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Ethiopia's Renaissance Dam: A Geohazard Assessment

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The Ethiopian government's announced construction of the Renaissance dam, the largest dam in Africa, with a reservoir that can hold up to 74 billion cubic meters, has provoked many questions about the dam's safety. Ongoing political instability in Ethiopia, in addition to other issues, has led several Sudanese authorities, including the Sudanese Prime Minister Abdalla Hamdok, to raise growing concerns that the Renaissance Dam threatens the safety of half of the Sudanese population[1]. This is because the vast number of highly populated Sundanese cities, including the capital city Khartoum, are located along the Nile River and its tributaries.

Although dam safety was stipulated the Declaration of Principles signed by Egypt, Sudan and Ethiopia in Khartoum in 2015, it has received much less attention than necessary in the ongoing dam negotiation between the three countries[2]. In this article I will address the dam safety question from the perspective of seismic hazards and provide suggestions toward resolving the gridlock in dam negotiations.

According to a technical study published by the US Bureau of Reclamation in 1984 on dams and public safety, the existence of a dam is often significantly affected by natural forces, such as unexpected floods, landslides, earthquakes, and deterioration of the heterogeneous foundation and construction materials[3]. Another study released by the same agency in 2005, suggested that dam safety is no longer regarded as an engineering matter focusing only on appropriate design and construction[4]. Despite the vital necessity of dam safety in the proper design and construction, catastrophic dam failures can be caused by other factors such as floods, unknown geological conditions, water leaks in foundations and embankments, defects in design and construction, and soil liquefication resulting from earthquakes.

Seismicity related to dam reservoirs is a well-known phenomenon. It was observed in the Koyna Dam in India, the Kremasta Dam in Greece, the Kariba Dam in Zambia, the Aswan High Dam in Egypt, and the Hsinfengkiang Dam in China. The seismicity around a revisor dam occurs due to elements such as, chemical alterations that weaken rock strength, increase of pore pressures due to water leakage that decrease normal stresses, seepage of water into the dam foundation can initiate release of cumulative tectonic strain, the reservoir weight on the crust, and decline in the frictional forces due to a change in pore pressure in rock layers beneath the reservoir. This decline in frictional forces allows rocks to slip and causing earthquakes[5]. These elements keep interacting with each other until the water reservoir and crust reach a state of equilibrium.

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1 "Ethiopia dam threatens safety of half of Sudan's population," *Middle East Monitor*, 6/5/2021, accessed on 10/6/2021, at: https://bit.ly/3pEaw1f

2 Noha El Tawil, "Declaration of Principles on Renaissance Dam is 'exclusive agreement' binding Egypt, Ethiopia, Sudan together: intl. law expert," *Egypt Today*, 23/6/2020, accessed on 10/6/2021, at: https://bit.ly/3zgUJtJ

3 Robert B Jansen, *Dams and Public Safety: A Water Resources Technical Publication* (Washington: United States Department of the Interior, 1980).

4 David P. Billington, Donald C. Jackson & Martin V. Melosi, *The History of Large Federal Dams: Planning, Design, and Construction in the Era of Big Dams* (Denver: Colorado: U.S. Department of the Interior Bureau of Reclamation, 2005)

5 Jansen.

In May 2008, the world witnessed a devastating earthquake in the Sichuan Province, China. That earthquake left 80,000 people dead or unaccounted for[6]. Geologists in the US and China attributed the event to the four-year-old Zipingpu Dam reservoir that was built near an active seismic zone. The water seepage from the dam reservoir into the crust caused the lubrication of subsurface faults, which triggered this deadly event, along with the weight of the dam reservoir on the crust beneath the area.

The Zipingpu Dam reservoir holds 1.2 billion cubic meters, while the Renaissance dam is proposed to have a reservoir holding 74 billion cubic meters. The same geological conditions that contributed to the 2008 earthquake in China are present in the Blue Nile River Basin, including seismicity, joints, faults, and water leakage from the huge dam reservoir.

Ethiopia is the most active tectonic region in the world, where rifting is taking place and the Nubian Plate, the Arabian Plate, and the Somali Plate are all moving away from each other [7]. In addition, the crust beneath the region is transitioning from thick continental crust (average 40 km) to much thinner oceanic crust (average 6 km). There are also two plateaus, the Eastern and Western Plateaus, where the Renaissance dam is located.

The tectonic activity is often manifested by earthquakes. Thus, Ethiopia has been experiencing numerous earthquake events annually. A recent earthquake catalogue compiled by a group of researchers revealed that a total of 7000 events occurred in Ethiopia and adjacent areas between 1900-2016[8]. Moreover, The US Bureau of Reclamation was the first institution to conduct a comprehensive study on the Blue Nile River Basin in Ethiopia between 1958 and 1964, subsequently releasing a report suggesting that "*the Blue Nile River Basin is an earthquake area, and this fact must be considered in the design of engineering work.*" The Renaissance dam is located in the Blue Nile River Basin. Therefore, it is within this active seismic area.

In addition, the aforementioned earthquake catalogue indicated that several events occurred in the Blue Nile River Basin area confirming the US Bureau's findings. However, the absence of detailed seismicity monitoring using advanced sensitive instruments in the Blue Nile River Basin area in Ethiopia has led to a false belief in a lack of earthquake activity in the Renaissance Dam area. Other misinformation spread on social media platforms, sometimes by Sudanese authorities, is that the Renaissance Dam is far from the main Ethiopian rift, the Afar Triangle, and volcanic areas.

However, from a tectonic point of view, the area stretching from northern Eretria to Lake Malawi and Mozambique is called the East African Rift System[9]. This area includes the western Ethiopian

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6 Sharon LaFraniere, "Possible Link Between Dam and China Quake," *The New York Times*, 5/2/2009, accessed on 10/6/2021, at: https://nyti.ms/3xaPU3s

7 Erik Klemetti, "Are We Seeing a New Ocean Starting to Form in Africa?" *Eos*, 8/5/2020, accessed on 10/6/2021, at: https://bit.ly/2REDT78

8 Geremew Lamessa, Tilahun Mammo & Tarun K.Raghuvanshi, "Homogenized earthquake catalog and b-value mapping for Ethiopia and its adjoining regions," *Geoenvironmental Disasters*, vol. 6, no. 16 (2019).

9 James Wood & Alex Guth, "East Africa's Great Rift Valley: A Complex Rift System," Ge*ology and Earth Science*, 3/1/2021, accessed on 10/6/2021, at: https://bit.ly/3g9M4Sw

Plateau where the Blue Nile Basin is located. The East African Rift System is an area characterized with brittle faulting, volcanic activities and earthquakes. In addition, several studies indicate the existence of fractures in the dam reservoir area[10].

Therefore, the idea that there are no faults or any types of fractures in the vicinity of the Renaissance Dam is pretty much untrue. The documented seismicity in the Blue Nile River Basin, crustal faulting and the anticipated seismicity as a result of the dam reservoir should raise concerns about dam stability. This issue of dam stability has to be one of the central matters in the discussion of the dam among the three countries.

In 1981, a 5.2-magnitude earthquake occurred beneath the Aswan High Dam reservoir. Moreover, The Aswan Dam reservoir area has experienced a higher than anticipated rate of seismicity with an average of 273 earthquakes per year. That is because the crust beneath the Aswan Dam is very stable and thick, which is characterized by low seismic activity[11]. In contrast, the crust beneath the Renaissance dam is thinner and active. The latter explains the seismic vulnerability of the Renaissance Dam as compared to the Aswan High Dam.

According to a report released in 2020 by the Sudanese Geological Research Authority, the number of earthquakes in the Merowe dam area, Sudan, has increased dramatically over the past few years. Between 2004 and 2006, before building the Merowe dam, there were only two events of magnitude less than three. Since 2011, when the Merowe dam was completed, at least twenty-two events of magnitude greater than 4.4 have occurred between 2017 and 2018. The rate peaked in 2017 with 62 events. Regardless of significant data recorded by the seismic stations located in the Merowe dam, I suspect that the seismic station suffered from lack of continuous events recording, which resulted in a smaller number of events.

Landslide hazards threaten Ethiopia's infrastructure development[12]. They are responsible for breaking roads, damaging properties, and destroying lives. Between 1993 and 1998 in Ethiopia, there were more than 200 houses damaged, more than 500 km of roads were disrupted and nearly 300 people lost their lives.

Numerous studies examined landslide events in the Blue Nile River Basin in Ethiopia[13]. They suggested that the Blue Nile River Basin in Ethiopia often experiences landslide events, due to high elevation terrain, heavy rain, earthquakes, faults and unconsolidated soil materials. The landslide events often allow millions cubic meters of unconsolidated materials to flow into the reservoir,

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10 Bekele Abebe (et al.) "Landslides in the Ethiopian highlands and the Rift margins," *Journal of African Earth Sciences*, vol. 56, no. 4–5 (March 2010) pp. 131 - 138.

11 Mohamed G Abdelsalama, Jean-Paul Liégeoisb, Robert J. Sterna, "The Saharan Metacraton," *Journal of African Earth Sciences*, vol. 34, no. 3–4 (April–May 2002), pp. 119 - 136.

12 Bekele Abebe (et al.) "Landslides in the Ethiopian highlands and the Rift margins," *Journal of African Earth Sciences*, vol. 56, no. 4–5 (March 2010), pp. 131 - 138.

13 Gebremedhin Berhane, "Landslide susceptibility zonation mapping using GIS-based frequency ratio model with multi-class spatial data-sets in the Adwa-Adigrat mountain chains, northern Ethiopia," *Journal of African Earth Sciences*, vol. 164 (April 2020).

which can threaten the safety of dam. In 1963, while the Vaiont Dam in Italy was in the initial filling process, landslides caused a mega-tsunami in the dam reservoir[14]. This event resulted 1,917 deaths. Furthermore, landslides can initiate tsunami-like waves that can cause huge damage to the dam body, gates, electrical poles and lines. Any dam gate malfunction could result in unprecedented flooding events in Sudan.

To help assess triggering hazards and plan mitigation policies in the case of dam failure, Sudan and the international community should encourage Ethiopia to reduce the dam water reservoir from 74 billion cubic meters to a maximum of 13 billion cubic meters. However, the dam water reservoir could be increased gradually, if all the geological hazards were investigated and mitigated.

Sudan should bear in mind that Ethiopia has the sovereign right to use its natural resources for economic benefits to improve Ethiopian lives. This should be quite clear to Sudan in particular, which faced heavy economic and social repercussions after hosting a large number of Ethiopian refugees during the droughts of the 1980s. Additionally, Sudan and the international community should compensate Ethiopia for any losses due to this reduction.

Whether Ethiopia agrees to reduce the dam reservoir to 13 billion cubic meters or not, the following steps can be followed to mitigate some of the risks during the Renaissance dam reservoir filling and operation:

1. Allow an international panel of experts to install seismograms in the vicinity of the Renaissance dam reservoir to monitor seismic activity during reservoir on/off filling operations.
2. Allow an international panel of experts to conduct comprehensive shallow geophysical surveys to map the distribution of subsurface soil materials, faults, joints, sinkholes and cavities, if any.
3. Allow an international panel of experts to deploy GPS stations to measure any tectonic block movements.
4. Allow an international panel of experts to install GPS stations to study the anticipated behavior of the crust beneath the dam reservoir when the huge reservoir water weight is in place. This is a critical step given the observed crust subsidence underneath Houston, Texas USA after Hurricane Harvey 2017(15).

14 Philip B. Williams, "The Debate Over Large Dams," *Civil Engineering—ASCE*, vol. 61, no. 8 (1991), pp. 42 - 48.

15 Shaena Montanari, "Weight of Water Dropped by Hurricane Harvey Flexed Earth's Crust," *EOS*, 14/12/2017, accessed on 10/6/2021, at: https://bit.ly/3ivZTvW