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ANALYZING THE ENVIRONMENTAL DISPUTE OVER THE GRAND ETHIOPIAN RENAISSANCE DAM BETWEEN ETHIOPIA AND EGYPT USING GAME THEORY

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----------ABSTRACT----------
This study applied game theory to examine Ethiopia and Egypt's strategic interactions and interests in the GERD dispute. The study discovered that the conflict could be resolved by considering the various concerns and motivations of the parties involved. The study also investigated potential collaborative solutions and negotiation strategies for resolving the environmental conflict. The study's research objectives were to identify the key players in the GERD debate. Analyze the decision-making procedures used by Egypt and Ethiopia, and consider any possible outcomes from the conflict. Make appropriate alternatives for resolving disputes. The study found that the GERD controversy is a complicated problem with conflicting interests. While Egypt is concerned about the dam's effects on its water supply, Ethiopia is interested in using it to produce hydroelectric power. The study discovered that both nations' concerns must be considered to resolve the conflict. The study considered various cooperative dispute-resolution options as well. These remedies include water-sharing contracts, payment systems, and other cooperative actions. According to the study, these solutions could promote a fair and protracted conflict settlement. The study's conclusions help clarify the complexities of the GERD controversy and offer guidance to those involved in the debate as policymakers and stakeholders. The study offers helpful recommendations for fostering communication, encouraging collaboration, and arriving at a conclusion considering the worries and interests of all parties involved in the GERD dispute.

KEYWORDS: *Ethiopia-Egypt relations, Game theory, Environmental dispute, Transboundary water conflict*

1. INTRODUCTION

The Grand Ethiopian Renaissance Dam (GERD) stands for potential and conflict in the complex geopolitical context of the Nile River basin. The GERD, which is positioned on the Blue Nile, the main tributary of the Nile River, has caused a protracted environmental battle between Egypt and Ethiopia, two of Africa's most populous and powerful nations (Madani et al., 2011). The primary discussion topic is how dam construction and operation may impact the political, economic, and environmental settings. Game theory is used to fully comprehend and evaluate this complex subject because it offers a valuable framework for examining the numerous parties' strategic interactions and competing interests. The Nile River provides life-sustaining resources to millions of people in its eleven riparian countries, including Egypt and Ethiopia (FAOSTA, 2019). The management and allocation of Nile waters have historically been controversial because of the increasing water demands and restricted supply (Bleischwitz et al., 2021). Ethiopia built the massive GERD hydroelectric project on the Blue Nile, a sizable tributary of the Nile River. Ethiopia can get the electricity it needs from the dam, the largest hydroelectric project in Africa while promoting economic growth (Pemunta et al., 2021). A protracted debate has resulted from worries about the project's possible effects on the environment of downstream countries, particularly Egypt. Egypt mostly depends on the Nile's water supply for agriculture and sustenance. Because of its worries about upstream water flow disruptions, lower water availability, increased salinity levels, and possible impact on its agricultural sector, Egypt regards the GERD as a danger to its water security (Verhoeven, 2021). Ethiopia claims that the GERD programme can eradicate poverty,

expand access to power, and promote sustainable development. According to Madani et al., (2011), the Ethiopian government prioritizes the ethical and responsible use of the Nile's resources and suggests gradually filling reservoirs to limit potential adverse effects on downstream countries (Madani et al., 2011). To describe tactical engagements and decision-making procedures in environmental disputes, game theory offers an analytical framework (Bekius & Gomes, 2023). To encourage the development of cooperative solutions and bargaining strategies, game theory predicts likely outcomes and equilibrium points. By applying game theory to the GERD debate, it is feasible to comprehend Ethiopia and Egypt's competing interests and strategic considerations. By analyzing their decision-making procedures and potential outcomes, researchers can examine collaboration and negotiation tactics that result in environmentally sound conflict resolutions.

1.1 Research Question

This study addresses the following research issue.

i. How can game theory be used to analyze Ethiopia and Egypt's strategic interactions and interests in the Grand Ethiopian Renaissance Dam environmental issue and identify viable outcomes and cooperative solutions?

1.2 Research Objectives

To address the research question, this study will pursue the following objectives:

i. Identify the main parties at stake in the GERD controversy and their interests.
ii. Using game theory models, examine the strategic interactions and decision-making procedures between Egypt and Ethiopia.
iii. Analyze the possible outcomes and the points at which the parties' competing interests will create an equilibrium.
iv. Investigate collaboration opportunities and bargaining strategies that could lead to an environmental solution.

2. LITERATURE REVIEW

The Ethiopian-Egyptian disagreement over the Grand Ethiopian Renaissance Dam (GERD) has drawn much attention because of its geopolitical and environmental implications. Since the Egyptian Khalif's futile pleas in the late 11th century, the ultimate fate of the Nile River's waters, which supply drinking water to approximately 300 million individuals in the basin, has remained uncertain. Has been the root of local strife and hydro-political anxiety. Ethiopia continues to control 85% of the river's water supply, although Egypt and Sudan own a sizable portion (Mulat & Moges, 2014). All the nations in the area are interested in the water of the Nile due to the region's rapid regional development, particularly in the last 50 years. The Nile River water conflict eventually spread across the entire basin because Egypt had an early 19th-century concept of a single, integrated basin under its control (Mohamed, 2017). Although Ethiopia was the primary aim of this domination, Egypt and Ethiopia engaged in sixteen significant engagements between 1832 and 1876 (Matewos, 2020). The need for just one basin that would enable Egypt to use the water from the Nile served as the primary driving force behind hydro-political tensions in the region. Egypt, Sudan, Eritrea, Uganda, Tanzania, Kenya, Rwanda, Burundi, and the DRC share the Nile River basin. Egypt has historically used the river's massive accumulation of salt and water for irrigation in its large agricultural regions. Egypt is a downstream riverside country that dominates the region's politics (Verre, 2022). Using game theory as an analytical framework can provide helpful insights into comprehending and effectively managing this complex problem. Many academics who participated in the literature on the environmental war over time have built the groundwork for comprehension of the conflict's historical setting and geopolitical aspects. Studies by Mohamed Yihdego et al., (2017) and Abdallah, (2021) focus on the legal and historical aspects of the dispute, highlighting the ongoing disputes and challenges Egypt and Ethiopia have faced when dividing the Nile's resources. These older papers provide crucial historical context for understanding the origins and complexities of the dispute, even though some may need to reflect current developments. Recent research on the GERD environmental debate emphasizes game theory as a conflict-resolution analytical tool. For instance, Pemunta et al., (2021) and Aljefri et al., (2022) research examine the strategic interactions between Egypt and Ethiopia and their outcomes under various game theory situations. These most recent studies add to prior works and offer new viewpoints on the complexity of the conflict. This literature review includes the most recent information on the game theory analysis of the environmental debate by looking at these recent papers. There are significant research gaps and information shortages on the environmental issue of GERD, notwithstanding the quantity of available research. First, there needs to be more focus on incorporating many dimensions, such as environmental, economic, and political factors, into game-theoretic research. This gap makes it challenging to fully comprehend the dispute's possible effects and results. Second, more investigation is required into the negotiating and cooperation

approaches that might result in win-win outcomes. Furthermore, only a few studies consider other stakeholders' contributions to the analysis outside Ethiopia and Egypt. By filling in these research gaps, we can better understand the environmental conflict and inform sustainable settlement tactics.

There is a scarcity of studies that specifically employ game theory to analyze the strategic interactions and decision-making processes between Ethiopia and Egypt during the environmental dispute. Further research is needed to utilize game theory as a comprehensive framework to understand the complexities of the dispute and explore potential resolution strategies. The literature frequently needs to pay more attention to integrating numerous aspects within a game-theoretic study and concentrates on separate dimensions like environmental repercussions or economic implications. An integrated strategy that considers environmental, economic, political, and social factors would give a complete understanding of the conflict and aid in making wise decisions (Abdelhaleem & Helal, 2018). Investigating the possibility of collaborative strategies and negotiation techniques in a game-theoretic setting is necessary. Finding viable avenues for resolving the conflict and obtaining mutually beneficial outcomes can be aided by researching trust-building techniques, incentive systems, and power dynamics(B. Y. Yihdego et al., 2020). This study aims to achieve four primary objectives. First, identify the key parties and their respective interests in the GERD dispute. Second, employ game theory models to analyze Egypt and Ethiopia's strategic interactions and decision-making processes. Steps three and four investigate the potential outcomes and the points at which the parties' conflicting interests will form an equilibrium. These measures could result in the resolution of the environmental issue. By focusing on these objectives, this study adds to the body of knowledge regarding environmental governance and dispute settlement in transboundary river basins.

2.1 Game theory

In several academic fields, including politics, economics, and environmental studies, game theory is an effective analytical tool frequently employed. The Grand Ethiopian Renaissance Dam (GERD) environmental conflict between Ethiopia and Egypt offers crucial insights into the strategic interactions and decision-making processes of the contending parties according to game theory (Abdelhaleem & Helal, 2018). Using pertinent references to support the discussion, this section of the literature review examines the idea of game theory and how it relates to analyzing the GERD dispute. The study of strategic interactions between rational decision-makers in scenarios where the results depend on the decisions made by multiple participants is known as game theory (Wu, 2023). It offers a framework for examining how people or nations decide based on their interests and the expected reactions of others. The introduction of game theory to the GERD issue permits an examination of Ethiopia's and Egypt's tactical actions and their probable results under different scenarios.

2.2 The Graph Model for Conflict Resolution

A valuable paradigm for examining and controlling disputes across many areas is the Graph Model for Conflict Resolution (GMCR). The GMCR and its applicability to the investigation of the GERD controversy are reviewed in this section of the academic review (Hipel et al., 2019). Conflicts are simulated and analyzed using the Graph Model for Conflict Resolution (GMCR), a decision-making tool developed by Gerard Regnier and Alain Roubens. It depicts the conflict as a directed graph with nodes denoting decision variables or objectives and edges denoting connections between them. By examining the relationships and trade-offs between decision variables, the GMCR enables the discovery of the best possible solutions. Thomas L. Saaty wrote a 1996 paper titled "The Analytic Hierarchy Process." An essential element of the GMCR, the Analytic Hierarchy Process (AHP), is first introduced in this seminal work (Cheng et al., 2020). With the help of the AHP, it is possible to identify the best answers to complex conflicts using a structured method to rank and rank decision variables based on pairwise comparisons. The analysis of the GERD dispute can be done using the GMCR framework because it enables the representation and evaluation of opposing goals and deciding factors about the dam's development, management, and operation (Nematollahi et al., 2022). To visually analyze the relationships, dependencies, and trade-offs between various goals, decision-makers and stakeholders can build a graph model of the dispute.

3. The Grand Ethiopian Renaissance Dam discussions between Ethiopia and Egypt

A massive hydroelectric facility called the Grand Ethiopian Renaissance Dam (GERD) was built on Ethiopia's Blue Nile River, an important tributary of Egypt's Nile. Since the dam was completed, Ethiopia and Egypt have been fighting over Nile River water ownership. Egypt worries the dam will reduce downstream water flow and harm its economy and food security (Pemunta et al., 2021). Egypt claims a "historical right" to most of the Nile River's waters

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for agriculture, drinking water, and other uses. Egypt fears the dam's water flow reduction will hurt its economy and food security due to water scarcity and population growth. Ethiopia needs the dam for energy and economic growth. Ethiopia claims it can develop with Nile River waters like Egypt and other riparian countries. The GMCR can be used to analyze negotiations. By charting the conflict and analyzing objective relationships and trade-offs, the GMCR assists in identifying the best solutions and understanding interdependencies (Abdelhaleem & Helal, 2018). Figure 1 shows a Map of the Grand Ethiopian Renaissance Dam bellow.

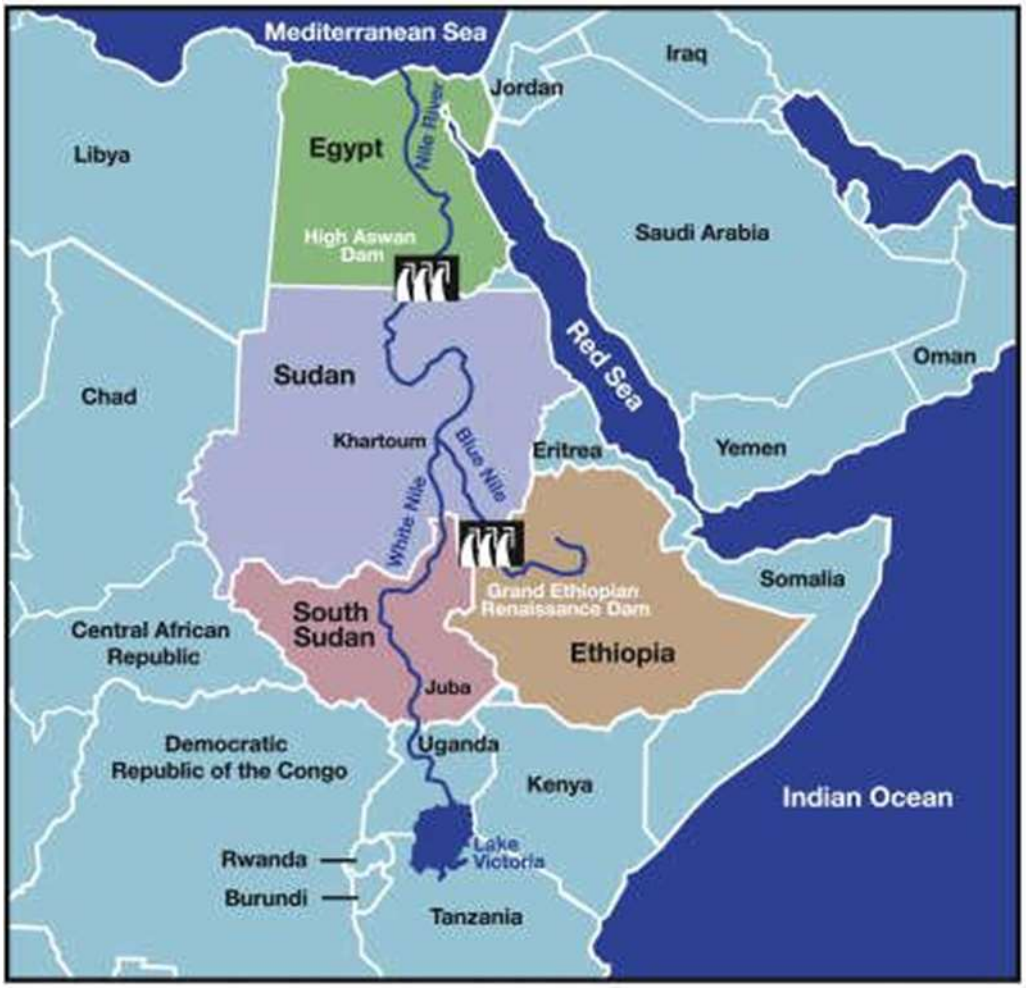


Figure 1 Shows a Map of the Grand Ethiopian Renaissance Dam

In April 2011, the Ethiopian government officially started construction on the Grand Ethiopian Renaissance Dam (GERD), which aims to make use of the electrical potential of the Blue Nile River. The Egyptian Government raised serious issues regarding the ecological sustainability of the project (Hipel et al., 2019). The Grand Ethiopian Renaissance Dam (GERD) negotiations began in 2012, and the Egyptian government asked the African Union (AU) to help resolve the dispute and make recommendations. 55 member states from the African continent make up the African Union (AU), an international body (Madani et al., 2011). The model for this conflict encompasses the Ethiopian Government, the Egyptian Government and the International African Union (AU). The options of action controlled by each DM are listed in Table 1. The Ethiopian Government has two options: 1. Delay the construction of the dam and engage in more negotiations with Egypt to find a mutually acceptable solution or 2. Seek support from the African Union to promote Ethiopia's right to use the Nile River for development and address the concerns of downstream countries. The government of Egypt has two options: 3. Accept the dam's construction as long as specific requirements are met, like a legally enforceable agreement on water sharing and payment for any harm the project may do to Egypt's water supply and agricultural output or 4. Disagree totally with the construction of the Dam. African

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Union (AU) controls a single option: 5. Mediate negotiations between Ethiopia and Egypt to find a peaceful and sustainable resolution to the dispute. Figure 2 shows a picture of the Grand Ethiopian Renaissance Dam bellow.

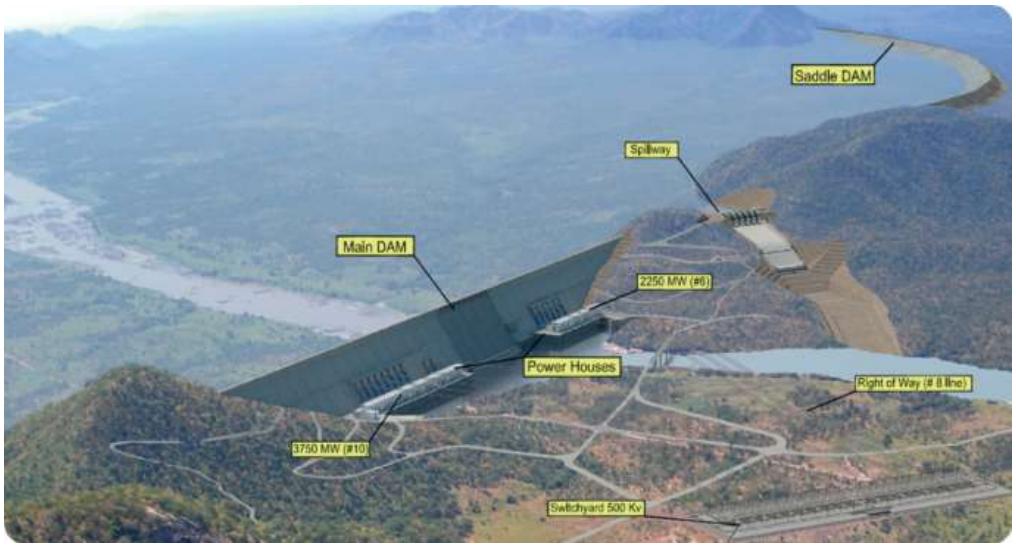


Figure 2 shows a picture of the Grand Ethiopian Renaissance Dam

3.1 Table 1: DMs and options for the international negotiation over the GERD

DMs	Options
1. The government of Ethiopia	(1). Delay the dam's construction and negotiate more with Egypt to find a mutually acceptable solution (Delay). (2). Seek support from the African Union to promote Ethiopia's right to use the Nile River for development and address the concerns of Egypt (Negotiation).
2. The government of Egypt	(3). Accept the dam's construction as long as specific requirements are met, like a legally enforceable agreement on water sharing and payment for any harm the project may do to Egypt's water supply and agricultural output (Compromise). (4). Disagree totally with the construction of the Dam (Disagree)
3. The African Union (AU)	(5). Mediate negotiations between Ethiopia and Egypt to find a peaceful and sustainable resolution to the dispute (Mediation).

Table 1: DMs and options for the international negotiation over the GERD

Table 1 portrays the decision-makers (DMs) and their alternatives for the international GERD negotiation. The DMs are the Ethiopian government, the Egyptian government, and the African Union (AU). Delay, negotiation, compromise, disagreement, and mediation are all options. The table demonstrates that the DMs have various interests and objectives. The GERD is something that Ethiopia's government wants to build to produce electricity and boost the national economy. The GERD could lead to a decrease in agricultural productivity and water availability, according to the Egyptian government. To facilitate negotiations between Egypt and Ethiopia and find a peaceful, long-term resolution to the crisis, the AU plans to act as a mediator. The table further demonstrates the variety of options open to the DMs. Ethiopia's government has three options: postpone building the project, talk to Egypt, or enlist AU assistance. Egypt's government has three options: agree to the project's construction on specific terms, object to the dam's construction, or take no action. The African Union can mediate Egyptian and Ethiopian negotiations. The options available to DMs will evolve. The Egyptian government's options may be constrained if the GERD is successful. The AU may become more involved in negotiations if the violence worsens. The goals of other regional countries may also influence the options available to the DMs. For instance, Sudan is interested in the GERD negotiations because it is a downstream nation on the Nile River. There is no simple way to resolve the conflict, according to the analysis of the DMs and possibilities for the global dialogue over the GERD. The DMs have various interests and objectives, as well as a variety of possibilities. The negotiations will be impacted by the DMs' options and forthcoming events. The goals of

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other regional countries were likely to influence the options available to the DMs. For instance, Sudan is interested in the GERD negotiations as a nation downstream of the Nile River.

3.2 Table 2: Feasible states for the GERD conflict

DMs	Options	Feasible states											
		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
Ethiopia	Delay	Y	N	Y	Y	N	Y	Y	N	Y	Y	N	Y
	Negotiation	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y
Egypt	Compromise	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N
	Disagree	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
AU	Mediation	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y

Table 2: Feasible states for the GERD conflict

Table 2 displays the possible outcomes of the GERD conflict. A feasible state is reachable if decision-makers (DMs) choose their alternatives wisely. According to the table, 12 states are feasible. These states are labelled S_1 to S_{12}. The table also indicates various alternatives each DM in each state has. In state S_1, for example, the Ethiopian government can choose to delay, whereas the Egyptian government can only opt to compromise. The feasible states demonstrate that there are numerous approaches to resolving the GERD conflict. However, some states are more likely to be reached than others. For example, state S_{12} is only achievable if all three DMs agree. This is an improbable scenario because the DMs have opposing interests and aims. The feasible states also illustrate that there are several potential deadlocks. State S_5, for example, is possible if the Ethiopian government chooses to delay and the Egyptian government chooses to disagree. This is a deadlock since both DM will keep their stance. The feasible states are an excellent tool for comprehending the GERD conflict. The states depict the various options accessible to the DMs as well as the potential outcomes of the battle. States can also be used to identify possible deadlocks and generate conflict resolution techniques.

3.3 Integrated Graph Model for the GERD Conflict

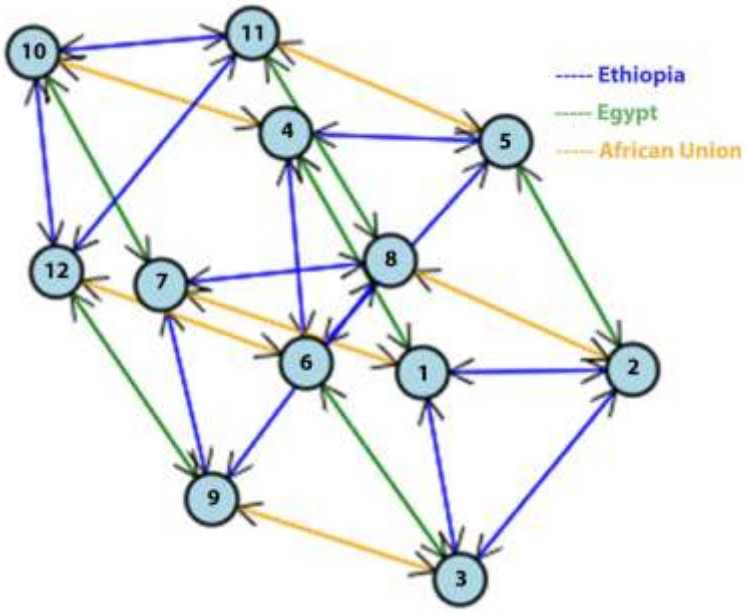


Figure 2. Integrated Graph Model for the GERD Conflict

The graph in Figure 2 shows the possible movements that decision-makers (DMs) in the GERD model can make between various states. The graph demonstrates the existence of reversible and irreversible actions. Moves that can be reversed are called reversible moves. For instance, the Egyptian government may return to state S_1 if it moves from state S_2 to state S_1. Unreversible actions are referred to as irreversible actions. For instance, the Ethiopian government cannot return to state S_6 after moving to state S_9. The graph demonstrates two irreversible actions the Ethiopian government took, from state S_6 to state S_9 and from state S_8 to state S_5. This implies that once a decision has been

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made, the Ethiopian government cannot modify it. There are no permanent actions taken by the African Union (AU) or the Egyptian government. This implies that they are always free to change their thoughts. The idea of irreversible steps in the GERD model is crucial because it captures that certain decisions are more complex to undo than others. For instance, reversing the Ethiopian government's decision to construct a dam on the Nile River would be challenging. The GERD model is more challenging to solve because of irreversible moves. This is since finding a stable solution is more challenging when some moves are irreversible. The GERD model is a helpful tool for comprehending the various viewpoints on the GERD project, notwithstanding its difficulties. The model can assist in determining potential project outcomes and weigh the advantages and disadvantages of various solutions.

3.4 Preference Rankings of the GERD Model

DMs	Preferences
Ethiopian Government (DM1)	$(S_{12})>(S_{11})>(S_9)>(S_8)>(S_6)>(S_5)>(S_3)>(S_2)>(S_{10})>(S_7)>(S_4)>(S_1)$
Egyptian Government (DM2)	$(S_{12})>(S_{10})>(S_{11})>(S_6)>(S_4)>(S_5)>(S_9)>(S_7)>(S_8)>(S_3)>(S_1)>(S_2)$
African Union (AU) (DM3)	$(S_9)>(S_3)>(S_7)>(S_1)>(S_{12})>(S_6)>(S_{10})>(S_4)>(S_8)>(S_2)>(S_{11})>(S_5)$

Table 3: preference rankings of the GERD model

Table 3 displays the GERD model's preference rankings for three decision makers (DMs): Ethiopian Government (DM1), Egypt Government (DM2), and the African Union (AU) (DM3). According to the preference ranking, DM1 prefers state S_{12} the most, then state S_{11}, and so on. State S_1 is the one that DM1 prefers the least. The ordering of preferences for DM2 is comparable to that of DM1. State S_{12} is preferred most by DM2, then state S_{10}, etc. State S_1 is the least desired for DM2. DM3's preference rankings differ from DM1's and DM2's. State S_9 is the preference of DM3, followed by state S_3 and so forth. State S_5 is the least desired for DM3. The three DMs' preference rankings reveal no unambiguous agreement on the preferred state of the GERD model. While DM3 favors a state that would allow for a more equitable allocation of water, DM1 and DM2 favor conditions allowing them to maximize their water usage. Conflict may arise when the three DMs order their preferences differently. The argument may get worse if the three DMs can't agree on the preferred state of the GERD model.

4: Table 4: Stability Analysis Results

States	Nash				GMR				SMR				SEQ			
	DM1	DM2	DM3	E	DM1	DM2	DM3	E	DM1	DM2	DM3	E	DM1	DM2	DM3	E
S_1							✓				✓				✓	
S_2							✓				✓				✓	
S_3	✓				✓		✓		✓		✓		✓		✓	
S_4		✓				✓	✓			✓	✓			✓	✓	
S_5		✓			✓	✓			✓	✓				✓		
S_6	✓	✓			✓	✓	✓	•	✓	✓	✓	•	✓	✓		
S_7			✓				✓				✓				✓	
S_8			✓		✓		✓		✓		✓				✓	
S_9	✓		✓		✓		✓		✓		✓		✓		✓	
S_{10}		✓	✓			✓	✓			✓	✓			✓	✓	
S_{11}		✓	✓		✓	✓	✓	•	✓	✓	✓	•		✓	✓	
S_{12}	✓	✓	✓	•	✓	✓	✓	•	✓	✓	✓	•	✓	✓	✓	•

Table 4: Stability Analysis Results

The findings of the stability analysis of a game theory with three decision-makers (DMs) are shown in Table 4. The approach considers four different stability concepts: Nash, GMR, SMR, and SEQ. Nash stability implies that no DM has the incentive to stray from their plan unilaterally. Because of GMR stability, no DM is incentivized to depart from their plan, even if the other DMs are not using Nash's strategies. Because of SMR stability, no DM is incentivized to change from their approach, even if the other DMs use GMR methods. Because of SEQ stability, no DM is incentivized

to depart from their plan, even if the other DMs also use SEQ methods. According to the table, states S_3, S_9, S_{10}, S_{11}, and S_{12} are stable under all four stability concepts. As a result, these states could be potential conflict resolutions. Some concept of stability holds that states S_1, S_2, S_4, S_5, S_6, S_7, and S_8 are stable. These states may represent potential conflict resolutions. However, they are less stable than the states in S_3, S_9, S_{10}, S_{11}, and S_{12}. The states in the chart that are not marked as stable are not viable conflict resolution options. These states are unstable because at least one DM is incentivized to depart from their strategy. The table also demonstrates that the definition of stability grows stronger as you proceed from Nash to GMR to SMR to SEQ. This implies that the stable states under SEQ are also stable under GMR, SMR, and Nash, but that contrary is not necessarily true. The probability that the state will be a stable resolution to the dispute generally increases the stricter the definition of stability. However, the more rigid the definition of stability, the more challenging it might be to identify a state that fits the definition. The stability study results can be utilized to assist the DMs in coming to a consensus. The DMs can determine which states satisfy all four criteria for stability, and they can then try to negotiate a deal that leads to one of these states.

5. CONCLUSION

The analysis identified the essential parties involved in the GERD controversy and examined their interests. It understands the interests and viewpoints of the different parties, allowing for the development of a comprehensive picture of the dispute. Game theory models were used to examine how Ethiopia and Egypt interact strategically and make decisions. The game theory established a framework to evaluate the actions and responses of the parties involved while considering their competing interests and possible outcomes. The study evaluated possible outcomes and points where equilibrium would occur from Ethiopia's and Egypt's competing interests. It was feasible to have a more precise knowledge of the potential outcomes of the disagreement by looking at alternative scenarios and equilibrium states. The study investigated alternative collaborative solutions and negotiation tactics that might result in an environmental conflict resolution. The study looked at cooperative techniques and negotiation tactics to find routes to a mutually agreeable settlement. By highlighting the interests of important stakeholders, examining strategic interactions, and considering alternative resolution solutions, this research helps us comprehend the GERD debate. Policymakers, decision-makers, and other key stakeholders can use the study's results as guidance as they work to resolve the GERD controversy sustainably and collaboratively.

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