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Research article

Beyond the implications of Grand Ethiopian Renaissance Dam filling policies

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Abstract: The Grand Ethiopian Renaissance Dam (GERD) in Ethiopia and High Aswan Dam (HAD) in Egypt both operate on the Nile River, independent of a governing international treaty or agreement. As a result, the construction of the GERD, the Earth's eighth largest dam, ignited a furious debate among Ethiopia, Sudan, and Egypt on its filling policies and long-term operation. Ethiopia and Egypt's stance on the Nile River's water resources, combined with a nationalistic policy debate on the GERD's filling policies and long-term operation, has severely affected progress toward reaching agreeable terms before the first round of GERD filling was completed. These three countries continue to debate on the terms of agreement for the second round of GERD filling, scheduled to start by July 2021. We examined the GERD filling strategy for five- and six-year terms using time series data for the periods 1979–1987 and 1987–1992 to combine analyses for dry and wet seasons and investigate the potential impacts of filling the GERD above the downstream HAD using four HAD starting water levels. A model calibrated using MIKE Hydro results shows that during both five- and six-year terms of future GERD filling, Egypt would not need to invoke the HAD's minimum operating level. We pursued a narrative approach that appeals to both a technical and non-technical readership, and our results show the urgent need for cooperation at both policy and technical levels to mitigate and adapt to future climate change through the development of climate-proof agreements. Moreover, the results call for the riparian countries to move away from the current nationalistic policy debate approach and pursue a more cooperative, economically beneficial, and climate adaptive approach.

Keywords: dam filling; Grand Ethiopian Renaissance Dam; High Aswan Dam; loss; gains

1. Introduction

Population growth and economic development have sparked water demands for hydropower and irrigation developments in the river basin [1]. On the basis of utilizing these water resources for socioeconomic transformation and the alleviation of poverty, the Government of Ethiopia, with the support of the United Sates Government Bureau of Reclamation (USBR) [2], made the first assessment of potential irrigation and hydropower in Ethiopia's Abbay River basin in 1964. They identified that the basin has considerable irrigation and hydropower potential. The border dam site on the Nile River, which the USBR initially identified as having relatively less water storage at 14.5 billion cubic meters (BCM), a hydropower generation capacity of 800 mega watts (MW), and a height of approximately 80 meters above sea level (masl), is the current site of the Grand Ethiopian Renaissance Dam (GERD). The GERD is 1,874 km^2 in area and 170 masl in height, with a 5,150 MW hydropower generation capacity and 74 BCM water storage capacities. The GERD's minimum operating level (MOL) is 590 masl. In contrast, the height of the downstream High Aswan Dam (HAD), also located on the Nile River but within Egypt, is 183 masl, with a hydropower generation capacity of 21,000 MW and a MOL of 147 masl. The HAD's full reservoir capacity is 164 BCM with an active storage capacity of 107 BCM [3–5].

Before implementing the USBR recommendations on the utilization of the Abbay River basin, the then Ethiopian Imperial regime was overthrown by the Dergue regime in 1974; subsequently, the Dergue regime was engaged in active war for seventeen years, from which guerilla fighters came to be known as the Tigray People Liberation Front (TPLF) and Eritrean Peoples Liberation Front (EPLF). In 1991, the TPLF led the coalition of the Ethiopian People's Revolutionary Democratic Front (EPRDF) and seized the capital city of Addis Ababa, while the EPLF controlled the city of Asmara. After reconstructing and rehabilitating the war-torn economies and infrastructures, in pursuit of the United Nations Millennium Development Goals (MDGs) to improve the lives of impoverished peoples by 2015, Ethiopia created the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) under the EPRDF regime. The PASDEP was a medium-term development plan based on eight pillars, some of which were included in subsequent five-year plans. In line with Ethiopia's principle of exploiting indigenous resources, the PASDEP planned to construct three hydropower plants: the Tekeze, Gilbgel Gibe II, and Tana Belese plants. According to the Ministry of Finance and Economic Development (MoFED) [6], the PASDEP is the first of four comprehensive economic development plans launched since 2000 and was relatively effective until 2010 when, subsequently, the Growth and Transformation Plan I (GTP I), a five-year plan, was adopted by the MoFED to achieve the MDGs by 2015. Currently, through GTP I, the MoFED intends that Ethiopia should attain middle-income status during 2020–2023 and continue to prioritize infrastructure developments. For power generation, Ethiopia signed contracts for the GERD and the Gilgel Gibe III before the completion of GTP I. However, to commence construction of the GERD, Ethiopia was required to rely on its existing economic and financial capacities and improve development of its technical capacities [7–9], since constructing the GERD with financial and technical support from the international financial institution was not possible. The World Bank

Operational Directive 7:50 requires the approval of downstream countries for any construction envisioned by an upstream country if the upstream country seeks financial and technical support from the World Bank [10]. Therefore, global and internal circumstances compounded Ethiopia to delay the construction of the GERD until 2011 (Nile Basin Initiative [3,4].

Upon the construction of the GERD, riparian states have not yet agreed on nor established a filling strategy for the GERD reservoir. Therefore, to inform on possible filling strategies, we use historical and projected streamflow data to examine whether two filling strategies of the GERD (five- and six-year policies) could harm the downstream HAD operations. We selected historical flow data that are representative of low, medium, and high flows. The study objective was to exhaustively compare the two filling strategies and determine whether they cause any significant harm to HAD, and instigate Egypt to invoke its drought management policy (DMP). The study does not cover post-filling management and operational strategies. Nonetheless, given the impacts of climate change, climate variability, and uncertainties with respect to the directions and magnitudes of future climate change, the need to coordinate the GERD and HAD is imperative for maintaining the equitable utilization of shared water resources and benefitting from them. In conclusion, we highlighted the associated behavioral perceived and endowment effects of gains and losses under hawkish and nationalist policy debates over these transboundary water resources.

The construction of the GERD in the Abbay River basin, which launched in 2011 [3,4,11], was anticipated to be a platform for cooperation among Ethiopia, Sudan, and Egypt. The benefits provided by the GERD include electricity trading, water flow regulation, and sediment and flood control. However, due to perceived and real associated impacts induced on the HAD, some of which were undesired, controversial issues have persisted among the riparian countries [12–14]. As a result, various GERD filling policies and potential impacts have been previously examined [15–23]. However, although studies do encourage cooperation and benefit sharing, they disagree on the potential impacts of GERD filling strategies on HAD. The related irrigation and hydropower potential of the Abbay River basin for Ethiopia have been illustrated [11,12,24], and the Nile River's climate sensitivity and variability have been documented [25,26]. Similarly, studies on other environmental and socioeconomic impacts of Nile River flow on the HAD have also been documented [27–34].

Yet the future state of climate change in the Abbay River basin remains uncertain [26,35,36]. Forecast models have used different simulations, including synthetic river flows, to forecast future states, but the directions and scope of future climate changes largely remain unclear. Moreover, it has been recognized that high spatial and temporal interannual variability are the main characteristics of the Ethiopian highlands and the Abbay River basin's climatic conditions [37–39] which puts pressure on the availability of the basin's water resources.

Meanwhile, in addition to climate change pressure on water resources, both the Abbay and Nile River basins are experiencing high population growth. As a result, energy access and food supply are among the major issues in the riparian states [1]. Rapid population growth, food insecurity, and urbanization promoted the riparian states to develop competitive water resource development plans [40,41]. The GERD is the largest among the numerous project plans developed by the riparian countries in recent history. As the construction of GERD led to intense debate among Ethiopia, Sudan, and Egypt, the GERD's filling policies and long-term operations have similarly ignited controversial debates and prolonged negotiation between the riparian states. Due to the challenges in coming to mutually acceptable agreements, Ethiopia unilaterally completed its first GERD filling in the summer of 2020.

The second round of GERD filling has been scheduled for the summer of 2021, yet the riparian countries have yet to reach to an agreement in terms of the filling strategy. Assuming that the parties do not reach an agreement or fail to establish frameworks before the filling period commences, Ethiopia will be required to subsequently conduct the second round of filling as originally scheduled since the activity of filling is not considered illicit according to existing international customary law or general principle. In fact, this second round, as well as the presumed upcoming third round of filling, are in accordance with international customary laws, as exemplified by two similar disputes; one between France and Spain over Lake Lanoux and another between Argentina and Uruguay regarding the construction of a pulp mill on the Uruguay River. In the first case, Spain objected and resisted the basin development in Lanoux Lake by France, which was carried out without prior agreement. Similarly, Argentina originally resisted and objected to the development of a pulp mill on the Uruguay River before reaching an agreement. In both cases, the international court dismissed the objections because they were neither backed by general principles nor customary law [42,43]. In both cases, the court demonstrated the inappropriateness of insisting on having a prior agreement, as it would otherwise curtail the state's right to act unilaterally and unconditionally within its jurisdiction. Considering this, Ethiopia is expected to pursue its second round of filling as originally planned. Therefore, assessing the impacts of the two shortest-timeframe GERD filling policies (five- and six-year policies) is essential to searching for potential interventions.

2. Materials and methods

2.1. Study area

The Nile River is shared by 11 African riparian states. The Blue Nile (hereinafter the Abbay River) is major tributary of the Nile River, and its basin temperature spatial distribution is strongly related to altitude. Within the Abbay River basin, the highest temperatures are observed in the northwestern part of the basin (in the areas of Rihad, Dinder, Beles, and Dabus), where the maximum temperature is 28–38 °C and minimum temperature is 15–20 °C. Lower temperatures are observed in the highlands of Ethiopia, that is, in the central and eastern parts of the basin, where the maximum and minimum temperature ranges from 12–20 °C and from −1 to 8 °C, respectively. Potential evapotranspiration (PET) in the basin ranges between 1,056 and 2,232 mm per year. High PET is observed between 1,800 and 2,232 mm per year in the northwestern parts of the basin, that is, in Dinder, Rahad, and parts of the Beles and Didessa sub-basins. The eastern and southern parts have lower PET, ranging between 1,200 and 1,800 mm per year. The lowest PET (below 1,200 mm per year) is observed in parts of the highlands [38,44]

The basin has considerable inter-annual rainfall variability. It increases from approximately 1,000 mm near the Ethiopia and Sudan border to between 1,400 and 1,800 mm over parts of the upper basin, and exceeds 2,200 mm in some places in the south with a mean of approximately 1,420 mm/year. Around 85% of annual precipitation occurs during the summer, from July to October [45,46]. The basin contributes 54.5 BCM/year to the Nile River flow.

The basin's 11 riparian states: Burundi, the Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda. The Nile River is the result of two principal tributaries: the Abbay River and the White Nile, which originates in the Equatorial Lakes. The two rivers merge in Sudan near Khartoum. The Abbay River originates from a small spring called Gish Abay in the Ethiopian highlands, located 117 km from Lake Tana; however, multiple studies have proposed that the source of the Abbay River is Lake Tana itself. The Abbay River flows clockwise and enters a canyon through the Ethiopian gorge, joining the White Nile in Sudan. Monsoon rainfall contributes to the major rainy season in the Ethiopian plateau. Most of the water is produced upstream, and the downstream countries utilize significant portions of the river flow for both hydropower and irrigations (Please see Figure 1, for schematic view). For example, Ethiopia's present annual water consumption water from the Abbay River basin is less than 5% for irrigation and less than 3% for hydropower. These consumption rates have been a source of contention, but also have potential to be a source of collaboration among the riparian states [11,17,47–49]

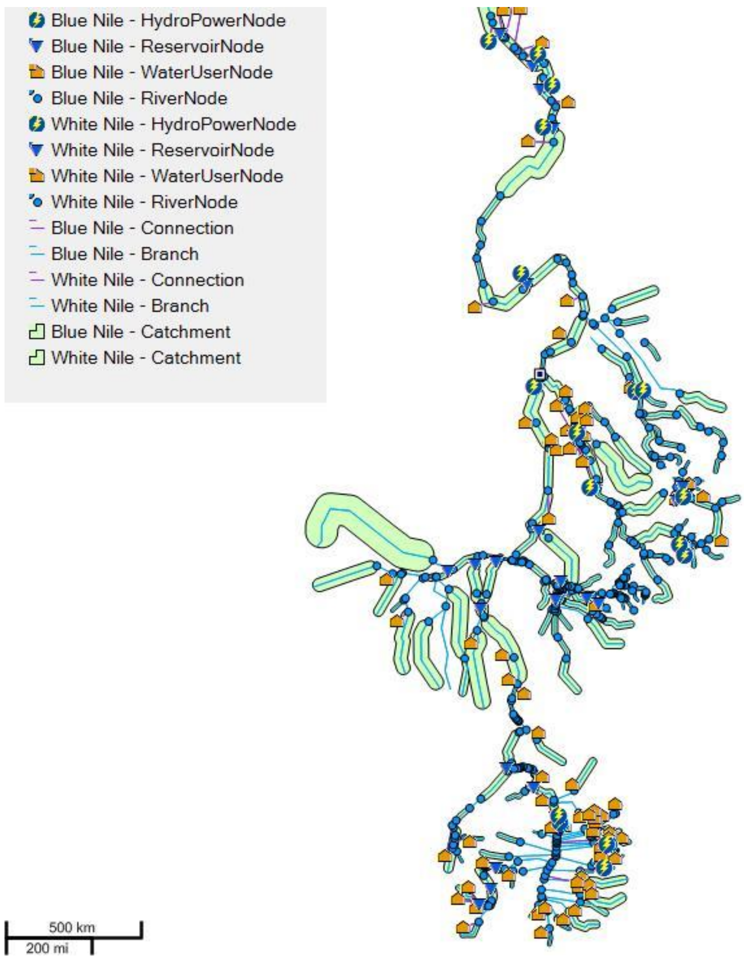

Figure 1. Nile model schematic view (Emphasis given to Blue Nile).

2.2. Methodology

This study employed a comprehensive analytical MIKE Hydro model, which simulated the Nile River from 2020 to 2060. The precipitation-runoff for every catchment area was simulated using the MIKE-NAM model. MIKE-NAM is used to conceptualizing the estimation and correct the bias based on the time series data of the climate research unit time series version 4.03 (CRU TS4.03) associated with potential evapotranspiration, precipitation, and temperature. In this study, MIKE-NAM observed the streamflow calibrated at each of the sub-catchments and developed a simulation of ungauged catchments, which aided the estimation of the streamflow at an outlet for each sub-catchment. The Nile River streamflow was required to meet the municipal and agricultural irrigation water demand, the power generation water requirement, and minimum monthly water flow requirements. The Nile Basin Decision Support System, which is generally tailored to the Nile River basin regime, has been used to combine temporal and spatial variability of precipitation and historical data of stream flow across the entire river basin; the major assumption of the MIKE Hydro model has been extensively reported in previous studies including those conducted by Yao and Georgakakos [50,51].

The sets of historical data were obtained from the NBI-ENTRO dataset from the Eastern Nile Technical Regional Office (ENTRO) [52]. The streamflow, hydrology, and hydropower models require inputs of monthly precipitation, daily mean temperature, and the diurnal temperature range. This historical period was selected to minimize the possible effects of climate change (i.e., post 2000). Accordingly, we purposefully selected the following scenarios for this study: a) two GERD filling inflow scenarios (average and dry flow sequence obtained from historical data), b) four of the HAD's starting water level conditions (obtained from historical water level conditions of the HAD), and c) different HAD drought management policies, adapted from [21].

The two GERD filling scenarios, which are five- and six-year filling policies (Figure 4), were analyzed as follows: i) a five-year annual filling policy that retains 4.5, 17.5, 17.5, 17.5, and 17.0 BCM each year by considering the average inflow conditions of the Abbay River from 1987 to 1992; ii) a six-year annual filling policy that retains 4.5, 15, 15, 15, 12, and 12 BCM of water by considering the dry inflow conditions of the Abbay River from 1979 to 1987. The filling was allowed in July, August, September (minimum), and October. The release in September was considered to be either minimal or zero to manage the filling of Sudan's Rosieres Dam during September.

The four different HAD starting water levels studied were 158.2, 160.0, 165.0, 170.0, and 175.0 masl. Water levels abstracted from historical water level data were considered for both dry and average flow conditions. It should be noted that these water level conditions represent possible realizations of the historical water levels at the beginning of HAD filling. Finally, for different HAD drought management policies, the historical annual release from the HAD reservoir ranged between 35.0 BCM (representing the dry season of 1984) and 86.0 BCM (the wettest season of 1988) (Figure 2). Despite the release rate of 55.5 BCM/year indicated in various documents, the outflow from HAD varies between 35 BCM (dry year) and 86 BCM (wet year), which indicates the implementation of water management policies at HAD for flood and drought years. Furthermore, Wheeler et al. documented Egypt's drought management policy in their recent study; a 5–10% release reduction was reported during the drought year [25]. A similar magnitude (5–10%) was observed for the increase in release during wet years.

It is well known that examination of the impacts of filling on downstream countries during the filling period is complicated by the filling strategies' multifacetedness and correlations. Therefore, our study is based on the features and operations of two major factors: average historical water release (Figures 2, 6, and 8) and the starting water level at HAD (Figures 5 and 8), which was 178.4 MASL in August 2020 [5].

3. Results and discussion

3.1. Historical and contemporary flow and HAD level before the construction of GERD

In the summer of 2020, Ethiopia completed the first round of GERD filling by securing 4.9 BCM of water. During all planned filling periods, a certain portion of the river flow is intended be diverted to fill the reservoir, while the rest makes its way downstream to the HAD through its turbine. The flow of the Abbay River differs from that observed without the GERD. With the existence of the GERD, water flow at the HAD decreases, and the hydropower generation at the HAD also declines due to the lowering of the hydraulic head on its turbine. However, the river flow will return to normalcy upon completion of GERD Reservoir filling [53].

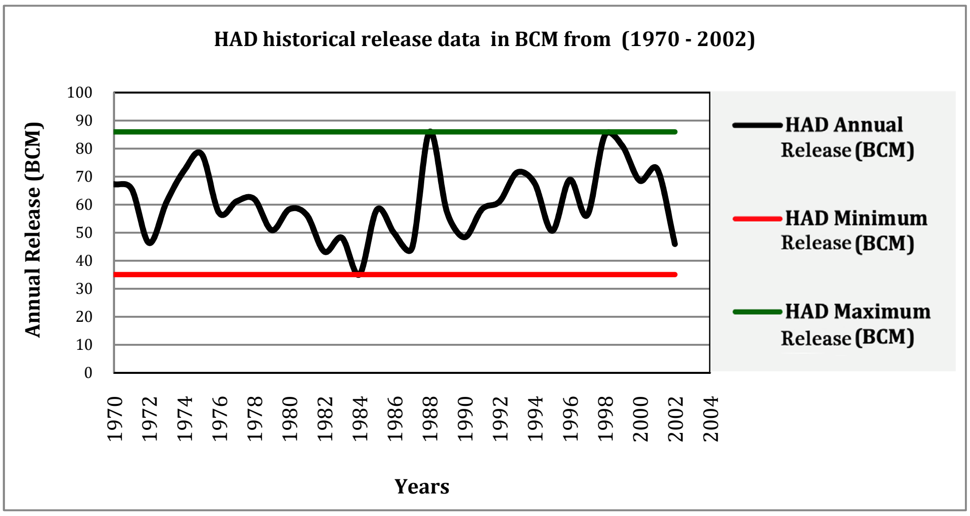

Figure 2. Historical annual release downstream of HAD (includes water use and flood spill) from 1970 to 2002.

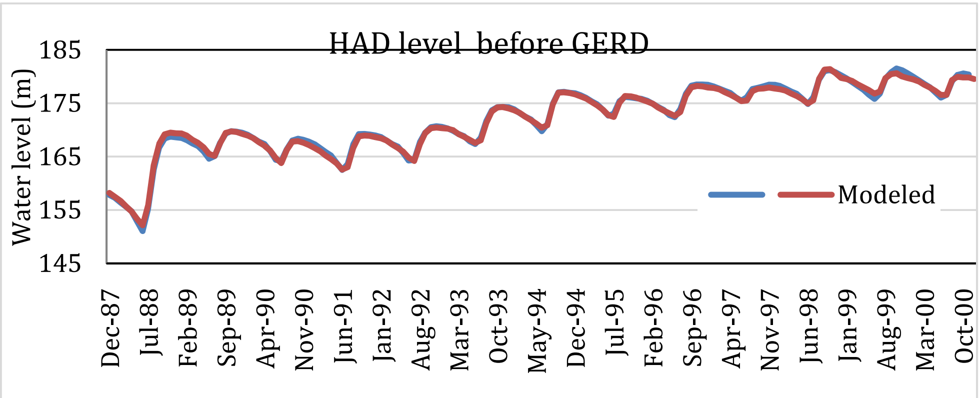

Figure 3. Model calibration results of the HAD water level (before GERD).

Figure 2 shows the historical HAD release from 1970 to 2002, while Figure 3 demonstrates the HAD level without GERD, and Figures 3 and 8 show the HAD water level at various conditions. When the model flow is subjected to the historical flow data of 1970–2002 under the five-year strategy, the scale of the annual water shortfall in the HAD before and after the GERD could be calculated in relation to Egypt's historical average annual water release of 55.5 BCM. In the model, when the HAD reservoir received water based on the historical data series from 1987 to 1992 under the five-year strategy of 4.5, 17.5, 17.5, and 17.0 BCM, the filling of the GERD had no adverse impacts on Egypt (Figures 4 and 5). Moreover, the model shows that the GERD's storage would be full in five years. Upon achieving maximum storage capacity, the flow of the river resumed its regular flow pattern, and the HAD's storage recovered speedily. The simulation shows that the HAD storage capacity did not drop below its MOL, which is 60 BCM. Therefore, initiating the DMP of HAD would not be necessary under the five-year strategy, and Egypt could potentially maintain its historical average annual release of 55.5 BCM (Figures 5 and 6).

Similarly, based on the historical average annual flow from 1979–1987 and the six-year annual filling strategy of 4.5, 15, 15, 15, 12, and 12 BCM, modeling results show that the filling of the GERD had no adverse effect on the HAD reservoir, and that again, Egypt could potentially retain its annual release of 55.5 BCM without the need to invoke the DMP. The GERD was full after six years. According to the model results, a stable and regular flow of the river was established and the HAD recovered quickly to 74 BCM.

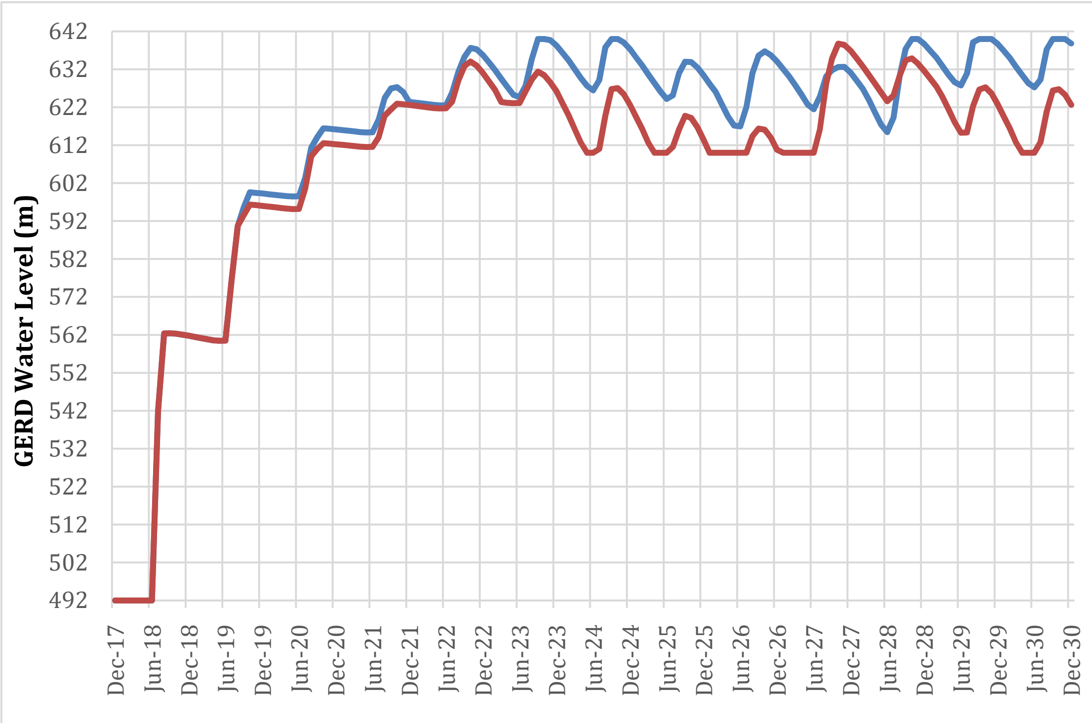

Figure 4. GERD filling performed for a) five years during average flow conditions (blue line) and b) six years during dry flow conditions (red line).

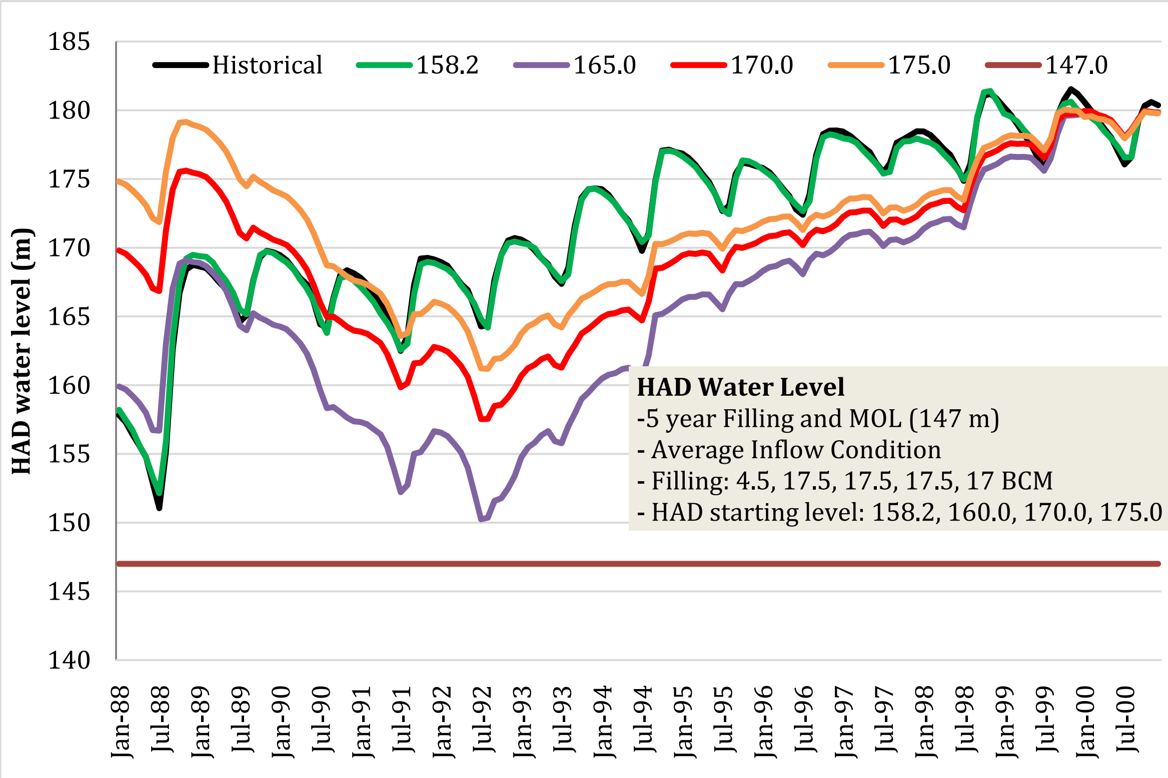

Figure 5. HAD water level conditions.

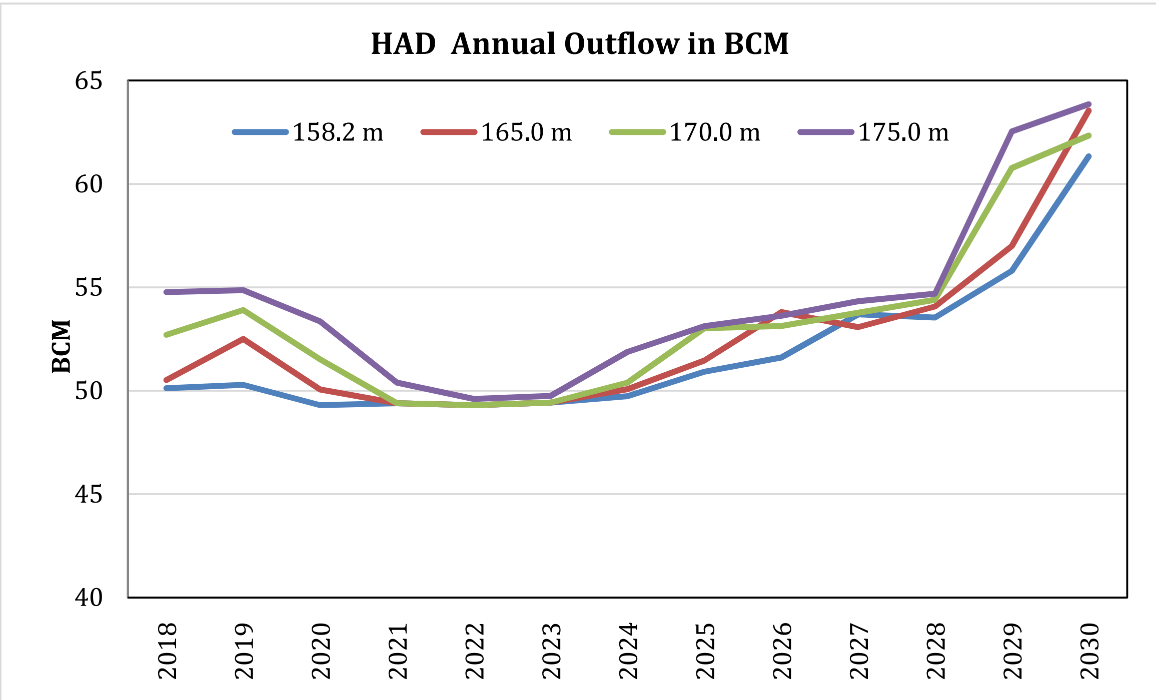

Figure 6. HAD release downstream under different starting water level conditions.

In both the five- and six-year scenarios, the HAD did not reach its lowest recorded reservoir level of 34.7 BCM (147 masl). Therefore, both the five- and six-year filling strategies would not call for the establishment of the DMP in Egypt. Furthermore, the likelihood of drought occurrence during the filling period would be considered remote; this is because drought conditions were historically observed only in two years, 1978 and 1987, and the probability of the re-occurrence of such conditions is estimated to occur only once in more than 20 years [51]. Although such a drought may occur during either of the two filling strategies, a dynamic filling model can be developed in the ongoing negotiations by using past scientific evidence to account for this possibility. Furthermore, the majority of climate models for the Abbay River basin exhibit wetter climate conditions in the future with high interannual variabilities of rainfall, while related studies have recommended the construction of additional storage in the Abbay River basin [26,53–55].

3.2. GERD filling during average and dry inflow conditions

Based on the filling models, filling was allowed in July, August, September (minimum) and October. The release in September was considered to either be minimal or nonexistent, with regard to Sudan's Rosieres Dam filling during this period. Based on the five-year strategy under average inflow conditions, model results show that GERD storage volume was able to almost reach its full capacity of 69.5 BCM safely without affecting the HAD, as shown in Figure 5. Based on the six-year strategy and dry flow conditions the starting water level conditions of the HAD should be considered in the filling of the GERD. In the unlikely event of consecutive dry conditions such as those observed in 1980s, the filling of the GERD could be initiated if the initial water level of the HAD is maintained at 175 m or above to avoid significant negative consequences.

3.3. HAD water level (average flow conditions)

Using the average inflow conditions, the proposed GERD filling policy under the five-year strategy suggests that the HAD can be operated above the MOL of 147 m under all starting water level conditions (Figure 5). Figure 5 shows the dry and wet historical flows, as January is the dry season of the year while July is the wet season. Regardless of the average inflow sequence and the starting water level conditions, the model shows that the water level did not fall below the MOL.

As shown in Figure 6, the modeled outflow/release downstream of the HAD was in accordance with the HAD management policy regime and remained within the historical release sequence illustrated in Figure 5. Similarly, as presented in Figure 7, regardless of the HAD starting period, the energy produced may be reduced by 10–25%, particularly if the initial level of the HAD reaches 158.2 m before it recovers. Moreover, considerations of annual operation policies based on seasonal forecasting and joint optimization of rules may further decrease the reduction rate of energy through a water transportation mechanism. Water transportation involves retaining more water during the wet season to compensate for the low supply of water during the dry seasons.

3.4. HAD water level (dry flow conditions)

When calibrating the dry inflow conditions of the GERD filling under the six-year strategy, we found that the HAD can be operated above the MOL of 147 m when the starting level of HAD exceeds 170 m. When the HAD starting water level conditions during the start of filling are below 170 m, the water level may exceed the MOL. However, conditions similar to those observed in the 1984 drought are not likely to recur in the same sequence, and as shown from the historical water level conditions, HAD exceeded 170 m. In a dry scenario, the combination of a joint safeguard policy and stringent drought management measures can be implemented to foster cooperation and goodwill.

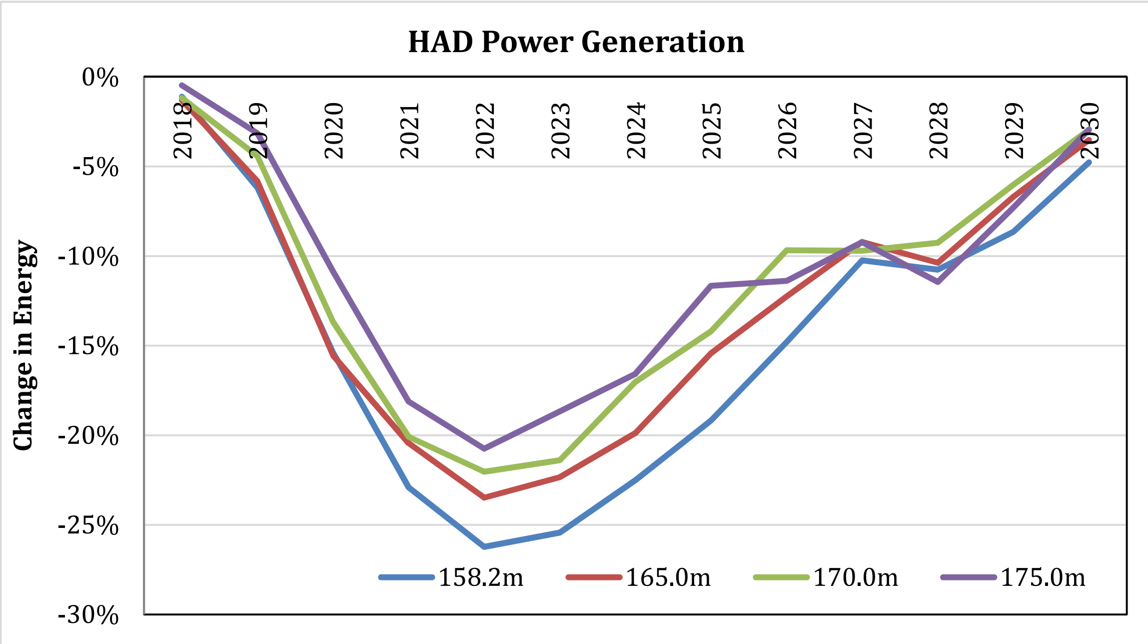

Figure 7. Hydropower generation levels.

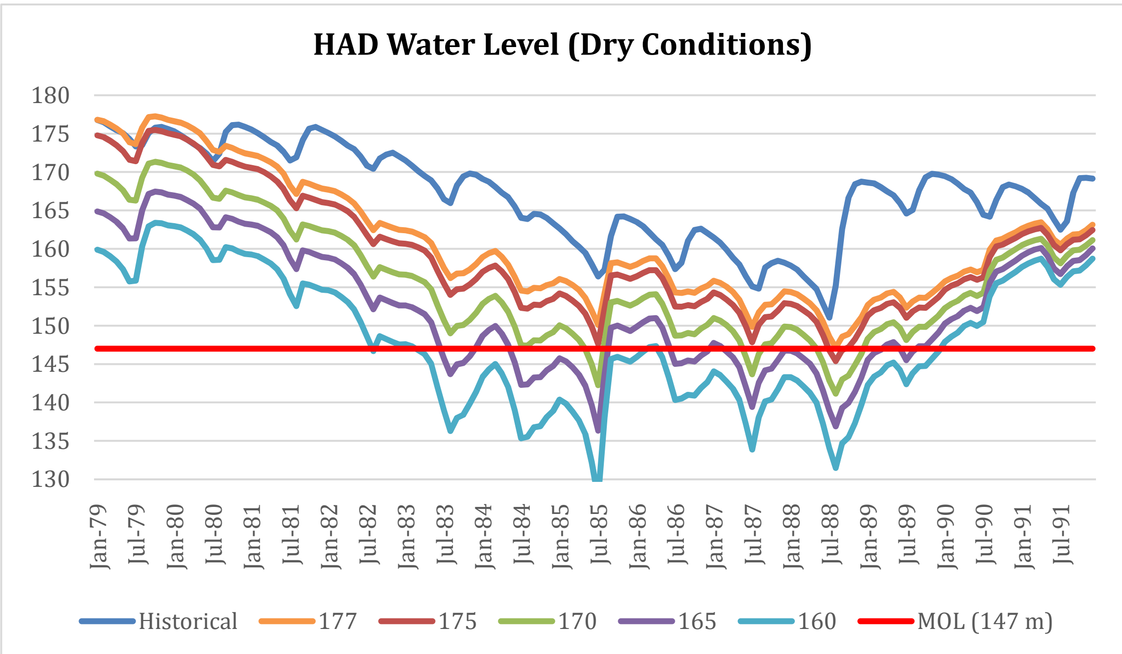

Figure 8. HAD water fill levels under dry inflow conditions and according to different starting water levels.

3.5. Study limitations and perspectives for future research beyond the impacts of the GERD filling policies

This study attempts to elucidate the challenges of the ongoing and future negotiations associated with sharing a water resource and managing the two biggest African dams (i.e., the GERD and HAD) built in a single river system in two different countries. We also determine that upon completion of the GERD construction (it was 90% complete at the time of this study), the dynamics of the Nile River basin will change; therefore, a "new normal" in terms of operation as well as a novel hydrological order and approach utilizing revised logic will be needed [56]. We demonstrated negligible impacts on the HAD during the five- and six-year GERD filling strategies. Therefore, in addition to the potential impacts of GERD filling, it is deemed that the ongoing problematic and complicated negotiation surrounding the operation of the GERD is one example of the onset of a new normal owing to the construction of the GERD, which necessitates continual negotiation to manage the perceptions and definition of gains, biases and losses based on a given point of reference,

As we have demonstrated by analyzing the two shortest-timescale filling policies, although Ethiopia is currently pursuing longer-timescale filling policy, filling the GERD would not prompt Egypt to invoke the HAD's DMP. Thus, the challenge to reach an agreement goes beyond hydrological matters. We suggest that the challenge is based on the perceptions and biases that originated with the 1902 Nile treaty signed by Great Britain, the 1929 Anglo-Egyptian treaty, and the 1959 Nile Waters treaty signed between Egypt and Sudan. The 1929 treaty allocated 48 BCM waters to Egypt and 4 BCM to Sudan, while the 1959 treaty allocated Egypt 55.5 BCM of Nile River waters and allotted 18.5 BCM to Sudan while leaving only 10 BCM for evaporation. Moreover, the treaty provided Egypt veto power over any constructions in the Nile River system. Both treaties excluded Ethiopia, which hosts the origin of the Abbay River (i.e., Blue Nile) that contributes approximately 80% of overall Nile River flows. In turn, Ethiopia deemed the treaties null and void and dubbed them as colonial treaties. Thus, the factors mentioned above could be the basis for the ongoing debate that commenced upon construction of the GERD. Since that time, the riparian states have not been able to agree on either the short-term filing policies or the long-term operations and continue to be reluctant to fully endorse the international panel of experts' recommendations. The ensuing disagreement on the mediating roles of the African Union Commission negotiation, along with Egypt's and Sudan's calls for the Arab League Nations to become involved in the matter, and the subsequent internationalization of the diplomacy by taking the dispute to the United Nations Security Council calls for an even more comprehensive research investigation including physical sciences, further historical data, and decisions science to work towards a resolve. Such an investigation may provide a framework for resolving similar issues arising elsewhere in the world.

As discussed, it was found that the water flow from Abbay River basin to Egypt under the two filling policies should not drop below the MOL of the HAD. Therefore, the associated impacts of the GERD on the two shortest-timescale filling polices should be negligible during both average and drier conditions. However, the mere construction of the GERD may have caused uneasiness and frustration among policymakers and Egyptians at large [57,58]. Behavioral scientists and researchers have highlighted the negative impacts of random variability and systematic errors in decision-making and opinion formations. Endowment factors of losses or gains and decision-making biases and noises are considered to be among other factors that cause policy debate polarization in international negotiation and decisions [59–61]. Any perceived losses would elicit strong reactions and prompt resistance among those who feel affected; in turn, the endowment effect will reinforce this into a vicious cycle [59–63]

Similarly, confirmation bias causes both policymakers to become resistant to change by establishing their status quo. In the era of climate change, the past does not necessarily reflect the future, thus water resource strategies need to adapt to the associated changes, thereby recognizing the new normal of a changing climate. However, attaining the required change and adapting to the new normal at regional levels for transboundary water regimes will be an uphill task. This is because each party continually affirms the subjective narratives of its domestic political elites. Such behavioral and psychological factors thereby cause differences in policymakers' view of the world, particularly with respect to the reasonable sharing of resources through the "echo chamber" phenomenon [64]. This is because people tend to accept information and data that resonate with their beliefs and disregard information and data that conflict with their beliefs and cognitive modeling processes [62,63,65,66]. The relevance of this hypothesis to our study result is that without verifying the reduction in the water flow owing to the GERD, the mere construction of the GERD could lead to a perception of water loss in Egypt and trigger confirmation biases, such as those provided by Herodotus's inaccurate comment that *Egypt is the gift of the Nile* [67], and generates gaps in terms of policy cooperation and benefit sharing mechanisms among all 11 Nile River basin riparian states.

The perception of water loss is more extensive and deeply rooted as compared to that of the actual loss of related commodities [68]. In this way, confirmation biases to the status quo "do not form in a vacuum but rather correspond to the way water issues are integrated in pre-existing political dynamics" [69]. Accordingly, the political denotation and connotation of the Nile River basin have been deeply integrated into the cultures and national symbols of affected countries. Therefore, the decision of political elites to cooperate with each other or with peer riparian states could depend on their analysis of domestic political benefits or reprisal costs in their respective political domains [70]. Still more, besides the cognitive biases of losses and gains, the new concept of noise and its roles in decision variability should also be a factor in future research and search for an adaptable solution. Noise is a random and unexplainable error in decisions and can be triggered by various emotional and relational factors. In our case, the perceived and natural use of water resources by any of the riparian states may trigger a certain country's policymaker to make a noisy decision [62–66]. Noise is defined as judgment variability between experts whose judgments are expected to be interchangeable. Thus, substantial judgment variability between experts has recently been brought to attention by researchers. For example, Jaya Ramji-Nogales et al. [71] researched the Miami courthouse to understand decision variability where the clerk randomly tabled similar asylum cases to different judges. The research found that a judge granted asylum to 88% of the asylum seekers, while another judge in the same building granted asylum to only 5% of the applicants [62,71]. Moreover, their research result noted that the asylum seekers' origin was unable to explain the variations. Therefore sources of significant variability between experts in interpreting the same data while following the same measurement criteria cause poor decision qualities and disagreements.

Finally, the circumstances may render it difficult for government officials to make decisions or form agreements based on scientific results. Such an agreement would require a broader comprehensive regional approach that fosters and enhances solidarity among the Nile River basin riparian states and addresses policies and technicalities by focusing primarily on sustainability. In the future, international communities can help demystify the perception and definitions of losses, gains, and biases of the societies of Ethiopia, Sudan, and Egypt by targeted intervention through education.

The international community can also help to maintain the integrity of negotiators by playing the impartial and genuine role of a mediator.

4. Conclusions

Egypt will not be compelled to invoke the DMP based on the five- and six-year annual filling policies of the GERD. Although filling of the GERD increases the generation of hydropower for Ethiopia, the energy generation at the HAD could decrease by 5%, or by 20% in the worst-case scenarios. Thus, collaborations among the riparian states could help realize the potential economic and environmental benefits through benefit sharing within trade and responsibility sharing within mitigation and adaption measures.

The GERD, being located in the Ethiopian highlands, has a low-level evaporation rate of 0.09 m, while the HAD evaporation rate is 0.199 m. Therefore, the GERD does not contribute to overall evaporation losses within the basin and saves water for the benefit of all. Furthermore, the GERD helps to regulate water flow, reduce sedimentation, arrest floods, enhance dam operations, and mitigate and reduce the impacts of climate change. Nevertheless, to materialize the shared benefit and collaboratively mitigate the future impacts of climate change, the effected riparian countries of Ethiopia, Sudan, and Egypt need to coordinate their respective development plans for the basin based on their comparative advantageous and environmental suitability. In light of this, the political and technical leaders of these countries must build mutual trust and adhere to evidence-based decision-making practices so as to develop climate-proof Nile River basin agreements. In doing so, these countries may be able to reach a climate-proof and future-oriented Nile River basin governance system at both policy and technical levels. At the policy level, a vision for benefit sharing and economic cooperation should be fostered, while at the technical level, the countries may need to cooperate on data and skill sharing that aims to reduce the impacts of climate change by undertaking mitigation and adaptation strategies through the use and application of water efficient and effective technologies. Such technologies may involve deploying water-efficient irrigation infrastructure, water-efficient and drought-tolerant crops grown using biotechnology and/or new breeding techniques, and training programs for farmers to encourage effective and efficient use of irrigation water.

The authors suggest the importance of having a dynamic, phased-based, procedural, and substantive filling agreement in the short term to de-escalate associated tensions. While parties continue working towards reaching a long-term basin-wide agreement, the phased-based short-term agreement could also be extended to a medium-term river-based agreement, similar to that of the Uruguay and Rio de La Plata statutes signed between Uruguay and Argentina in 1975.

To achieve the long-term basin-wide agreement, experience can be considered from other relevant locations within Africa. For example, there are at least 20 effective international agreements across 63 river basins, and effective institutionalized systems exist for 16 river basins that coordinate countries' river basin development initiatives and activities including the Niger Basin Authority, Organisation pour la Mise en Valeur du Fleuve Sénégal, and Lake Chad Basin Commission. Nevertheless the authors suggest investigating the underlined cause of the impasse while the international community continues to collaborate in providing integrity-saving opportunities for policymakers that foster the development of a basin-wide, long-term, climate-proof operations agreement.

Based on the findings of this research, we suggest that future studies should examine the upstream countries' actual water utilizations under a changing climate, as well as their actual and perceived impacts on downstream countries. We believe that insight into such intervention would help to avoid water conflicts and foster cooperation through by demystifying the perceived losses and gains of the transboundary water resources.

Conflict of interest

The authors declare no conflict of interest.

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