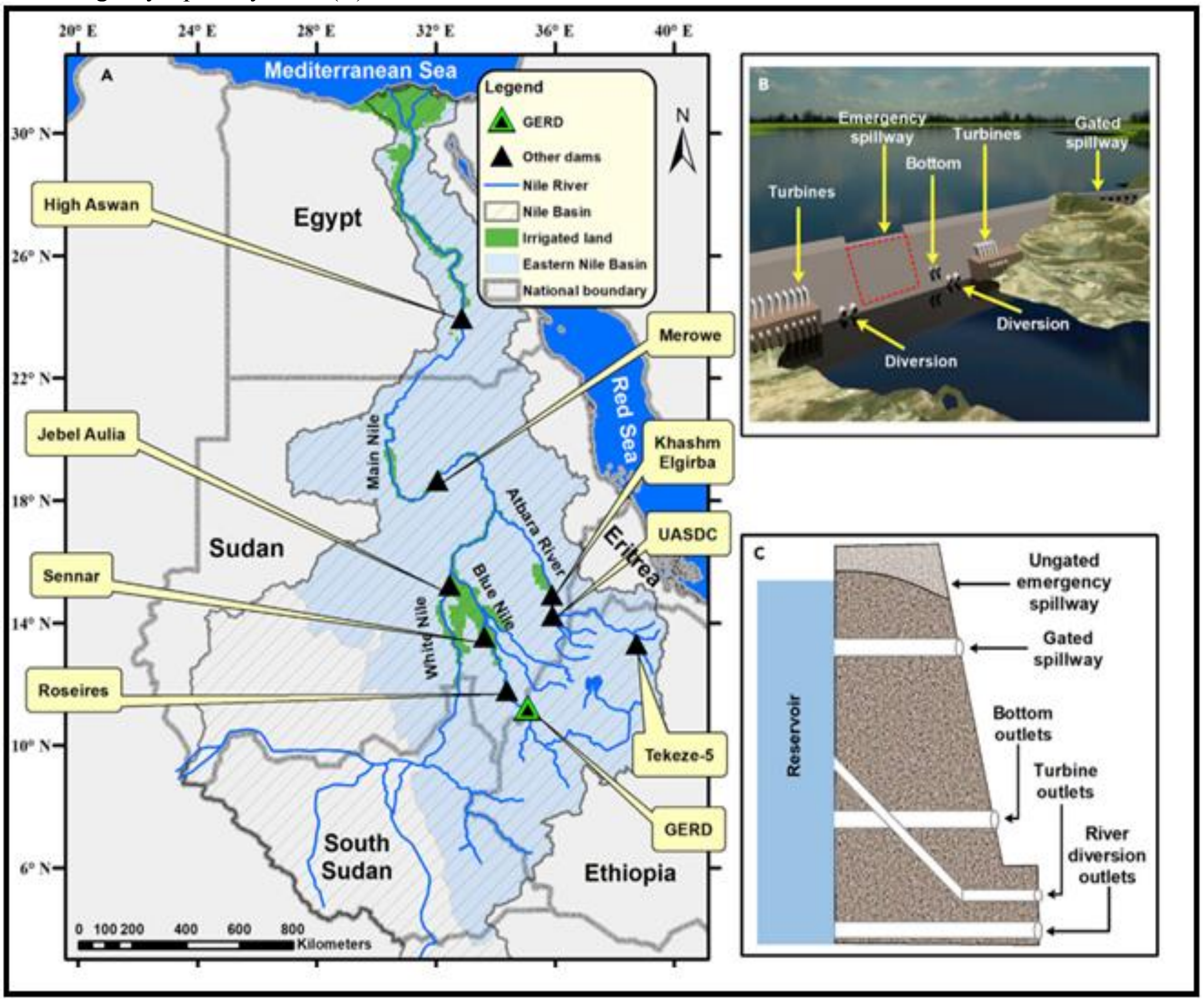

Figure 1-The GERD and the Eastern Nile Basin [11]

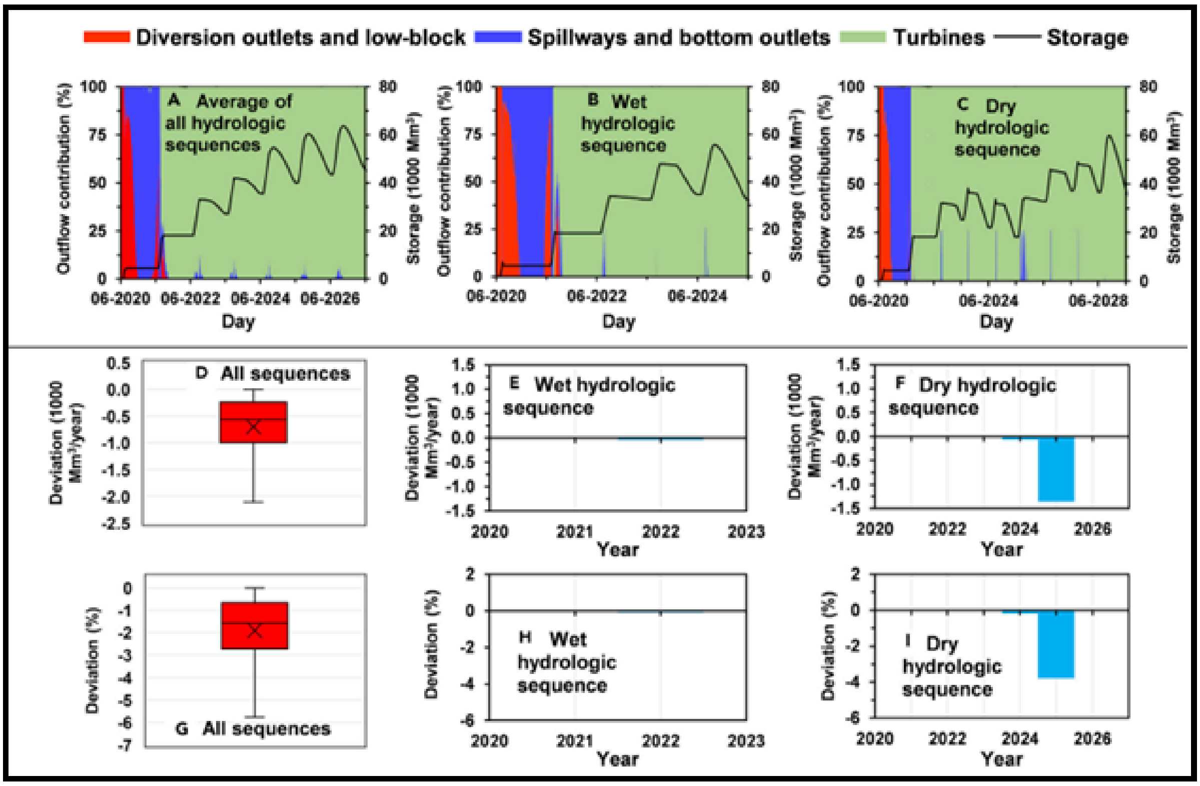

Figure 2-A range of Potentially Realistic Hydrologic Scenarios [11]

3. Ethiopian and Seismic Hazard Assessment

A seismic hazard is the probability that an earthquake will happen in a known location, within a known time duration, and with a higher intensity of ground motion than a specific threshold. Once a hazard has been determined, risk can be evaluated and considered for several purposes, including establishing insurance rates, designing larger buildings and infrastructure projects, and establishing building codes for conventional buildings [18-20]. According to Table (1), which contrasts the available EM-DAT earthquake data for these four nations, Ethiopia has experienced the most earthquakes of any of them, with seven as opposed to two or one for the others. However, the anticipated economic losses from the earthquakes in Somalia and Kenya were larger.By tracing the events that occurred in the Horn of Africa between 1900 and 2010 [21], Figure (3) illustrates the region's seismicity. The red dots indicate the magnitude of an earthquake, with sizes ranging from 3.5 to 7.2. The yellow stars represent Ethiopia's main towns, suggesting that inhabited places are often located near seismic zones.

Table1- Effects of Earthquakes on Human and Economy in African Countries (1900-2013) [19]

Parameter	Country			
	Ethiopia	Kenya	Somalia	Sudan
Number of events	7	2	1	1
Killed	24	1	298	3
Injured	165	0	283	15
Affected	0	0	104800	8000
Homeless	420	0	0	--
Cost, USD	7.07	100	100	--

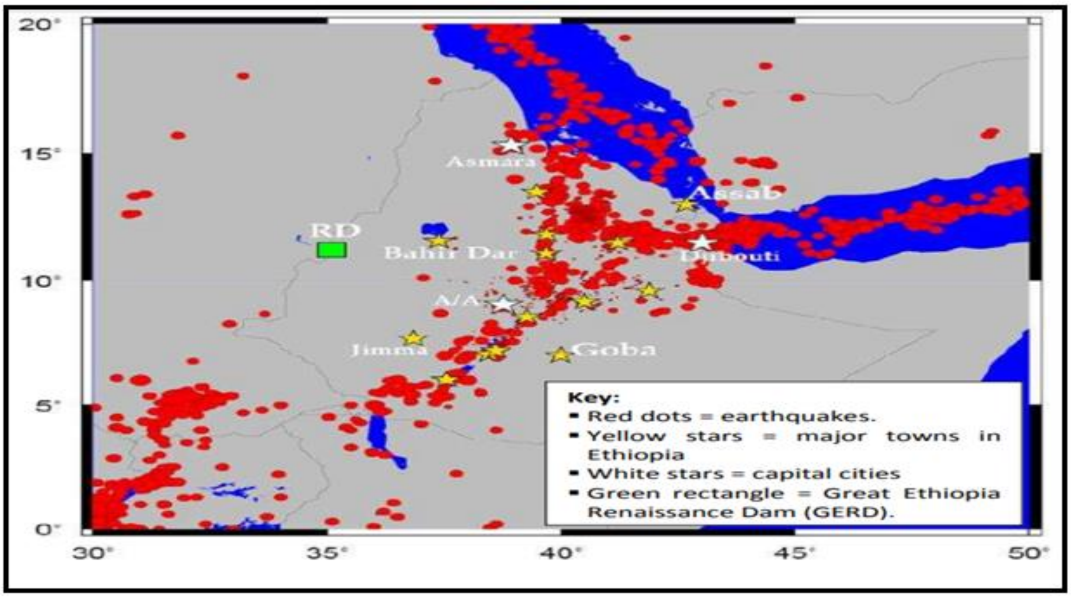

Figure 3- Earthquake Statistics from 1900 to 2010 in the Horn of Africa [21]

The main Ethiopian cities are plotted in Figure (4) based on seismic hazards. Addis Ababa (3 million), Dire Dawa (273,600), and Mek'ele (271,600), three of Ethiopia's most populous cities, are particularly situated in the most seismically hazardous areas, which are marked in yellow in the country's center and are classified as having a medium risk of seismic hazard. Awassa, Dire Dawa, Nazret, and Addis Ababa are all close to important fault lines, including the Wonji, Nazret, Addis-Ambo-Ghedo, and Fil Woha cracks. There have been many earthquakes in the past along these fault lines [20].

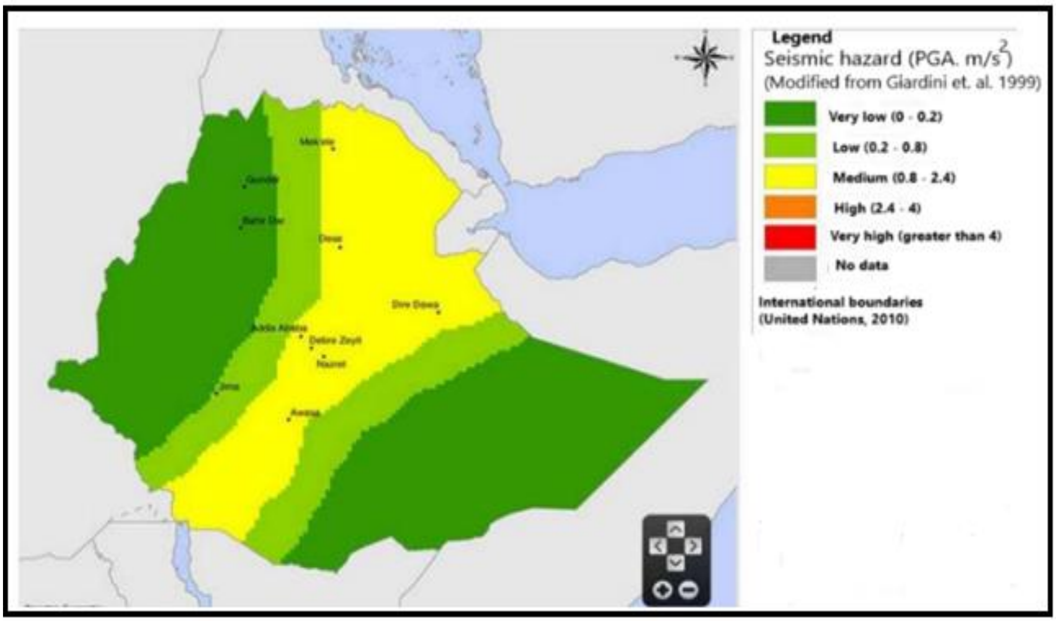

Figure 4- Ethiopia's Seismic Vulnerability's Geographic Distribution

Figure (5) shows the earthquake's magnitude as measured by the scale of the Modified Mercalli [20], which ranges from I to XII. As a result, degree VI, VII, and VIII intensity scales are found in Ethiopia. A magnitude VI earthquake has the potential to topple bookcases, swing hanging objects, and sway trees. Degree VII earthquakes are very strong and might cause a wall to collapse. In contrast, degree VIII earthquakes are destructive, making it impossible to control a moving vehicle, causing concrete to fracture, and damaging poorly constructed buildings. While Degree VII intensities dominate in the middle Ethiopian rift valley region, Degree VI intensities are generally found across Ethiopia. Only the Omo Valley in Ethiopia and the Afar triangle are home to Degree VIII organisms [7].

Figure (6) also displays Ethiopia and its environs' projected regional seismic risk distribution. Ethiopia has a reduced seismic risk compared to other nearby East African nations because South Sudan, Uganda, and Djibouti are comparatively situated in seismic risk hotspots. However, Ethiopia is more vulnerable to seismic hazards than Somalia and Sudan.

Once more, Ethiopia's high-risk area is confined to the Omo Valley's southwest and the Greater Rift Valley Afar triangle. While there is little risk in Ethiopia's eastern and western highlands, there is an average amount of risk in the middle region of the Rift Valley. The GERD dam is the farthest point in Ethiopia from those hotspots; it is located in the west, bordering Sudan [7]. According to Table (2), 26% of Ethiopians are exposed to "very low" levels of seismic hazards, 24% to "low" levels, and 46% to "medium" levels [19].The information source doesn't divide the data according to geography or other factors.

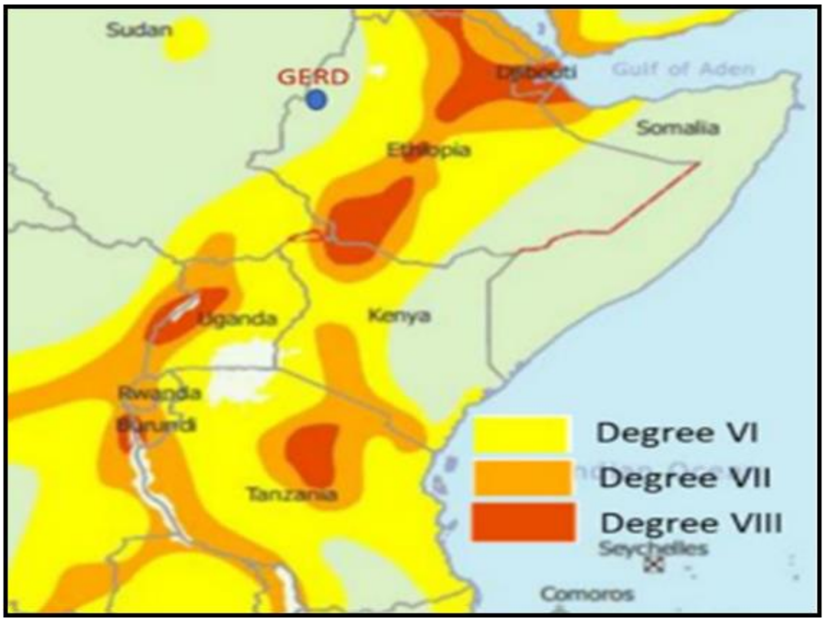

Figure 5- Seismic Hazard for Ethiopia and Neighboring East African Countries

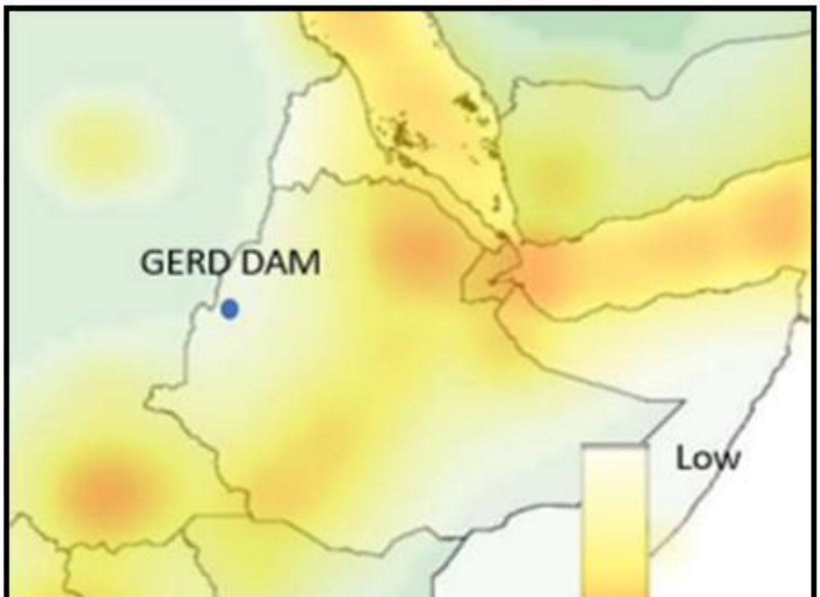

Figure 6- Spatial Pattern of Risk in Ethiopia and Neighboring East African countries

Table 2- Ethiopia's Seismic Hazard Intensity Levels (Associated Population Exposed and Percentage)

Seismic hazard intensity	Population (millions) and percentage
Very high	0
High	0
Medium	39.04 (45.9 %)
Low	20.41 (24.0 %)
Very low	25.53 (30.0 %)
No data available	0

In their review of the multi-criteria seismic hazard analysis of Ethiopia with implications of infrastructure development, Ayele et al. [22] recommend that more attention be paid to local site effects or geology, including dynamic soil properties (shear wave velocity, shear modulus, and standard penetration resistance), site response analysis, liquefaction potential to control seismic hazard, and risk mitigation on Ethiopia. Additionally, data from Ethiopia shows that earthquakes originate on faults; however, it is unclear what kind of faults they are, as well as their quantity, orientation, length, and directivity pulse, and additional multidisciplinary research is required.

The ground motion prediction equation is used to determine route effects. Unfortunately, no work has been published because Ethiopia lacks registered earthquake data. Therefore, using numerical modeling, a ground motion prediction equation must be developed to evaluate path impacts and reduce seismic hazards. Ethiopia is creating an infrastructure, including roads, bridges, power plants, multi-story buildings, railways, and electric power lines. Numerous of these projects cross and are being built in potentially unstable locations in the center of the Ethiopian Main Rift System. According to the report, there is an urgent need to assess the liquefaction potential and earthquake condition in order to create a safe environment for any project constructed in a seismically active area without first conducting an earthquake hazard study.

In their study work, Fentahun et al. [23] discussed the sensitivity evaluation of "Seismic hazard in the Ethiopian Rift, using an integrated method of AHP and DInSAR techniques." Seismic hazard sensitivity maps were produced in this study by combining the Analytical Hierarchy Process (AHP) with differential interferometric Synthetic Aperture Radar (DInSAR) techniques. The study region is located in the center of the Awash River drainage basin in the Main Ethiopian Rift Valley (MERV). It is situated geographically between latitudes 8˚ 45′ 30MN and longitudes 39˚ 25C 16ME and 41˚ 12C 19M E. Six factors, slope, lineament density, soil texture, closeness to previous earthquake epicenters, and distance from the fault, were devised and assessed for the AHP technique in this study. Based on the results of the sensitivity mapping, 8% (561.51 km^2) of the research region was listed as low-risk, 53% (3801.99 km^2) as medium-risk, 35% (2526.04 km^2) as high-risk, and 2% (142.82 km^2) as extremely high. With a maximum uplift of 1.7 mm/year and a maximum subsidence of 9.8 mm/year, a mean annual vertical displacement map was produced using the DInSAR technique instead. The study results indicate that the area under investigation is within a medium seismic hazard sensitivity zone. In a study conducted by Al-Ajameeet al.[24], they used deterministic seismic hazard analysis (DSHA) to investigate the dam. 713 faults were used to analyze the hazards in this study, which used linear sources close to the dam site (both indicated and implied faults). For the region of the dam, data on seismic activities were gathered and homogenized to the magnitude scale moment, and then the events of foreshock and aftershock were de-cluster. On a seismotectonic map, 1375 earthquakes with moment magnitudes between 4 and 7 were considered. Ground Motion Prediction Equations (GMPEs) were found for the dam site. A MATLAB software developed specifically for this purpose was used to conduct DSHA. Next, a grid cell measuring 100 m by 100 m was created from the dam site, and hazard characteristics were determined at the grid cell's midpoint while considering all sources of seismicity situated within a radius of 500 km. The USGS Instrumental Intensity scale was used to compare the acquired PGA values. Lastly, a hazard map illustrates the regional diversity and threats connected with the dam site.

4. Declaration Agreement on Principles Between Upstream and Downstream and Countries

Mindful of the growing demand for transboundary water resources and the role of the Nile as a vital resource for development; the World Bank's attendance demonstrates its previous global financial involvement in formulating river issues and the initiative to sign this agreement. Regarding the GERD, the following are the principles that the three countries pledge to uphold:

- Cooperation Principle.
- The development, sustainability, and regional integration principles.
- Fair and Reasonable Use as a Foundation.
- The Principle of Not Doing Considerable Harm.
- The cooperative plan for the first filling and operation of the dam.
- The Building Trust Principle.
- Information and Data Exchange Principle.
- The Dam Safety Principle.
- The Sovereignty and Territorial Integrity Principle.
- The Peaceful Settlement of Conflicts Principle.

5. GERD Filling Stages

In 2020, the Ethiopian Minister of Irrigation announced that, despite the inability of Ethiopia, Sudan, and Egypt to reach a consensus, the most current satellite photos of the Renaissance Dam were accurate and that 4.9 BM^3 of water had been added to the dam. In August 2020, the water level reached 540 meters, 40 meters above sea level, and 500 meters over the riverbed's bottom [25]. On July, 2021, the second filling phase was finished, and with approximately three billion cubic meters, the water levels increased to about 575 meters [25]. It was estimated that 13.5 BCM of water was filled in the GERD during its second filling cycle.

6. GERD's Effect on Egypt and Sudan

It's unclear exactly how the dam will affect the nations downstream. Egypt is worried that as the reservoir fills, the water it holds can temporarily decrease before vanishing and decreasing permanently. According to the study, the Aswan High Dam's initial reservoir height, rainfall throughout the filling stage, and the negotiated agreement between the three countries will largely decide the impact during this time. These studies also show that in order to reduce or eliminate the possibility of adverse results, significant and continuous cooperation amongst all three nations is required [26]. At 74 cubic kilometers, the reservoir's volume is more than 1.5 times the 49 billion m^3 of Blue Nile that typically flows close to the Egyptian-Sudan border annually. If the governments agree, this damage to the downstream countries could spread over several years. This may impact two million farmers' lives [27]. Additionally, Egypt's electricity supply will be affected by 25 to 40 percent due to GERD, as the sources stated, during dam construction. Yet in 2010, 14 out of 121 billion kWh, or less than 12% of Egypt's electricity generation, came from hydropower. Accordingly, a brief 25% decrease in hydropower output corresponds to a brief reduction of less than 3% in Egypt's total electricity generation [28]. However, Ethiopia's increased storage capacity would provide a stronger safety net against lack in Egypt and Sudan in the case of droughts in the future if these countries can resolve their differences [29]. Silt will be retained in the dam. As a result, many dams in Sudan, including the Sennar, Merowe, and Roseires dams and the High Dam of Aswan in Egypt, will have a longer operational lifespan. The benefits and drawbacks of flood management would impact parts of the Blue Nile basin in Ethiopia and Sudan downstream of the project [29]. By maintaining a reservoir in the narrow gorges of the northern Ethiopian Highlands, the GERD would specifically lessen seasonal flooding in the lowlands surrounding the Roseires Dam reservoir at Ad-Damazin, similar to how the Tekeze Dam lessened flooding at the Khashm el-Girba Dam in Sudan [30]. The temperate Ethiopian Highlands are home to the 140-meter-deep reservoir. The water will evaporate much less than in reservoirs downstream, such as Egypt's Lake Nasser, which loses 12% of its water flow to evaporation after 10 months in the lake. This would allow for a 5% increase in Egypt's water supply and a 5% rise in Sudan's water supply through the controlled downstream flow of water from the lake [31]. According to Odidi et al. [32], the availability of reasonably priced energy, flood management, decreased siltation, and a rise in irrigated farming.

Danburam et al. [33] revealed that if the riparian countries collaborate on irrigation and cropping patterns, this will enhance irrigation and contribute to an increase in GDP of these countries. But, the study indicates that these benefits won't materialize until the dam becomes fully operational. Many Sudanese researchers and politicians confirm, through discussions, workshops, and questionnaires, that the GERD affect the Sudanese dams and irrigation systems.There may be harmony and agreement between the official positions of Sudan and Egypt regarding the Renaissance Dam. Additionally, various studies have assessed the effects of dam failure on the Sudanese dams and environment. Tesfa [34] evaluated GERD failure through a pipe failure process using a 1-D HEC-RAS model. At the whole reservoir level of 640 ASL, the GERD storage capacity is 74 BCM [35 and 36]. Due to the relatively flat terrain of the dam site, the saddle dam aids in maintaining the water level and design storage for the gravity dam built across the Blue Nile. The main dam's design discharge is 4305 m^3/s [37]. Water flow to Sudanese dams will be impacted by GERD [37 and 38], and Aswan High Dam [39-41]. According to Kandeel [42] the GERD issues between riparian nations intensified when Ethiopia started construction in 2011 without notifying Egypt or Sudan.

The total length of the Nile River is about 6700 km, Abtew et al. [43], and it covers more than 3.18 million km^2 of Eastern Africa [44]. Based on Gebreluel [45], GERD will be the most hydropower project in African countries. The 2015 Declaration of Agreements, which the three countries have attached as a reference document and which forms the basis for discussions addressing the dams' initial filling and yearly operation, is also used by Sudan and Egypt to present their perspectives, El Tawil [46]. Sudan claims that the levels of water of the Nile in the Ethiopian-born Blue Nile River have dropped by 90 million cubic meters daily, Abdelaziz et al. [47]. As Africa's largest hydroelectric power plant, the GERD's 6,450 MW rating will suitably outperform the Egyptian AHD's 2,100MW rating in terms of energy production. Perceived as "a national project," the GERD project gets a portion of Ethiopian government employees' wages, Hicks [48]. Ethiopia's energy capacity is 3,200 MW. However, its annual per capita power usage is among the lowest in the world—65 kWh in 2013—much lower than the global average of 3,104 kWh and the typical of 488 kWh for sub-Saharan African states, Kimagai [49]. GERD will also contribute significantly to water conservation because Ethiopia Highland has a lower rate of evaporation, El-Nashar et al. [50]. The annual water requirements for Egypt are approximately 120 BCM, according to Mahmoud [51]. When the GERD operates at full capacity, its hydropower is assumed to generate nearly $1 billion annually, Lashitew et al. [52]. For example, two years ago, Egypt reduced the amount of land used to produce rice by more than 50%, from 1.76 m to 750,000 acres, to conserve 3 BCM of water volume. Egypt has warned that filling the reservoir will increase tensions and may lead to a disruptive regional conflict [53].

7. Results and Discussion

Based on previous studies and agreements concluded on the Nile waters between the riparian countries, the results of this study show that the Grand Ethiopian Renaissance Dam represents a source of regional tension between Ethiopia on the one hand and Egypt and Sudan on the other. Tensions have arisen between the three nations surrounding the Ethiopian Dam due to worries about the management of the resources of water and possible effects on the downstream countries, especially Sudan and Egypt, which heavily depend on the supplies of Nile water. Ethiopia, Sudan, and Egypt have engaged in talks and negotiations on the building and managing of the Ethiopian dam. The possible influence on downstream water flow, agriculture, and other parts of the Nile River's ecosystem has been exciting. Politicians, diplomats, and specialists in various disciplines, such as hydrology, engineering, and international law, have participated in these talks. Among other parties, the European Union, the African Union and the United States have mediated the ongoing negotiations. However, because the parties concerned have different interests and concerns, it has not been easy to agree. The discussions during the negotiations have included the dam's operation and filling, how water will be distributed during dry spells, how to resolve disputes, and the project's overall effect on countries downstream. However, no definitive agreement that pleased all parties concerned had been reached. This work and a review of previous studies clarified that the countries upstream and downstream of the dam disagree on some issues, including the design, construction, filling stages, and geological seismic examinations of the Renaissance Dam.

Researchers from Ethiopia and other countries maintain that the Renaissance Dam was planned per international dam building guidelines and that earlier studies on seismic hazards and geological assessments were carried out. The main point of contention between these countries is how to fill the Renaissance Dam. Ethiopia has filled the dam on its own initiative, claiming that the technique does not substantially lower water flow downstream. Rapid GERD filling raises concerns among Egyptian officials that it may cut off water flow to Egypt, impacting drinking water, agriculture, and the Aswan High Dam's ability to generate electricity. Sudan, on the other hand, is concerned that mishandled dam filling and operation would interfere with its own dams and water supplies, harming infrastructure and agriculture. But in order to ensure that Ethiopia coordinates GERD operations with downstream nations to ensure minimum water flow and avert possible water shortages, Egypt and Sudan also want a legally mandated framework.

8. Conclusions

The dispute between the riparian countries (Ethiopia, Sudan, and Egypt) on Ethiopia's construction and filling operations is complicated and calls for a multipronged strategy to be resolved. The study's findings, which highlight the primary disputes between these riparian countries over the Ethiopian dam, are as follows:

1. Downstream countries are concerned that the construction and operation of the project may restrict their access to Nile water, which they heavily rely on for agriculture, drinking water,

and other purposes. They worry that Ethiopia's power to control the flow of the Nile could jeopardize their access to water.

2. Ethiopia views the GERD as an essential national development program to boost supply power and economic prosperity. However, countries downstream regard Ethiopia's influence over the flow of the Nile as one that might give Ethiopia greater leverage in negotiations and control over shared water resources.
3. Despite ongoing discussions and attempts to negotiate a trilateral agreement between Ethiopia, Sudan, and Egypt, no complete deal that considers the interests and concerns of all sides has been reached. There are still issues on how to run and fill the dam, how to divide water in times of drought, how to settle disputes, and how to regulate the flows of the Nile over an extended period.
4. The possible impacts of the dam on the environment and society, which could include changed river flow patterns, sedimentation downstream, decreased biodiversity, and community uprooting, are another concern for the countries downstream. They argue that these consequences should be appropriately assessed and mitigated before the dam is operated.
5. The GERD debate could increase regional tensions and damage relations among the countries involved. It might also worsen already-existing conflicts and increase instability in the Horn of Africa.
6. Ethiopia and Egypt argue about where the Renaissance Dam should have been built. Experts from Ethiopia claim that seismic activity occurs in Ethiopia and many other countries in the East African Rift region due to tectonic factors related to the rifting process. In contrast to different places in the world, the seismicity in the area of the GERD site is generally considered low to moderate.

This study recommends that the concerned countries return to the agreements signed between them to manage the remaining filling operations, as well as the rational management of the waters of the Nile so that the downstream countries are not harmed. These countries should focus on the following aspects regarding the GERD: Negotiation and Diplomacy, International Mediation, Joint Technical Committees, Information Sharing and Transparency, Legal Framework, Compromise and Flexibility, Regional Cooperation, Investment in Alternative Solutions, Long-Term Planning, Public Engagement and Awareness, etc. By combining these approaches and fostering a spirit of cooperation and mutual respect, a resolution to the conflict surrounding GERD that meets the needs and concerns of all parties involved may be possible.

9. References

[1] Soliman, H. Bekhit, K. Ahmed and A. Elzawahry. "Impact of Grand Ethiopian Renaissance Dam Failure on Downstream Region", Journal of Engineering and Applied Science, Faculty of Engineering, Cairo University, Vol. 61, No. 4, PP. 371-389. Aug. 2014.

[2] Ahmed H. Soliman, Alaa El Zawahry, HeshamBekhit. "GERD Failure Analysis and the Impacts on Downstream Countries", The Handbook of Environmental Chemistry Grand Ethiopian Renaissance Dam Versus Aswan High Dam, p. 149-171.Springer International Publishing, 2017.
DOI: 10.1007/698_2017_135.

[3] Mohamed Mostafa Mohamed &Samy Ismail Elmahdy,"Remote sensing of the Grand Ethiopian Renaissance Dam: a hazard and environmental impacts assessment", 'Geomatics, Natural Hazards and Risk Geomatics, Natural Hazards and Risk", 8:2, 1225-1240, 2017,
DOI: 10.1080/19475705.2017.1309463. ISSN: 1947-5705 (Print) 1947-5713 (Online) Journal: https://www.tandfonline.com/loi/tgnh20.

[4] Hazem Eldeeb, Magdy H. Mowafy, Mohamed N. Salem, Ali Ibrahim, ((28 March 2023). "Flood propagation modeling": Case study "the Grand Ethiopian Renaissance dam failure". Alexandria University Alexandria Engineering Journal. 71, 227-237, March 28, 2023.

[5] Sisay Alemayehu and Jima Asefa,"A Review of Earthquake Source Parameters in the Main Ethiopian Rift", Hindawi: International Journal of Geophysics Volume 2023, Article ID 8368175, 14 pages, 2023.
https://doi.org/10.1155/2023/8368175.

[6] Hazem M. Eldeeb, Ali Ibrahim, Magdy H. Mowafy, Martina Zeleˇnáková, Hany F. Abd-Elhamid, Katarzyna Pietrucha-Urbanik and Mahmoud T. Ghonim, "Assessment of Dams' Failure and Flood Wave Hazards on the Downstream Countries", A Case Study of the Grand Ethiopian Renaissance Dam (GERD)", MDPI Journal, Water 2023, 15, 1609. https://doi.org/10.3390/w15081609.

[7] Tekleab S. Gala,"The Exposure of Triggers of Grand Ethiopian Renaissance Dam (GERD) to Seismic Hazards and Vulnerability", GERD Newsletter, Winter Issue 1 (1), 2022, DOI:10.13140/RG.2.2.22379.82724.

[8] Mohamed Rami Mahmoud, Hussam Fahmy and Luis A. Garcia, "Potential impacts of failure of the Grand Ethiopian Renaissance Dam on downstream countries", Journal of Flood Risk Management,15: e12793, 2022, DOI: 10.1111/jfr3.12793.

[9] Hesham al-Askary, Amr Fawzy, Rejoice Thomas, Wenzhao Li, Nicholas Lahaye, Erik Linstead, Thomas Piechota, Daniele Struppa and Mohamed Abdelaty Sayed, '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), 2021, 4287; https://doi.org/10.3390/rs13214287.

[10] Prakrut Kansara, Wenzhao Li, Hesham El-Askary, Venkataraman Lakshmi, Thomas Piechota, Daniele Struppa and Mohamed Abdelaty Sayed,"An assessment of the filling process of the Grand Ethiopian Renaissance dam and its impact on the downstream countries", Remote Sensing, 2021, 13(4), 711; https://doi.org/10.3390/rs13040711

[11] Mohammed Basheer, Kevin G. Wheeler, Nadir A. Elagib, Mikiyas Etichia, Edith A. Zagona, Gamal M. Abdo, and Julien J. Harou, "Filling Africa's Largest Hydropower Dam Should Consider Engineering Realities", One Earth, Volume 3, Issue 3,Pages 277-281, 2020, https://doi.org/10.1016/j.oneear.2020.08.015.

[12] ETHAN CHIU, "The Grand Ethiopian Renaissance Dam": "Cooperation and Conflict Resolution", E-International Relations, ISSN 2053-8626, 2023. https://www.e-ir.info/2023/03/26/the-grand-ethiopian-renaissance-dam-cooperation-and-conflict-resolution/.

[13] Mohammed Basheer, Victor Nechifor, Alvaro Calzadilla, Khalid Siddig, Mikiyas Etichia, Dale Whittington, David Hulme and Julien J. Harou, "Collaborative management of the Grand Ethiopian Renaissance Dam increases economic benefits and resilience,2021, Nature Communications, 12:5622 https://doi.org/10.1038/s41467-021-25877-w.www.nature.com/naturecommunications.

[14] Ngambouk Vitalis Pemunta, Ngo Valery Ngo, Choumbou Raoul FaniDjomo, Sianga Mutola, Judith AchinSeember, Grace Annih Mbong and Enjeckayang Asomanei Forkim, (2021). "The Grand Ethiopian Renaissance Dam, Egyptian National Security, and human and food security in the Nile River Basin", Cogent Social Sciences, ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oass20, 2021, https://doi.org/10.1080/23311886.2021.1875598.

[15] Salman, S. M. A.,"The Nile Basin cooperative framework agreement": A peacefully unfolding African spring? Water International, 38(1), 17–29. 2013, https://doi.org/10.1080/02508060.2013.744273.

[16] Yihdego, Z., Rieu-Clarke, A., &Cascao, A. E. "How has the Grand Ethiopian Renaissance Dam changed the legal, political, economic and scientific dynamics in the Nile Basin?" Water International, 41(4), 503–511. 2016, https://doi.org/10.1080/02508060.2016.1209008.

[17] Swain, A., "Challenges for water sharing in the Nile basin": Changing geo-politics and changing climate", Hydrological Sciences Journal, 56(4), 2011, 687–702. https://doi.org/10.1080/02626667.2011.577037.

[18] Baker, Jack; Bradley, Brendon; Stafford, Peter, Seismic Hazard and Risk Analysis. Cambridge University Press. ISBN 9781108425056. Retrieved January 14, 2021.

[19] Siân Herbert, "Assessing seismic risk in Ethiopia", GSDRC Helpdesk Research Report, 2013, www.gsdrc.org, helpdesk@gsdrc.org.

[20] Kinde, S., "Earthquake Risks in Addis Ababa and other Major Ethiopian Cities - Will the Country be Caught Off-guarded?" Media ETHIOPIA. 2002, http://www.mediaethiopia.com/Engineering/EarthquakeHazard_ET.htm.

[21] Ayele, A., "Earthquake hazard and risk in Africa: assessment and mitigation needs", Presentation. Cape Town, South Africa. http://www.understandrisk.org/sites/default/files/files/useruploads/1.ur2012_session_4-ayele.pdf.

[22] Alemayehu Ayele, Kifle Woldearegay and Matebie Meten,"A review on the multi-criteria seismic hazard analysis of Ethiopia: with implications of infrastructural development", Geoenvironmental Disasters, Geo-environmental Disasters 8:9, 2021, https://doi.org/10.1186/s40677-020-00175-7.

[23] Tewabe Melkamu Fentahun, Murugesan, Bagyaraj, Melkamu Adimaw Melesse, Tesfaye korme, 'Seismic hazard sensitivity assessment in the Ethiopian Rift, using an integrated approach of AHP and DInSAR methods". The Egyptian Journal of Remote Sensing and Space Sciences Vol. 24, Issue 3, 735–744. 2021, https://doi.org/10.1016/j.ejrs.2021.05.001. Journal homepage: www.sciencedirect.com.

[24] Mohammed Al-Ajamee, Abhishek Babooand SreevalsaKolathayar,"Deterministic Seismic Hazard Analysis of Grand Ethiopia Renaissance Dam (GERD)", Proceedings of the 4th International Conference on Performance Based Design in Earthquake Geotechnical Engineering, Beijing,(pp.1903-1913), 2022. DOI:10.1007/978-3-031-11898-2_174.

[25] Rasha M. Abou Samra and R.R. Ali, "Detection of the filling phases of the Grand Ethiopian Renaissance dam using sentinel-1 SAR data". The Egyptian Journal of Remote Sensing and Space Sciences. Volume 24, Issue 3, Part 2, December 2021, Pages 991-997. DOI: 10.1016/j.ejrs.2021.11.006

[26] Wheeler, Kevin G.; Basheer, Mohammed; Mekonnen, Zelalem T.; Eltoum, Sami O.; Mersha, Azeb; Abdo, Gamal M.; Zagona, Edith A.; Hall, Jim W.; Dadson, Simon J., "Cooperative filling approaches for the Grand Ethiopian Renaissance Dam", Water International. 41 (4):611–634,2016. DOI:10.1080/02508060.2016.1177698.

[27] Elsayed, Hamdy; Djordjević, Slobodan; Savić, Dragan A.; Tsoukalas, Ioannis; Makropoulos, Christos, "The Nile Water-Food-Energy Nexus under Uncertainty": Impacts of the Grand Ethiopian Renaissance Dam. Journal of Water Resources Planning and Management. 146 (11),2020, doi:10.1061/1943-5452.0001285.

[28] "Egypt Overview", US Energy Information Administration, 18 July 2012. Retrieved 13 July 2013.

[29] Elsayed, Hamdy; Djordjevic, Slobodan; Savic, Dragan; Tsoukalas, Ioannis; Makropoulos, Christos, "Water-food-energy nexus for transboundary cooperation in Eastern Africa", Water Supply, 22 (4): 3567–3587, 2022, doi:10.2166/ws.2022.001. hdl:10871/128579.

[30] Wheeler, Kevin G.; Jeuland, Marc; Hall, Jim W.; Zagona, Edith; Whittington, Dale (December 2020), "Understanding and managing new risks on the Nile with the Grand Ethiopian Renaissance Dam", Nature Communications. 11 (1): 2020.

[31] Salem, Mahmoud, "Regarding the Dam", Daily News Egypt, June 3, 2013, Retrieved 3 March 2014.

[32] Sylvan Odidi, Rodgers Ombeck Oyoo, "Hydropolitics of the Grand Ethiopian Renaissance Dam (GERD): Appraising the Socio-Economic and Security Implications", International Journal of Scientific and Research Publications, Volume 11, Issue 10, ISSN 2250-3153, October 2021, DOI: 10.29322/IJSRP.11.10. 2021.p11853.

[33] Ahmed Danburam and Julien Briollais "GERD, a Path, or Hindrance toward SDG 6.5 in the Nile River Basin", Environmental Science proceedings, 9th International Conference on Sustainable Development, Virtual, (20–21 September 2021.

[34] Tesfa-Alem Tekle,"Sudan's Bashir supports Ethiopia's Nile dam project", Sudan Tribune, March 8, 2012, retrieved on April 12, 2013 Archived December 30, 2016 on Wayback Machine.

[35] Ali, H.A.N.; El-Moustafa, A.M.; Gad, M.A.E.-H., "Hydrodynamic Modeling of Flood Wave Propagation in Major Rivers due to Dam Failures", Case Study: "The Grand Ethiopian Renaissance Dam (GERD) on Nile River", Available online: http://azharcermjournal.com/CERMF1707/P17-07-07.pdf (accessed on 1 April 2023).

[36] Ahmed, A.T.; Elsanabary, M.H. "Environmental and hydrological impacts of grand Ethiopian Renaissance Dam on the Nile River", Int. Water Technology,260–271, 2015.

[37] Abtew,W.; Dessu, S.B.,"The Grand Ethiopian Renaissance Dam on the Blue Nile", Springer: Berlin/Heidelberg, Germany, 2019.

[38] Hassaballah, K.; Jonoski, A.; Popescu, I.; Solomatine, D. "Model-based optimization of downstream impact during filling of a new reservoir: Case study of Mandaya/Roseires Reservoirs on the Blue Nile River", Water Resour. Manag., 26, 273–293, 2012.

[39] Shahin, M. "Hydrology and Water Resources of Africa", Springer Science & Business Media: Davis, CA, USA, Volume 41, 2006.

[40] Hafsaas-Tsakos, H. "Ethical implications of salvage archaeology and dam building: The clash between archaeologists and local people in Dar al-Manasir", Sudan. J. Soc. Archaeol. 11, 49–76, 2011.

[41] Bosshard, P. "China's role in financing African infrastructure",Int. Rivers Netw, 14, 1–2, 2007.

[42] Kandeel, A.,"Nile Basin's GERD dispute creates risks for Egypt, Sudan, and beyond", 2020. https://www.atlanticcouncil.org/blogs/menasource/nile-basins-gerd-dispute-creates-risks-for-egypt-sudan-and-beyond/.

[43] Abtew, W., &Dessu, S. B., "The Grand Ethiopian Renaissance Dam on the Blue Nile": Springer, 2019.

[44] Mohamed, N. N., "Nile River Biography and its Journey from Origin to End", The Nile River (pp. 1-32), Springer, 2016.

[45] Gebreluel, G., "Ethiopia's Grand Renaissance Dam: ending Africa's oldest geopolitical rivalry?", The Washington Quarterly, 37(2), 25-37, 2014.

[46] ElTawil, N., "Declaration of Principles on Renaissance Dam is 'exclusive agreement' binding Egypt, Ethiopia, Sudan together": intl. law expert, 2020, Egypt Today Retrieved from https://www.egypttoday.com/Article/1/88909/Declaration-of-Principles-on-Renaissance-Dam-is-exclusive-agreement-binding.

[47] Abdelaziz, K &Awadalla, N. "Sudan says Nile water levels fall after Ethiopia starts giant dam", 2020, Reuters Retrieved from https://www.reuters.com/article/us-ethiopia-dam-sudan-idUSKCN24G2CS.

[48] Hicks, S., "The Grand Ethiopian Renaissance Dam": Power Dynamics in the Nile River Basin, 2017, Retrieved from https://www.americansecurityproject.org/the-grand-ethiopian-renaissance-dam-power-dynamics-in-the-nile-river-basin/.

[49] Kimagai, J., "The Grand Ethiopian renaissance dam gets set to open". IEEE spectrum. 2016, https://spectrum. ieee. org/energy/policy/the-grand-ethiopian-renaissance-dam-gets-set-to-open.

[50] El-Nashar, W. Y. & Elyamany, A. H.,"Managing risks of the Grand Ethiopian renaissance dam on Egypt", Ain Shams Engineering Journal, 9(4), 2383-2388, 2018.

[51] Mahmoud, M., "Egypt and Ethiopia": Fears of Drought and Dreams of Development Atlantic Council, 2016, Retrieved from https://www.atlanticcouncil.org/blogs/menasource/egypt-and-ethiopia-fears-of-drought-and-dreams-of-development/.

[52] Lashitew, A., &Kassa, H., "Of regional destabilization How can the friction between Egypt and Ethiopia over the GERD be resolved?", Africa Business, 2020, Retrieved from https://african.business/2020/05/economy/ethiopias-blue-nile-dam-is-an-opportunity-for-regional-collaboration/.

[53] Bearak, M., &Raghavan, S., "Africa's largest dam powers dream of prosperity in Ethiopia — and fears of hunger in Egypt", Washington Post, 2020, Retrieved from: https://www.washingtonpost.com/world/interactive/2020/grand-ethiopian-renaissance-dam-egypt-nile/