INTERNATIONAL JWM&D

International Journal of Water Management and Diplomacy

ISSN 2717- 8277

Volume: 1
Issue : 9
January 2026

Published by HPA Hydropolitics Association

International Journal of
Water Management and Diplomacy

Editor-in -Chief

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International Journal of

Water Management and Diplomacy

Official Journal of the Hydropolitics Association

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International Journal of

Water Management and Diplomacy

Official Journal of the Hydropolitics Association

Volume :1 Issue: 9 January 2026

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International Journal of Water Management and Diplomacy
Issue: 8 2025
e-ISSN:2717-8277

Renaissance Dam: Negotiations and Regional Cooperation Between Egypt, Sudan, and Ethiopia

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Abstract

This study examines the issue of the Grand Ethiopian Renaissance Dam (GERD) from the angle of the interaction between political negotiations and the potential for regional cooperation, based on analytical tools including multi-track water diplomacy, SWOT analysis, and the 2030 Sustainable Development Goals, taking into account the legal frameworks relied upon by Egypt, Sudan, and Ethiopia. The study concluded that the absence of a binding and effective legal agreement led to stalled negotiations, given the differing legal references of each party. The SWOT analysis also showed that Ethiopia capitalised on its geographical location and internal strengths to impose a different negotiating reality. At the same time, Egypt and Sudan remained committed to the principle of 'historical rights'. The study recommends establishing a permanent mechanism for coordination among the three countries, activating informal diplomatic channels, and capitalizing on opportunities to share benefits, not just water, with the option of international arbitration when necessary. This vision outlines a framework to move the dispute from tension to a just and sustainable development partnership.

Keywords: Renaissance Dam- Negotiations - Water Diplomacy – Egypt – Sudan – Ethiopia

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1. Introduction

The Nile River, one of the longest rivers in the world, measuring 6,850 kilometres in length, flows from south to north and traverses eleven African countries: Tanzania, Kenya, Uganda, Rwanda, Burundi, Ethiopia, Eritrea, South Sudan, Sudan, and Egypt. The Nile River has three main branches that feed it: the Blue Nile, the White Nile, and the Atbara River. The Blue Nile originates from Lake Tana in Ethiopia and accounts for approximately 53 percent of the Nile River's flow, which is a seasonal river that fluctuates in response to the rainy season. The Blue Nile meets the White Nile in Sudan, which originates from Lake Victoria, and its contribution to the Nile is reduced due to the loss of water to evaporation in the dam area. The Nile flows north for about 322 kilometres to meet the Atbara River, which originates from Ethiopia. The river continues its flow to Egypt and branches off into the Damietta and Rashid branches to flow into the Mediterranean Sea. The Nile River is of great importance to the Nile

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Basin countries, as only about 20 per cent of the areas through which the Nile River passes are rainy areas that form the Nile waters. Most of the areas through which the Nile River passes are arid or semi-arid, and the Nile River is its main resource (El-Fadel, M., El-Sayegh, Y., El-Fadl, K., & Khorbotly, D., 2003).

The Grand Ethiopian Renaissance Dam (GERD) is one of the millennium projects undertaken by Ethiopia in its development renaissance, implementing a range of projects to support and promote development in Ethiopia. The GERD crisis is one of the issues that occupy international and regional circles in Africa in general and the Nile Basin countries in particular. It is a dam built by the Ethiopian government on the Blue Nile River, which is the main component of the Nile River and accounts for about 85 percent of the Nile's water. The construction of the dam has sparked a crisis between Egypt, Sudan, and Ethiopia over Ethiopia's right to build a dam of this size and its concerns about its impact on water flows, as well as its historical share of Nile water under the 1929 and 1959 agreements, which Ethiopia and most other Nile Basin countries do not recognise.

Some literature has addressed resolving the GERD crisis by providing a wider negotiating space, and that it can be linked to issues other than water, as stated in a study by M. Atwan (2018) entitled Water relations between Ethiopia and Egypt, the possibility of conflict and future co-operation. Salman Mohammed Ali Salman (2016), in his study "The Grand Ethiopian Renaissance Dam (GERD): The Road to the Declaration of Principles and the Khartoum Document," discusses the Grand Ethiopian Renaissance Dam (GERD) and its imposition on Egypt and Sudan by signing the Declaration of Principles and the Khartoum Document. By signing the Declaration of Principles and the Khartoum Document, Ethiopia gained recognition from Egypt and Sudan of the reality of the dam. The report examines the opportunities that each country missed by unilaterally planning its development in isolation from the others, opportunities that could have been seized through co-operation.

The importance of this paper stems from the fact that it addresses this issue from an angle that combines analysing the reality of the negotiations and foreseeing the possibilities of regional cooperation, based on a set of analytical and strategic tools. The paper relies on the concept of water diplomacy as a key entry point to promote understanding between the three countries. In addition to employing a SWOT analysis to reveal the strengths, weaknesses, opportunities, and threats surrounding the issue. This is linked to international references such as the 2030 Sustainable Development Goals, especially the sixth goal related to clean water and sanitation, and the seventh goal related to clean energy.

The study aims to answer the question of whether the GERD negotiations can be an effective entry point for enhancing regional cooperation between Egypt, Sudan, and Ethiopia. This question is followed by many supporting questions that explore the possibilities of shifting from conflict to cooperation, the role of different parties, and how innovative tools can be Activated To Build Trust And Achieve Joint Development.

2. Materials and Methods

2.1. Renaissance Dam Negotiations

2.1.1. Trilateral Negotiations

Since ancient times, the Nile has been the lifeblood of Egypt. Throughout the ages, Egypt has maintained control over it and has codified this control through agreements with the Nile Basin countries or with colonial powers on their behalf. After gaining independence, Egypt used its strategic and political position in the Middle East to prevent Ethiopia from accessing the funds allocated for Nile River development projects. Even though about 85 percent of the Nile water comes from Ethiopia, the country is deprived of water and energy, unable to feed itself, and lacks development. In 2011, Ethiopia decided to make several developmental decisions, including constructing a large hydroelectric dam to produce electricity. The downstream countries considered the project a threat. Still, Ethiopia argued that the project would not affect the downstream countries, Egypt and Sudan, and would provide them with benefits, such as a stable water supply, silt retention, reduced evaporation, and lower electricity costs. Egypt and Sudan rejected the project, but Ethiopia had already started building the dam, and when Egypt saw that the project had become a reality, it demanded studies on the impact of the dam on it before construction was completed, which Ethiopia refused. Once again, Egypt demanded a reduction in the size of the dam, which Ethiopia also refused, and the three countries began negotiations on the dam (Zargau, T., 2024).

The three countries engaged in negotiations to reach a compromise. The negotiations continued for eight years as trilateral negotiations between Egypt, Sudan, and Ethiopia until another phase of mediation began, which included the United States, the African Union, the United Arab Emirates, and others, but all these endeavors failed. In 2012, the Committee of International Experts was formed to review the reports on the dam's design and the technical impacts on Egypt and Sudan. The committee recommended that further technical studies should be conducted on the design of the dam and the expected impacts on downstream countries (Basheer, M., 2021).

Following the publication of the Panel's report on 31 May 2013, negotiations continued and a mechanism called the ‘National Committee of Experts’ was formed, consisting of technical experts appointed by the governments of the three countries, whose task was to agree on ways to implement the recommendations of the International Panel of Experts. The committee hired a foreign consultant to conduct the studies recommended by the international team of experts, but the required studies were also not completed. Then a body was established by the three countries called the National Independent Scientific Research Group (NISRG), consisting of five hydrologists from the three countries, whose task was to agree on technical scenarios for the filling and operation of the Renaissance Dam, but unfortunately the committee also failed to fulfil its mission (Hilal, M., & Bakhit, H. M., 2023).

After the failure of all endeavours to achieve progress and agreement in the GERD negotiations, the differences between Ethiopia and Egypt intensified, especially after the leakage of a meeting between Egyptian President Mohamed Morsi and his leaders in which military action was proposed. Sudanese President Omar al-Bashir called for trilateral meetings at the presidential level in Khartoum, which began in November 2013 and lasted a year and a half, during which seven meetings were held, culminating in an agreement on 23 March 2015 called the 'Declaration of Principles Agreement between the Arab Republic of Egypt, the Federal Democratic Republic of Ethiopia and the Republic of Sudan on the Grand Ethiopian Renaissance Dam Project' (Gibson, R. A., 2023).

The agreement consisted of ten principles that dealt with cooperation between the three countries, in which Egypt and Sudan recognised Ethiopia's right to development and also endorsed the principles of development and regional integration. One of the principles dealt with the principle of non-damage to other countries, and that in case of damage, the damage should be eliminated or mitigated by discussing compensation. Another important principle that was agreed upon was the principle of reasonable and equitable use of water, taking into account geographical and environmental conditions and social needs such as population and economic needs of other countries. Regarding the initial filling of the dam, the parties agreed to cooperate in the initial filling and operation of the dam by agreeing on guidelines and rules for filling the GERD and annual operation, with the possibility of changing them by the owner of the dam according to circumstances and informing the downstream countries of any changes. The principles include building trust between the countries and Ethiopia's prioritisation of Egypt and Sudan in purchasing energy from Ethiopia. It was also agreed to exchange information and transparency to assist the Committee of Experts, and that Ethiopia will continue to implement all the recommendations of the Committee of Experts to ensure the safety of the dam. In the event of disputes between countries, they should be resolved peacefully, and if the matter is not resolved, mediation, conciliation, or evaluation by the heads of state can be used to help resolve the dispute (DoP, 2015).

Despite all efforts, the three countries could not agree on the terms of reference for the studies, and the negotiations collapsed. In 2018, negotiations resumed, and an independent national scientific research group consisting of the three countries was established. No agreement was reached, but the findings of the research group were taken as the basis for the next round of negotiations (Basheer, M., 2021)

The reason for the collapse of the tripartite negotiations was the lack of agreement on how to fill and operate the dam, in addition to Egypt's insistence on its share of the Nile River according to the historical Nile water agreements, which Ethiopia rejects. The parties also disagreed on the filling period of the dam, which Egypt set at no less than twenty years, while Ethiopia wants it to be between five and seven years. Egypt has demanded to have a hand in the operation of the dam, but Ethiopia believes that the dam is an entirely national project located in Ethiopian territory and that this would be considered an interference in Ethiopia's internal sovereignty. As for Sudan, its position changed from supporting the dam to siding with Egypt against the dam, governed by the political changes that occurred in Sudan (Zargau, T., 2024).

2.1.2. Mediation in Renaissance Dam Negotiations

After the trilateral negotiations between Egypt, Sudan, and Ethiopia failed to reach a solution that satisfied all parties, Egyptian President Abdel Fattah al-Sisi requested, on the sidelines of the 74th session of the United Nations General Assembly in 2019, that the United States mediate in the GERD issue. This is due to the influence of the United States on the three countries. Although Ethiopia rejected the principle of external mediation, it accepted the mediation of the United States. It is also due to Egypt's strategic partnership with the US and the improved relations between Sudan and the US after the 2019 revolution. Negotiations under US mediation began on 6 November 2019 at the invitation of the US Treasury Secretary to the three countries and the World Bank. The negotiations continued until February 2020 and consisted of twelve rounds, seven of which were held in the United States and five between the three countries. The meetings aimed to determine what was achieved in the trilateral negotiations, identify points of convergence and divergence between the three countries, and agree on some principles for future negotiations (Helal, M., & Bekhit, H. M., 2023).

At the end of each of the meetings held in Washington, a joint declaration was made by the three countries: the United States and the World Bank. At the end of the meetings, an agreement was announced, called the 'Washington Talks Agreement ', which prohibited Ethiopia from filling the GERD until an agreement was reached, which led to Ethiopia's refusal to sign the agreement. Ethiopia stated that Egypt and Sudan, according to the 2015 Agreement of Principles signed in Khartoum, agreed to synchronize the construction of the dam with the negotiations, so Ethiopia demanded that the role of the United States be reduced from mediator to observer (Zargau, T., 2024).

Regarding the disagreement between the three parties on how to fill and operate the dam in years of drought or prolonged drought, the three countries issued a statement explaining the need to develop a mechanism to mitigate the effects of drought during the filling and operation of the dam. As is standard procedure in these cases, the United States and the World Bank made some recommendations (Sidi, W. M., & Fantini, E., 2023). These recommendations are that 'Ethiopia should release the same proportion of water that normally flows to downstream countries and utilise the reservoir in the GERD' during periods of drought. Ethiopia believes that it will not be able to own its allocated share of the Blue Nile and will not be able to use its tributaries for irrigation and hydroelectricity. Ethiopia has also recognised Egypt's share of water according to the 1959 Water Treaty, so the GERD will be a storage facility for Egypt. Egypt also requested that an arbitration clause be added to the US draft agreement regarding the dispute resolution process (Tekuya, M. E., 2020).

No agreement was reached between the three countries on the Washington Agreement because Ethiopia rejected the agreement and accused Washington of siding with Egypt.

After the failure of the US mediation, a new mediation led by the African Union began. The first meeting was held at the end of June 2020 under the chairmanship of South African President Ramaphosa, and the meeting was held via video conference to assess what had been reached through the tripartite negotiations. The negotiations began in a tense atmosphere, with Egypt and Sudan threatening to withdraw from the negotiations or suspend them, but the South African president insisted on continuing the negotiations (Side, W. M. & Fantini, E. 2023). The AU negotiating team consisted of representatives from the European Union, the United States, which acted as an observer, and South Africa, which was an observer but after assuming the AU presidency shifted to a leadership role (Ranjan, A., 2024).

Although several media outlets reported that the negotiations had collapsed, on 26 June 2020, the African Union issued a statement confirming that the negotiations had been successful and that about 90% of the points of disagreement had been resolved. The statement stated that 'the three parties are free to refrain from making any statement or taking any action' but should not take any action that could complicate the negotiation process. However, Ethiopia announced through its media the start of the planned filling of the dam in the first year (estimated at 4.9 billion cubic metres), and it was not clarified whether this acceleration in filling was due to the high volume of water needed to test the turbines. This action prompted Egypt and Sudan to submit a memorandum to the United Nations condemning Ethiopia's behaviour in starting the filling without binding rules on the filling of the dam, and that this action leads to a threat to regional peace and security (Makoni, F., 2021).

Negotiations resumed on 21 November 2020 in Kinshasa, the capital of the Democratic Republic of Congo, under the auspices of EU President Felix Tshisekedi, but no satisfactory agreement was reached. The reasons for the disagreement were the rate of filling the reservoir, the annual filling plan, and the resolution of future disputes. Egypt and Sudan wanted a legally binding agreement for all parties, and Ethiopia wanted a less stringent agreement. Egypt and Sudan demanded that the mediation be expanded to include the European Union and the United States, along with the African Union, while Ethiopia wanted 'full ownership of the process by the three countries and the integrity of the AU-led process'.

The situation between the three countries became tense, and the Egyptian and Sudanese air forces carried out joint manoeuvres called 'Nile Eagles 2'. President Abdel Fattah al-Sisi stated that all options, including the military option, are open. The Ethiopian Minister of Water and Irrigation invited Egypt and Sudan to appoint key employees or operators of the dams to exchange data between the three countries for the second year, 2021, but the two countries rejected the request. On 13 April 2021, Sudanese Prime Minister Abdalla Hamdok invited his counterparts to a summit to assess the negotiations (Makoni, F., 2021).

The three countries agreed not to take unilateral actions, including filing, before reaching a binding agreement, but Ethiopia started the first filing immediately after the summit (Ranjan, A., 2024). Negotiations through the AU also failed, and no agreement was reached between the three countries.

After the failure of the AU-mediated negotiations, in March 2021, the United Arab Emirates (UAE) requested to play a mediation role in an attempt to reconcile the three parties. Sudan welcomed the mediation but requested the participation of the US, EU, and UN as observers in the negotiations (Ranjan, A., 2024). The UAE is geopolitically and geo-economically active in the Horn of Africa and has good relations with Ethiopia. The negotiations were held in three rounds and emphasised 'the importance of reaching common understandings between the two sides'. The UAE Ministry of Foreign Affairs issued a statement emphasising 'the importance of reaching a mutually acceptable solution that guarantees the water rights and security of the three countries'. After this statement, the Egyptian government and Egyptian newspapers launched a fierce campaign against the UAE, arguing that the UAE's talk of 'the rights of all parties' is a clear bias in favour of Ethiopia and against Egyptian policy. The UAE is working to protect its interests in the region and wants to have a diplomatic presence there. The negotiations did not reach a positive outcome and collapsed in June 2022 (Ahmed, J.K., 2024).

Ethiopia is adopting a strategy of procrastination by prolonging the negotiations while the construction, filling, and operation of the dam continue to put both Egypt and Sudan in front of the reality that the dam is finished and operational (Matar, A.B. & Hardan, E., 2022: 669-670), also, due to the lack of trust between the parties and the belief of Egypt and Sudan that Ethiopia does not only use the dam for development and hydropower production but has other political agendas. This is intended to compel Sudan and Egypt to recognize Ethiopia's water sovereignty over the Blue Nile, thereby legitimizing Ethiopia's control over the Nile and its unrestricted right to use its waters through a new agreement (Hilal, M., & Bakhit, H. M., 2023).

2.2. The legal dimension of the Renaissance Dam from the Ethiopian, Sudanese, and Egyptian perspectives and the perspective of international law

In establishing its legal right to the Nile River in general and constructing the Renaissance Dam, Ethiopia relied on a set of legal agreements and principles of international law. These include the Cooperative Framework Agreement signed between most of the Nile Basin countries in 2010 and some principles of international law, such as 'the common interest of states, the supremacy of agreements between states, and state responsibility'. These principles are the basis of Ethiopia's foreign policy regarding the Nile as an international river (Alibacho, H., 2014).

In addition to the right to development referred to in the UN Declaration adopted by the UN General Assembly on 4 December 1986, which states that 'every human person and all peoples have the right to participate in and contribute to the enjoyment of economic, social, cultural and political development in which all human rights and fundamental freedoms can be fully realised'. The African Charter on Human and Peoples' Rights, the 1992 Rio Declaration, the 1993 Vienna Programme of Action, the Millennium Declaration, and the 2015 Sustainable Development Goals recognise the right to development of peoples (Jamal, N., 2021).

As for Egypt and Sudan's reliance on the 1902 colonial agreement signed between Britain and King Menelik of Abyssinia, Ethiopia claims there is an error in the translation of Article 3 from English to Amharic. Article 3 states that 'no work shall be done or permitted to be done on the Blue Nile, Lake Tana or the Sobat River that would impede the flow of their waters without the consent of His Britannic Majesty's Government and the Government of Sudan.' The word 'stop' was mistranslated as 'as long as King Menelik does not stop the flow of water, the agreement does not prevent him from using and diverting the waters of the Blue Nile'. Hence, Ethiopia considers the agreement invalid (Zostiet, K. M. L. T. A., 2020). Ethiopia argues that the agreement did not enter into force because Britain did not ratify it, in addition to the fact that the agreement is a border agreement and not a water agreement (Jamal, N. 2021).

Ethiopia defended Egypt and Sudan's claim to have specific quotas in the Nile waters according to the 1929 and 1959 agreements, stating that according to the 1969 Vienna Convention on the Law of Treaties it did not ratify these colonial agreements and that they are not binding on it according to Article 34 of the Vienna Convention on the Law of Treaties, which states that 'the Convention cannot create obligations or rights for a third State without its consent or express will', and also according to the clean slate principle (Zostiet, K. M. L. T. A., 2020). Ethiopia considers that these two agreements, the first of which was signed in 1929 between Egypt and the United Kingdom on behalf of Sudan and the East African countries bordering Lake Victoria (Kenya, Tanganyika [now Tanzania] and Uganda), and amended in 1959 between Egypt and Sudan after Sudan gained independence, cannot be binding on Ethiopia and considers it a bilateral agreement that no other party is bound by (Jemal, N., 2021).

Egypt relies on historical agreements to prove its legal right to reject the Renaissance Dam, arguing that the 1902 Anglo-Abyssinian Agreement recognises Egypt's 'historical and natural rights' to the Nile. Ethiopia waives any rights to the Nile River and to take any measures that could reduce the flow of water to downstream countries, only after referring to the two downstream countries, which makes the construction of a dam as large as the Renaissance Dam illegal. This is because the Renaissance Dam could limit the development of upstream countries' water resources and reduce the volume of water flowing to them, according to Article 7 of the Convention, which "imposes on States the duty to take appropriate measures to prevent serious harm to other States sharing an international watercourse" (Abebe, D., 2014).

The 1929 and 1959 agreements with Sudan gave it the right to veto projects on the riverbed. Egypt also relies on the support of international financial institutions such as the International Monetary Fund, the World Bank, the African Development Bank, and powerful countries. Egypt can also use the national security and water security card (considering water an existential security issue) to gain regional and international support (Darwish, H. 2021). Egypt claims that the 1929 and 1959 agreements between Egypt and Sudan, which share the waters of the Nile, apply to all countries in the Nile Basin (Abebe, D., 2014).

Egypt also relies on several international principles, such as the principle of 'international duty' to Ethiopia as a country located upstream. In the case of constructing projects on the Nile River or one of its branches, it must submit preliminary notification documents to verify the technical safety of the project, according to the international principles of 'not altering the course of international rivers' and 'not harming riparian states' (Alibacho, H. 2014: 3). Egypt also relies on the doctrine of prior and historical use, which adopts the idea that 'the first user who uses a certain amount of water for a beneficial purpose enjoys an exclusive property right over the amount of water used against subsequent users.' Here, Egypt is the first user of the Nile River, and Ethiopia is the subsequent user and, therefore, cannot use the Nile River if the use conflicts with Egypt's previous use. As for Ethiopia's reliance on the principle of fair and reasonable use of the Nile, Egypt believes that Ethiopia is a desert country and has no access to the Nile River, and that Ethiopia has other options to meet its water resources needs, as it is a rainy country and has other rivers, so this principle cannot be applied here (Zostiet, K. M. L. T. A. 2020).

From the perspective of international law, several principles and doctrines regulate transboundary rivers, river management laws and projects on them, the most important of which are the four theories:

1/ The theory of absolute territorial sovereignty, 'The Harmon Doctrine', is one of the first theories that emerged in the regulation of international rivers. It states that 'the state has full control over all waters within its territorial jurisdiction and can use these waters without considering the effects on other countries that share the river, especially downstream countries'. But this principle is at odds with the current ethos in Egypt and Ethiopia, which promotes 'mutual benefit' as a guiding principle.

2/ The second theory, 'Absolute Territorial Integrity', is the successor to Harmony's theory. It states that upstream states can utilise the river if this utilisation does not affect downstream states. 'A state has the right to expect the same volume of water to flow without interruption in quantity and without deterioration in quality' and 'there shall be no interruption, reduction or increase in flow resulting from the use of water located in a coastal state.' Downstream states also have the right to object to any use of upstream water that may adversely affect the flow of water (Alebachew, H. 2014).

3/ The 'common interests' theory, which emphasises that the development of the entire river basin is the responsibility of all countries in the basin. Countries should cooperate to rationally develop and utilise shared water resources and share the benefits. The basin should be managed as a single unit, and regional and national boundaries are of no importance in this theory. This theory was favored by Ethiopia in the past, but rejected by Egypt for several reasons, especially about non-navigational uses of international waterways, namely that the theory 'does not take into account the different degrees of dependence on international waters among states, does not take into account the existence of alternative water sources for upstream states, and does not take into account the different capacities of states to use international rivers'.

4. The theory of limited sovereignty and territorial integrity states that 'States have the sovereign right to use water resources in international waterways located within their territories to the extent that such use does not cause any harm or damage to other states'. Accordingly, 'if a state's use of water resources in international waterways affects the interests of the state with which it shares a river, the state's sovereign right to use water in international waterways is limited', and Egypt adopts this theory (Alibacho, H. 2014).

Also, among the customary laws and principles adopted by the United Nations in its resolution 1803 (XVII) of 14 December 1962 is the 'Law of Permanent Sovereignty over Natural Resources'. According to the International Court of Justice, sovereignty over natural resources should not be divorced from the rights of other states, so that the utilisation of natural resources from within a state should not harm other states that share the resource. Therefore, all states involved in the GERD dispute are obliged to exercise their sovereign rights over natural resources within their territories, but are obliged to ensure that their activities do not cause transboundary environmental damage (Valles, M.S., & Borquez, S.B., 2022).

According to the principles of international water law concerning transboundary watercourses, the two most important laws, the Helsinki Rules (1966) and the United Nations Watercourses Convention (1997), can be referred to. Among the basic principles is the principle of equitable and reasonable utilisation, as set out in Articles 5, 6, 7, 15, 16, 17, and 19 of the Helsinki Rules. The principle of non-substantial harm, as set out in Articles 5, 10, 11, and 29(2) of the 1997 Watercourses Convention and Articles 7, 10, 12, 15, 16, 17, 19, 20, and 21(2) of the Helsinki Rules. The principle of co-operation and exchange of information is contained in Articles 29(1), 29(2) and 31 of the 1997 Convention and Articles 5(2), 8, 9, 11, 12, 24(1), 25(1), 27, 28(3) and 30 of the Helsinki Act. The principle of peaceful settlement of disputes is enshrined in Articles 26 to 37 of the 1997 Agreement and Article 33 of the Helsinki Act. These articles are the basis for resolving disputes over the construction of the Renaissance Dam (Zostiet, K. M. L. T. A. 2020).

According to the 1911 Madrid Declaration, which deals with the framework for the development of water cooperation, countries sharing a single water resource must be 'in continuous material dependence on each other'. According to the rules of modern international law, there are two principles specific to the Nile River waters regarding the sharing of water resources: The first is the principle of equitable utilisation, which grants each state 'a reasonable and equitable share in the beneficial uses of the waters of the international drainage basin within its territory'. The second principle is basin-wide management, which, according to the first UN Secretary-General, Dag Hammarskjöld, means that all countries sharing a water basin should share in its management. It is also supported by the Bar Association, which considers that a geographical area is an 'integrated entity' and that development within it should be integrated and not 'fragmented', and therefore, joint administration should be established to manage the affairs of the basin.

If we apply these two principles, Egypt's control of more than half of the Nile River is a clear violation of the principle of equitable use of water. As for Ethiopia, it cannot consume more water and use more than it is entitled to, as evidenced by the massive production of electricity from the Renaissance Dam. Ethiopia is supposed to generate some electricity for the Nile Basin countries, especially at reduced prices. Ethiopia is also violating the principle of joint management of the basin by building the Renaissance Dam on its own and without the consent of the other Nile Basin countries (Hussein, M.D. 2021).

From an international law perspective, this paper examines the GERD issue from the perspective of international law principles and historical agreements. The GERD case is linked to the principles of fair and reasonable utilisation, prevention of significant harm, and prior notification. From Ethiopia's point of view, the dam does not represent any harm to Egypt and Sudan, but both countries consider that filling and operating the dam without a binding agreement may cause them serious damage and affect the flow of water and water projects and plans in both countries. Despite Ethiopia's verbal pledge not to harm it, it refuses to sign a legally binding agreement. Regarding prior notification, the countries involved must 'consult and provide prior notification'. Ethiopia notified Egypt and Sudan of the construction of the dam, but no consultation took place, and Ethiopia began construction and filling the dam while negotiations continued, and no agreement was reached.

The other perspective of international law is the historical agreements that are considered legal documents, such as the 1902 agreement in which Ethiopia committed not to build any project on the Nile River that could stop the flow of water without the consent of Sudan and Egypt, as well as the 1929 and 1959 agreements called the Nile Water Partition Agreements between Egypt and Sudan. The 1929 and 1959 agreements that were called the Nile Water Partition Agreements between Egypt and Sudan, as well as the Declaration of Principles signed between the three countries in 2015, which included a commitment to do no harm and cooperation between the three countries, but did not provide any solutions regarding the differences between the three countries in filling and operating the dam. So legally, there is no binding legal agreement on the filling and operation of the dam to

Issue: 8 2025
e-ISSN:2717-8277

guarantee the rights of Egypt and Sudan, and at the same time, projects within other countries cannot be objected to unless it is proven that there is serious harm. Failure to reach an agreement could lead to litigation before the International Court of Justice and the Security Council.

2.1.3. Using the Renaissance Dam to promote regional cooperation between Egypt, Sudan, and Ethiopia

Some recent studies suggest that the next war will be a water war, driven by the decline in the proportion of freshwater, population growth, and environmental issues that affect water. Also, about 263 transboundary rivers can be a reason to ignite wars between countries that share water resources. However, some studies have emphasised that transboundary water can be a source of cooperation between countries and that water incentivises cooperation by managing shared basins, even when other issues are present (Wolf, A. T., Stahl, K., & Macomber, M. F., 2003).

However, the process of shared water management faces challenges, including the need to involve all stakeholders competing for the resource. The second challenge relates to the evolution of governance, whereby water management approaches that once focused on engineering and technical solutions, and on modelling water basins and ecosystems, have expanded into multiple strategic approaches. Here, there can be a contrast between the technical approach and the political approach, as the political approach is concerned with supply and trying to provide as much water as possible, so resorting to the construction of dams and water stations on the main rivers and their branches, which leads to the emergence of the philosophy of command and control. The third challenge is related to environmental and climatic changes that affect the amount of water. The fourth challenge is how to reconcile political and basin boundaries (the transboundary challenge), by reconciling national interests with the management of the shared resource. The exchange of information and data about projects and the basin is an indication of the health of relations between the basin countries (Zeitoun, M., Goulden, M., & Tickner, D., 2013).

The paper addresses three ways to resolve the Renaissance Dam crisis, to bring Egypt, Sudan, and Ethiopia closer together, and to open the door to cooperation and regional approaches using the Renaissance Dam, through water diplomacy, analysing the basics, and using the 2030 Sustainable Development Indicators (SDIs).

2.1.3.1. Water Diplomacy

Water diplomacy can be defined by expressing it in five aspects: Political, Preventive, Integrative, Cooperative, and Technical. The normative basis of water diplomacy is considered to be trust, interaction between the parties, recognition of their different interests and positions, and the identification of fair and reasonable use of shared waters as a goal to be achieved (Keskinen, M., & others, 2021). Water diplomacy emerged after the emergence of global events such as armed violence, political tensions, and mismanagement of water at the local or regional level in shared or transboundary waters. Transboundary basins such as the Amu Darya River, Colorado River, Ganges River, Indus River, Lake Chad, Nile River, Tigris River, and Euphrates River have experienced severe water stress as annual water withdrawals in these basins have exceeded their long-term flows (Klimes, M., Michel, D., Yaari, E., & Restiani, P. , 2019).

Water wars and conflicts in shared rivers in the early 2000s were linked to climate change, which affects the amount of water available. After 2010, the concept of water diplomacy, in anticipation of water wars, became widespread in water-scarce regions such as the Middle East and North Africa. The interest in water diplomacy is due to reasons such as working together on the sustainability of shared water resources, securing them at the national level, preventing conflict over them, and replacing nationalism in discourses with more regionalism to increase collective action, security and stability (Hussein, H., Campbell, Z., Leather, J., & Ryce, P., 2023).

One characteristic of water diplomacy is that it examines the causes of issues before developing solutions and distinguishes among values, interests, and means. Attention to values is one of the most important reasons for reaching satisfactory solutions for the parties, as it encompasses the beliefs people hold and their views of the world, and is reflected in economic, political, cultural, religious, and ethical considerations. For example, the Ganges River in India is considered sacred by many Hindus and is subject to religious restrictions; when developing solutions, this value must be prioritised. Interests are the reasons or goals that underlie the promotion of values. Means are techniques and processes that can be used to support potential outcomes and help make decisions about complex issues, but do not provide sustainable solutions. One of the main goals of water diplomacy is to 'develop and test a framework that will facilitate the production and use of actionable information to identify and manage complex water issues.' (Islam, S., & Rebella, A. S., 2015).

In this paper, multitrack water diplomacy will be used to reach a solution to the GERD crisis among Egypt, Sudan, and Ethiopia. Multi-track water diplomacy, or, as it is also called, formal and informal channels of water diplomacy, refers to the existence of multiple tracks that can be used simultaneously to reach diplomatic solutions satisfactory to all parties. The first method concerns official negotiations between the representatives of countries, whether foreign ministers, ambassadors, or others. The second path is at the level of non-state actors, such as civil society organizations and academic institutions, which is a path of dialogue and cooperation. Some studies indicate the existence of Track 1.5, a combination of the first and second tracks, comprising state and non-state actors in an informal setting. The fourth track is grassroots diplomacy, which usually occurs in border areas adjacent to the river. Stakeholders have recognised the importance of tracks 1.5, 2, and 3 in assisting first-level negotiators to build trust and increase cooperation in the previous tracks until formal negotiations are reached, ensuring the implementation of agreements (Sehring, J., Schmeier, S., ter Horst, R., Offutt, A., & Sharipova, B., 2022).

Using multi-track water diplomacy to resolve the Renaissance Dam crisis as follows:

First: Using the third track or starting with the last track that involves citizens from the private sector, as diplomacy is a collaborative effort. This is done by conducting dialogue sessions between citizens on the border and in the vicinity of the project, who are considered the first and largest beneficiaries and affected by the project. These talks are informal and do not formally involve governments, but can be led by civil society organisations and professional associations from the three countries. After the completion of these talks, a committee is formed to summarise the findings, concerns, and hopes of these people to be shared in the second track of the negotiations.

Second: Using the second track, these negotiations bring together academics, relevant civil society organisations, and politicians from the three countries. Originally, this dialogue is a collaborative negotiation aimed at exchanging information and data on the technical, engineering, environmental, social, and economic aspects of the GERD academically and scientifically. It is also an informal dialogue, but it increases trust among the three countries and includes the dialogue's outputs in the third track, which helps decision-makers make their decisions more effectively. After the dialogue concludes, a committee is formed to present its findings to the state.

Third, the use of Track 1.5, which includes the committee established by Track 2, comprising academics, politicians, civil society organisations, as well as government organisations and state representatives from the ministries of water, irrigation, dams, and foreign affairs of the three countries. These meetings are also informal, but discuss the results of the data and information exchanged between the three countries in Track 2 with country representatives.

Fourth: Using the first track, which is a game of formal negotiations between representatives of the three countries. The nature of these negotiations, after passing through the three tracks, differs from resorting to formal negotiations directly, in that an environment and a base of trust have been created, and the parties have full information on all technical, social, economic, and environmental aspects of the existing and potential Renaissance Dam in the three countries. It also helped bring the negotiators' views closer together, and the opinions of citizens and stakeholders from the private sector, academics, politicians, governmental organisations, and relevant civil society organisations were included. This would facilitate the identification of common ground, enabling the three countries to utilise and mutually benefit from the dam.

2.1.3.2. Using the 2030 Sustainable Development Goals

Sustainable development means meeting the needs of the current generation without compromising the needs of previous generations: 'economic growth, social inclusion and environmental protection' (Haliselic, E., and Suitas, M.E., 2019). On 15 September 2015, the United Nations developed the 2030 Sustainable Development Goals (SDGs) entitled 'Transforming Our World: The 2030 Agenda for Sustainable Development'. The SDGs are closely linked to the Millennium Development Goals (MDGs) but differ in several respects. The MDGs focus on poverty and hunger in the least developed countries, whereas the 2030 SDGs set 17 goals across 169 indicators and apply to all countries worldwide (Transforming Our World: The 2030 Agenda for Sustainable Development).

Of these goals, we focus on those related to environmental sustainability, namely Goals 6, 7, 12, 13, 14, and 15. These goals cover 'clean water and sanitation, clean and affordable energy, sustainable use of natural resources, climate change, life in underwater and terrestrial ecosystems, halting biodiversity loss and combating land degradation and desertification'

(Arora, N.K., & Mishra, I, 2019). These goals are binding on all UN member states and commit them to 'implement integrated water resources management at all levels, including, as appropriate, transboundary co-operation' by 2030. The link between water, sustainable development, and economic and social well-being is articulated in Goal 6, which addresses water and sanitation. Encompassing drinking water, sanitation, water quality, and sustainable management of the world's water resources, this goal focuses on equitable access to freshwater resources and sustainable management (Klimes, M., others, 2019).

Among the seventeen Sustainable Development Goals (SDGs) set for 2015, we can use several goals that can help solve the GERD issue and support cooperation between the three countries using the GERD:

- Goal 6, 'Clean Water and Sanitation', focuses on sustainable and equitable water management, and using this goal, the three countries should use the GERD to reach a fair and binding agreement that enables them to use the dam to achieve this goal. In addition to emphasising cooperation on transboundary water issues by establishing integrated water resources management at all levels, including cross-border cooperation.

- According to the seventh goal, which is related to 'clean and affordable energy', the Renaissance Dam is considered an important source of renewable hydropower, due to its expected high output. With this goal, the three countries can utilise the GERD to promote the cooperative use of energy generated by the dam at reduced prices for all three, but this cannot be achieved without a binding agreement among them.

- The thirteenth goal, 'Climate Action', can be used to address climate issues such as drought due to lack of rainfall and flooding, by using the stored water during droughts and filling the reservoirs during floods, which can be used to achieve sustainable development of the three disputing countries through dialogue and negotiation.

- The sixteenth goal is related to 'peace, justice and strong institutions' and can be used to achieve the sustainable development of the three countries in conflict with each other peacefully and through dialogue and negotiation to resolve all issues between them. Cooperation on the GERD project could open up cooperation on other projects as well as resolving other issues, such as political, economic, and border issues.

The 2015 Sustainable Development Goals could help address GERD by promoting regional cooperation and dialogue among the three countries. In addition, international and regional organisations could be enlisted to help reach solutions that are satisfactory to all parties in a formal and binding manner. Establish joint systems or joint management to exchange data on GERD, such as water flows, storage quantities, and climate changes that significantly affect water flows to Sudan and Egypt, or through a regional platform that relies on modern technology to manage transboundary water. Work on implementing joint development projects, such as establishing regional electricity grids that benefit from the energy generated and developing sustainable agriculture projects based on organised water. It is also possible to benefit from inviting international donors to support SDG-aligned solutions, such as funding projects that enhance water security and expand access to clean energy.

Using these goals, cooperation on the dam can be a model for establishing peace and stability in the region, ensuring sustainable and equitable distribution of water and energy among the three countries, managing resources more effectively, achieving sustainable development through economic and social benefits for all parties, and achieving regional integration and comprehensive development instead of conflict.

2.1.3.3. SWOT Analysis

The primary purpose of SWOT analysis is to develop a new system for managing change and control in Fortune 500 companies. The origins of SWOT analysis date back to the early 1950s, by Harvard University professor George Albert Smith Jr. at the Harvard Business School, and some argue that it can be traced back to C. Roland Christensen. In 1963, SWOT analysis was discussed extensively at a conference on business policy held at Harvard University and was recognised as a key development in strategic thinking. In the 1970s, SWOT analysis became used in strategic planning, in the 1980s its scope expanded significantly, and in the 1990s, it became the dominant framework for strategic management. Due to its accuracy and validity, SWOT analysis expanded to include education, industry, and agriculture. It was then used with other techniques and became available within the political, economic, social, technological, environmental, and legal framework (Benzaghta, M. A., Elwalda, A., Mousa, M. M., Erkan, I., & Rahman, M., 2021).

The SWOT analysis deals with four aspects, which are the components of this analysis: Strengths, which are considered internal components, and are a positive component or internal advantage of the project. The second component, weaknesses, is also internal but negative and is considered an internal inhibitor of productivity or characteristics necessary for the success of the project. The third component, opportunities, is a positive external reinforcer that, when utilised, can provide an opportunity for the project to succeed. **First, identify the SWOT factors**

Table 1. SWOT factors

Strengths	**Weaknesses**
1) Economic Growth in Ethiopia 1) Provides electricity to Sudan and other regional countries at affordable prices and meets local demand 2) Extends the life of dams in Egypt and Sudan by reducing the amount of sediment the GERD will trap. 3) It stabilises water throughout the year, ensuring that agricultural seasons continue throughout the year. 4) It works to control floods. 5) Improves water security through collaborative planning.	1) The safety factor in the construction of the dam is low. 2) If the dam collapses, it will cause a devastating flood in Sudan and extend to Egypt. 3) If the dam is operational, Egypt and Sudan's share of water will be reduced. 4) This will reduce the capacity of the High Dam and Sudan's dams to generate electricity. 5) It will affect the Egyptian economy due to water scarcity affecting agriculture and drinking water. 6) Impacts on the environment surrounding the dam.

	7) The evaporation rate increases due to the dam's location in an area with high temperatures.
Opportunities	**Threats**
1) Reach an agreement not on the division of Nile waters but on the utilisation of these waters. 2) A comprehensive agreement must be reached on the operation of the dam and the filling of its lake. 3) Strengthen regional cooperation between countries in the fields of energy, transport, and joint ventures. 4) Combat climate change by using the dam as part of a regional strategy to adapt to the effects of climate change and manage dwindling water resources. 5) Reducing electricity costs in the region. 6) Supporting regional peace, and the dam can be an opportunity for co-operation and confidence-building.	1) The dam is likely to collapse due to its construction in a seismic zone, fault lines, cracks, and collapsed rocks. 2) Egypt and Sudan remain committed to historic agreements. 3) Foreign interference, especially from Israel. 4) Ethiopia's political goal of the dam is to control the flow of water to Egypt and Sudan. 5) Environmental difficulties in filling and operating the dam in a gradual and balanced manner according to the amount of rainfall and floods. 6) Lack of trust between countries. 7) Ethiopia's failure to share clear data and information about the dam with Egypt and Sudan. 8) Ethiopia continues to build and fill the dam without reaching an agreement with Egypt and Sudan. 9) Military and terrorist attacks.

The fourth component, Threats, is a negative external component that reduces the project's achievements and threatens its survival. This analysis is presented in the form of a matrix in which the four components of the project are illustrated, thus covering all aspects of the project from all sides. Using the principle of comparison, the right decision can be made about the project (Lee, D., 2009).

A SWOT analysis is used to facilitate a decision that favours using the GERD as a cooperation project between Ethiopia, Sudan, and Egypt. It identifies the strengths, weaknesses, opportunities, and threats of the GERD project for Ethiopia and the downstream countries, and uses strategies to compare these factors to maximise opportunities for cooperation among the three countries.

Secondly, the derivation of dual strategies

After identifying the strengths, weaknesses, opportunities, and threats of the project, the relative importance of each factor is determined, and dual strategies are derived. These strategies include using strengths and opportunities to enhance collaboration, using strengths to minimise threats, minimising weaknesses and threats, and using opportunities to minimise weaknesses (Ghazinoory, S., Esmail Zadeh, A., & Memariani, A., 2007).

- One of the dual strategies is the strategy of capitalising on strengths to access opportunities (S-O): This is by exploiting the previously categorised strengths to reach potential opportunities for cooperation. For example, the power of the dam can be utilised to provide electricity to the basin countries to meet their power shortages. The large production of electricity expected from the dam can be utilised for regional cooperation in the field of energy and transport for the three countries in particular. The dam can also be used to stabilise the flow of water throughout the year and fight climate change, such as droughts or floods, which leads to the sustainability of water flow and thus leads to the sustainability of agricultural seasons in both Egypt and Sudan. Cooperation in the GERD project also opens the door for cooperation in other projects, other than those related to the Nile Basin, which means that it creates trust between the three countries, leading to regional stability and peace.

- The second strategy is how to use strengths to minimise the impact of threats (ST). This is by jointly utilising it in cooperation between the three countries, and improving the water security of the three countries by jointly planning to work on overcoming climate change. This is done by scheduling the filling of the dam by closing the gates to fill the flood periods and not filling during periods of low rainfall so that Egypt and Sudan are not affected by the lack of water. Also, in terms of cooperation in the fields of energy, transport, and joint projects that can create integration between the three countries, Egypt, Sudan, and Ethiopia. For example, utilising the fertile agricultural land in Sudan with Egyptian support to develop projects and sustainable water from Ethiopia. The aim is to create a sustainable agriculture that provides different crops and creates joint programmes to store and distribute food in times of crisis.

- The third strategy is to overcome weaknesses through opportunities (WO). The opportunity for cooperation between the three countries enhances regional cooperation in the region in the field of energy, transport, and joint ventures. Use the dam as part of a solution to minimise the effects of climate change and preserve water flows to Sudan and Egypt. Also, joint agricultural projects can minimise the impact of food scarcity and open up investment between countries in many areas. A very influential vulnerability is the low capacity of Sudanese and Egyptian dams to produce hydroelectric power due to the lack of water. Egypt and Sudan can import electricity from Ethiopia at low cost through joint agreements with Ethiopia in the field of energy. Here, Egypt and Sudan represent a market for Ethiopia, and at the same time, reduce the cost of electricity production for Sudan and Egypt.

- The fourth strategy is to avoid vulnerabilities and threats (WT). This is done by minimising vulnerabilities, which in turn leads to minimising threats. The technical issues of the dam can be avoided by cooperation in the engineering field, as Sudan and Egypt are ahead of Ethiopia in the field of dams and are sure to be superior in this regard.

3. Results and Recommendations

Using descriptive, historical, and analytical research methods, the study came up with a set of results:

- There is no binding legal framework for the three countries to refer to in the GERD issue. This is due to Ethiopia's disagreement with the historical agreements (1902, 1929, 1959) that Egypt and Sudan adhere to as a binding legal reference, which Ethiopia considers as colonial agreements that do not bind it. Ethiopia also relies on its sovereign right to develop and exploit its natural resources in its lands. Despite the signing of the 'Declaration of Principles' in 2015 in Khartoum, Sudan, the three countries were unable to solve the issue of filling and operating the dam.

The strengths that Ethiopia possesses, which give it superiority over Egypt and Sudan, can be considered weaknesses for them. Ethiopia's strengths are its ability to put Sudan and Egypt in front of a fait accompli by completing the construction of the dam and starting the filling and storage of water, as well as its geographical location that enables it to control the flow of the Nile waters, especially after the completion of the dam. Egypt's complete dependence on the Nile River is one of the weaknesses that force Egypt to sit down to resolve the issue through negotiations with Ethiopia. It is no less than Sudan's dependence on the Nile for its dams and irrigation water supply. Therefore, the use of ordinary diplomacy cannot enable the parties to reach solutions, as happened in both trilateral negotiations and mediations, so multi-track diplomacy must be used. The importance of multi-track diplomacy comes from the participation of all civil society organisations, research centres, and the private sector, which leads to taking into account the circumstances of each party and better assessing the situation to open wider areas for mutual understanding, confidence-building, and regional cooperation.

- The project can be used to achieve the 2030 Sustainable Development Goals. By capitalising on the dam's provision of clean electricity, the SDG 7 'Clean Energy' can be achieved. Cooperation between the three countries can also achieve the second goal of the development goals, which is the eradication of hunger, by conducting joint projects between the three countries that relate to the provision and exchange of food resources. In addition to providing clean water and sanitation, the sixth goal of the development goals and the sixteenth goal of strong institutions and international cooperation. However, all of this is linked to achieving regional cooperation between the three countries, and the GERD is the ideal project that can open the way for regional cooperation.

- Use SWOT analysis to clarify the strengths, weaknesses, threats and opportunities to clarify the picture in front of the three countries. Both strengths and opportunities can be used to minimise the impact of weaknesses and threats through cooperation between the three countries. Therefore, the three countries must move from conflict to co-operation based on mutual benefits. This is done by moving beyond the unilateral, legalistic discourse and moving to a view of the Nile River and its projects in terms of benefit-sharing rather than water-sharing.

The study recommends the following:

1- Work to establish a permanent regional technical and legal mechanism or committee to manage the waters of the Eastern Nile, concerned with monitoring the operation of the Renaissance Dam and coordinating water management on a daily or seasonal basis, composed of the three countries. This ensures fair and equitable distribution under the rules of international law for waterways and minimises the chances of misunderstanding or escalation.

2- Using multi-track diplomacy by involving universities, research centres, regional organisations, and civil society organisations in informal negotiations that are parallel to the official negotiations, to enhance trust and convey scientific and technical proposals that may not appear in traditional diplomatic channels.

3- Utilise SWOT analysis to develop flexible negotiation strategies by realistically analysing each party's strengths and weaknesses and exploiting available opportunities, such as joint energy projects or cross-border infrastructure development, rather than focusing only on points of disagreement. Threats must be minimised, especially climate change, which increases tensions over resources.

4- The management of the dam should be aligned with the 2030 Sustainable Development Goals (SDGs) by balancing power generation (Goal 7) and water and food security in downstream countries (Goals 2 and 6). In addition to supporting joint projects such as regional electricity grids and water-smart agriculture that contribute to minimising pressure on water quotas.

5- One of the most important recommendations on which cooperation between countries is based is to build trust through transparent procedures and the exchange of information between the parties. Such as the immediate exchange of hydrological data, the scheduling of operation and filling works, and the submission of quarterly reports through a joint monitoring body or international observers.

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Received: June 23, 2025

Accepted: September 25, 2025

Issue: 8 2025
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

Beyond Egypt's Historical Narrative: The Completion of the Grand Ethiopian Renaissance Dam and Its Hydro-Political Implications on the Nile Region

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Abstract

The main objective of the paper is to assess the historic narrative of Egypt over the Nile River and the positions of Ethiopia against it, and how the completion of GERD challenges a historic narrative and a shift in the hydro-political landscape of the Nile region. To meet its objectives, the study mainly employs a descriptive and explanatory approach under the qualitative research methodology. In doing so, the study utilizes primary and secondary sources of data from books, journal articles, legal and document analysis, media sources, and open sources like websites. The GERD, located in Guba, Benishangul-Gumuz regional state, is the largest African hydroelectric power plant. It symbolizes the determination, resilience, and unity of the Ethiopian people, who financed the project by their own contributions, including buying bonds and preparing fundraising campaigns. In celebrating the completion of the GERD, the media outlets like print media, digital media, broadcasting media, and other social media echo the "impossible made it real", which signifies the reality is there beyond Egypt's historic narrations; and it became the de facto changes of the existing status quo in the Nile region. The completion of the GERD remarks as a historic milestone for reshaping the broader Nile basin region, and a new approach of hydro-politics analysis in the area. The accomplishment of GERD is a game-changer or shift of power dynamics that creates new emerging water-sharing by substituting the existing status quo in the region.

Keywords: Historical Narrations, Grand Ethiopian Renaissance Dam, Hydro-politics, Nile region

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1. Introductions

Trans-boundary water has multiple uses and users due to the nature of the cross-boundary of multiple spatial and temporal scales (Warner and de Man, 2020). Trans-boundary water resources are also a crucial potential for either cooperation or exacerbating conflicts due to their inherent nature of political, social, and environmental interdependence (Pohel, 2014). As most of the world's largest rivers cross national and regional borders, there were confederations of independent states; nearly 40% of the world's population was highly dependent on these shared river basins (Pohel, 2014; Salman, 2015).

Literature points out that there are 43 in America, 20 in Europe, 27 in Africa, and 50 in Asia, which constitute a number of shared transboundary rivers in the world (Mumma-Martinon, 2010). For instance, the Amazon basin is shared by seven nations, the Danube basin is shared by more than eight, the Niger basin is shared by more than seven, and the Nile basin is shared by eleven basin states[3], and the Rhine basin shared by seven states (Mumma-Martinon, 2010). As Mumma-Martinon further discussed, throughout these basin interactions, there will exist disputes and tensions; for instance, India and Bangladesh negotiate or face tensions over the Ganges-Brahmaputra, while Mexico and the USA face the same over the Rio Grande; Egypt, Ethiopia, and Sudan have long-lived disputes over the Nile; Iraq, Syria, and Turkey over the Euphrates and Tigris rivers. However, the Nile basin's water disputes are more vulnerable to political landscapes and economic futures for Africa, the Middle East, and Arabian countries' geopolitical competitions (Tafesse, 2000; Mumma-Martinon, 2010).

The Nile, the world’s longest river, embodies the challenges of transboundary river basin management, and it has had a significant impact on inter-state politics in the region (Zedan, 2013). The monopoly of Egypt and Sudan on the water resources of the Nile in history has already played a role in exacerbating regional tensions (Nunzio, 2013). Practically, the Ethiopian GERD, located 30 kilometers from the border with Sudan, has received much criticism, mainly due to Egypt’s hostile response to its construction. For more than a decade, Egypt and Ethiopia have been negotiating over the Grand Ethiopian Renaissance Dam. A large number of technical reports have been drawn up, dozens of statements have been issued, and hundreds of meetings have been held with heads of state and government, foreign ministers, hydrologists and engineers, foreign mediators, and international observers (Mahamud, 2020). However, all of these efforts of mediation and negotiation processes failed due to the Egyptian grand historic narratives; nevertheless, the GERD is now completed, and the reality is there beyond the historic narrations of Egypt, and it is the de facto change of the existing status quo and challenges the downstream hydro-hegemons.

The main objective of the paper is to assess the historic narrative of Egypt over the Nile River and the positions of Ethiopia against it, and how the GERD challenges a historic narrative and a shift in the hydro-political landscape of the Nile region. To meet its objectives, the study mainly employs a descriptive and explanatory approach under the qualitative research methodology. In doing so, the study utilizes mainly the secondary sources of data, such as books, journal articles, legal and document analysis, media sources, and open sources like websites. The paper is organized into seven sections. The first section provides an introduction that outlines the background of the paper. The second section focuses on the Egyptian’s Historical Narratives over the Nile River and includes its sub-sections. The third section addresses the Ethiopian perspective on historical legal claims, discussed in detail in its own subsections. The fourth section highlights the construction of the Grand Ethiopian Renaissance Dam (2011). The fifth section analyzes the diplomatic efforts over the GERD between Ethiopia, Sudan, and Egypt. The six sub-sections of the paper look into the Hydro-political Implications of the GERD on the Nile Region. Finally, the seventh section presents the conclusion of the paper.

[3] (Egypt, South Sudan, Sudan, Ethiopia, Eritrea, Tanzania, Uganda, Burundi, Rwanda, the Democratic Republic of the Congo, and Kenya)

2. Egyptian's Historical Narrative over the Nile River: Supported by Myth and Legal Norm

According to the Egyptian historical myth, the Nile River was often seen as a divine blessing that emphasized its sacredness and inviolability by the upper riparian states. The Egyptians told mythological stories linked with their traditional culture and the Nile River. For example, **Hapi**, linked with the god of annual Nile floods, ensures the fertility of the land; Osiris, linked with the god of life after death, shows the Nile's regenerated power; Sobek, associated with the god of crocodile-headed, is seen as the destructive and protective forces of the Nile River (Baines, 2011).

The Greek historian Herodotus wrote that 'The Nile is the natural gift and lifeline of Egyptian people', which was an old-age story (Chesire, 2010, Arsano, 2007). For many years, the downstream states, particularly Egypt, have been the Nile Basin's principal hegemon state. Egypt has applied a myriad of mechanisms and tactics to maintain its regional hegemony and effectively control any competition for upstream water over the Nile water sharing (Mahamud, 2019). He further argued that the existence of 'restrictive and oppressive' mechanisms has become a historic challenge for reasonable and equitable utilization of the Nile River. In addition to this, the myth that Egypt is 'the gift of Nile' was first coined by Greek historian Herodotus, used as a base rock for Egyptian hegemony over the Nile basin, and its very existence still depends upon these historic descriptions of the Nile. In the 18th and 19th centuries, for instance, Egypt used the most explicit coercive tactic, mainly military force, to control the Nile from its sources; its goal was not effective under the Blue Nile, because of the successive defeat by Ethiopia (Yacob, 2007).

2.1. Colonial Treaties and Agreements over the Nile River

During the colonial period, the British made a dramatic concern for Egypt at the expense of other Nile riparian states (Ellias, 2009: 72). Ellias further argued that Ethiopia was the only sovereign independent state in the Nile basin states during the colonial period; while, Britain, a master of colonial power dominated the two downstream of Nile basin states, Egypt and Sudan that she did everything to ensure control over or an unobstructed flow of Nile to its independencies. During the colonial period, Ethiopia's main concern was its survival as a sovereign state; water development and management were hardly an immediate agenda under the political-economic circumstances of the time (Yacob, 2007).

The 1891 Anglo-Italia Protocol: The British Nile policy framed in line with European colonial strategy in Africa and the Middle East, with conflicting visions of Nile management. On the other hand, it sought secure more water for Egypt in order to boost agricultural production, and especially the profitable cotton production, and to enrich the country under its own benign oversight (Tvedt, 2010). On April 15, 1891, the Anglo-Italia Protocol was signed between Italy, representing Eritrea, and the United Kingdom, representing Egypt and Sudan (Essa, 2015). The primary objective of the protocol was to demarcate the boundaries of Britain and Italy within their respective spheres of influence in Eastern Africa (Owiro, 2004).

However, Article III of this Protocol mainly sought to protect the Egyptian interest in the Nile waters contributed by the Atbara River, which were read as: *"The Government of Italy undertakes not to construct on the Atbara any irrigation or other works which might sensibly modify* *its flow into the Nile" (Owiro, 2004:6).* This protocol is senseless and irrelevant because of the fact that it did not include the upper riparian state of Ethiopia, where the majority of the Nile water comes from. For Ethiopia, this protocol is irrelevant since Italy, which is one of the parties to this protocol, was neither in control of Ethiopia nor a member of the Nile Basin. Italy was engaged in negotiations over the headwaters found in Ethiopia, which were not under its control during that period.

The 1902 Treaty between Great Britain and Ethiopia: The treaty between Great Britain and Emperor Menelik of Ethiopia was signed on May 15th 1902 at Addis Ababa. Great Britain, acting for Egypt, the Anglo-Egyptian Sudan, and its aim was the issue of the boundary between Ethiopia and the Sudan. However, article III of the treaty was mainly concerned not with boundaries but with the use of Abbay River (Owiro, 2004). It was read as:

> *"His Majesty the Emperor Menelik II, King of kings of Ethiopia, engages himself towards the Government of His Britannic Majesty not to construct or allow to be constructed. Any works across the Blue Nile, Lake Tsana or the Sobat, which would arrest the flow of their waters into the Nile except in agreement with his Britannic Majesty's Government and the Government of the Sudan"* (Owiro, 2004: 7).

From this treaty, we can infer that on the Ethiopian side, not to arrest or stop the flow of the Nile River did not mean not to utilize the Nile River. In addition, the treaty was signed between Ethiopia and Britain, not between Ethiopia and Sudan at that time. Therefore, after Sudan gained its independence, the agreement was not effective, relevant, or legitimate, and this agreement was not an impediment to the current construction of the Grand Ethiopia Renaissance Dam.

The 1929 Anglo-Egyptian Nile agreement: In 1929, Egypt and the British government negotiated an agreement on Nile water-sharing on behalf of Sudan and the Lake Victoria riparian countries. However, Ethiopia, which contributes the majority of the water to the Nile River basin, is not included in this agreement. East African countries were not allowed to engage in any water development initiatives in the upper Nile basin before consulting Egypt and Sudan, according to the 1929 agreement (Swain, 2008). The agreement was founded on the results of political negotiations between Egypt and the United Kingdom in the 1920s; specifically, the exchange of notes over the Nile Waters in 1925 was part of this agreement. Its objective was to ensure and facilitate an increase in the amount of water that reached Egypt (Owiro, 2004: 8).

Accordingly, the 1929 Nile water agreement was concluded:

- ❖ Egypt and Sudan utilize 48 and 4 billion cubic meters of the Nile flow per year (92.2 percent and 7.7 percent of the total Nile water utilization, respectively.
- ❖ Egypt claims 'historic and natural rights' in the use of Nile water, without the consent of upstream states.
- ❖ Egypt was granted the right to monitor the Nile flow in the upper states.
- ❖ Egypt was given the right to undertake Nile River related projects without the consent of the upper riparian state and any construction project in upper state have affected by the veto power of Egypt.

The 1929 Nile water agreement was the most controversial bilateral agreement during the era of the colonial period. This agreement implies a deliberate exclusion of the upper riparian state by Egypt and its colonial master, Great Britain (Owiro, 2004). Lumumba (2007) rise very important questions to interpret the 1929 Nile water agreement such that: do the treaties bind the riparian countries, which are not part of them? And what is the legality and legitimacy of Egypt to threaten war to protect its national interests against Ethiopia? An honestly the interpretations of the 1929 Agreement between Egypt and the United Kingdom show a deal that is strongly biased in Egypt's favor. Another vitiating factor that makes this Agreement null, void, and illegal is the fact that not all relevant parties (members of riparian states) were consulted during its negotiations and ultimate finalizations (Lumumba, 2007). The 1929 Nile agreement generally committed to ensuring the interest of Egypt and downtrodden the interest of upper riparian states. The agreement also recognizes that Egypt had the right to inspect upstream water projects that would affect the volume and perennial flow of the river. Moreover, the agreement expresses the recognition of Egypt's "natural and historic rights in the water of Nile" by its colonial masters, Great Britain. Thus, this agreement is one of the basic tools used by Egypt to attain its hegemonic influences in the Nile region that is why Ethiopia constantly opposed the applications of the 1929 Anglo-Egyptian treaty (Bayeh, 2016). Therefore, as a result of the above instances, the 1929 Anglo-Egyptian treaty was a great challenge, which Egyptians claimed implicitly in the current negotiations process it is an outdated and biased colonial treaty, which is strictly forbidden to refer this treaty in the negotiations process of the Grand Ethiopia Renaissance Dam (GERD).

The 1959 Blue Nile Agreements between Egyptian and Sudan: After Sudan has become an independent state from Great Britain in 1956, the new Sudanese Government demanded a great share in the Nile waters. Sudan's new stance threatened the Egyptian Government's new plan of constructing a High Dam in southern Egypt. They declared non-adherence to the 1929 agreement and demanded a renegotiation of water sharing on the Nile River (Yacob, 2007). This makes the dissatisfaction of Sudan in the 1929 Nile agreement, which led to the conclusion of another water agreement with Egypt on 8 November 1959 (Essa, 2015).

Both Sudan and Egypt reached such an important agreement on the sharing of the Nile River because it asserts that the total exclusion of other Nile riparian states (Yacob, 2007; Swain, 2008; Ellias, 2009). According to the 1959 agreement, Egypt was granted the right to use 55.5 billion cubic meters per year from the newly estimated discharge of 84 billion cubic meters per year at Aswan, while Sudan was given 18.5 billion cubic meters. The remaining 10 billion cubic meters were set aside for evaporation and seepage losses from Lake Nasser behind the Aswan High Dam on an annual basis (Yacob, 2007). The agreement also contained provisions for regulating the filling of the Aswan Dam's storage reservoir. Sudan was given permission to construct several dams and reservoirs to use its own share of water. Furthermore, both countries agreed not to engage in any negotiations with third parties over Water resources until they had jointly formed a position (Swain, 2008). The preamble of the 1959 water agreement, which reads " the Nile water agreement concluded in 1929 provided only for the partial use of the Nile Water and did not extend to include a complete control of the river water." Therefore, the request of Sudan was ignored as mentioned above, and besides the preamble also further underlined the main motive of this treaty as follows:

> *"As the River Nile needs projects, for its full control and for increasing its yield for the full utilization of its waters by the Republic of the Sudan and the United Arab Republic…full agreement and cooperation between the two republics in order to regulate their Benefit and utilize the Nile Water in a manner which secures the present and future requirement of the two countries"* (The 1959 Agreement).

Thus, from the above idea, one can conclude that the 1959 Sudan and Egypt Nile agreement was the broadening face of the 1929 treaty. Despite the fact that it divided all of the upstream states, this agreement was only bilateral and did not include any of the upper Nile's riparian countries. Ethiopia, which provides about 86 percent of the water, was not consulted, and no water was reserved for future use by any upstream country other than Sudan. It is even less comforting for the other riparian countries (other than Sudan) that all of the Nile's average water flow was divided between the two downstream countries. Therefore, the main objective of the 1959 agreement was the full control of the Nile water by Egypt and Sudan, and they tried to divide the entire Nile flow between Egypt and Sudan.

2.2. Post-colonial Treaties and Agreements over the Nile River

1960 was the year of African independence, because most African states gained their independence from European colonies and marked the beginning of a new era of continental organization. In fact, Ethiopia was not recognized in most of the colonial era agreements, including the 1959 treaties; such non-recognition inspired other upstream riparian states, particularly Tanzania, where Julius Nyerere (the first president of Tanzania) repeatedly dismissed the colonial treaties of the Nile (Ellias, 2009). **The HYDROMET Project (1966-1993)**: The HYDROMET (the hydro-Metrological Survey of Lake Victoria, Kyoga, and Albert began in 1967, by the East African Nile water coordinating committee with the support of the United Nations Development Program (UNDP) and World Meteorological Organization (Ellias, 2009). The HYDROMET was proposed by the World Meteorological Organization and financially funded by the United Nations Organization, but Ethiopia, DRC (Zaire), and Kenya participated as observers (Adar, 2007). The purpose of this project was to keep the water balance at the catchment of Lake Victoria in order to assist in any control and regulation of the Lake level as well as to keep flood disasters in the region. This project lasted for about 25 years, but Ethiopia was not included in this project despite the fact that Ethiopia contributes the lion share of the water of the Nile River and the project was unsuccessful in its effort to develop an effective basin-based arrangement (Swain, 2011).

Undugu (1983-1993): The Swahili language "Undugu" means "brotherhood", which was held in Khartoum, Sudan, in 1983 by the initiations of Egypt (Yacob, 2007). On the part of Egypt, these initiatives were the result of changes in the domestic policies towards solving the issue of the Nile through cooperation. The initiative was accepted by Egypt, Sudan, Uganda, DRC, and the Central African Republic (though not a state in the basin), which led to the establishment of an organization in Khartoum, Sudan, in 1983, while Kenya, Tanzania, and Ethiopia participated as observers (Tesfaye, 2001: 105). According to Dereje (2010), Undugu was the first informal organization, which grew out of the Egyptian proposal. The official objective of this initiative was to discuss the issue of Nile waters for different purposes, such as agriculture and resource development, promotion of the economy, and technical and scientific cooperation among the riparian countries. However, preserving the dominance of

Egypt in the region was the hidden agenda of Undugu. Unfortunately, this basin-wide initiative was failed because of a lack of clear objectives, failure to incorporate Ethiopia and the development of mistrust among the Nile basin states (Dereje, 2010).

TECCONILE (1993-1999): Following the demise of Undugu, Egypt, Rwanda, Sudan, Tanzania, Uganda, and Zaire (DRC) formed the Technical Cooperation Committee for the Promotion of Nile Development and Environmental Protection (TECCONILE) in 1992, with Ethiopia, Burundi, Eritrea, and Kenya remaining as observers (Dereje, 2010: 427). Since TECCONILE was established as an offshoot of Hydromet and placed a strong emphasis on technical aspects, major upper riparian states such as Ethiopia were discouraged from being full-fledged members of the project (ibid). Unlike the historical bilateral and multilateral attempts, TECCONILE was the first to focus on a longer-term development agenda, and it became a springboard for the development of the Nile Basin initiative for further cooperation among the riparian states.

In 1997, with the request of the Council of the Ministry of Water Affairs of the Nile basin states (Nile-COM), the World Bank, the United Nations Development Programs, and CIDA became cooperative partners to facilitate cooperation among the Nile basin countries (Bronee and Toope, 2002). Therefore, unlike Undugu and Hydromet, TECCONILE was successful in bringing the countries of the Nile basin together for a dialogue that resulted in the inception of more consolidated organizations, the NBI and CFA (Dereje, 2014).

2.3. The Way to the Multilateral Cooperation Process in the Nile Basin States

The attempt at basin-wide cooperative initiatives from Undugu to TECCONILE has a track record of failure in terms of changing the inequity of the historic status quo. However, the Nile Basin countries have been in serious talks to develop shared water resources more cooperatively in order to realize the Nile Basin Initiative (NBI) process (Whittington, 2004).

The Nile Basin Initiative (NBI): The Nile Basin Initiative was officially launched at Dar es Salaam, Tanzania in 1999, by the Council of Ministers of Water Affairs of the Nile Basin States (Nile-COM) as the countries of the Nile basin states have recognized the need for a meaningful agreement for their development potential. It could be appropriately regarded as a breakthrough from computation to cooperation until a permanent Cooperative Framework Agreement was established (Dereje, 2010). In terms of institutional form, the NBI was composed of a two-track agenda: a technical track, through which the NBI has worked to gather and analyses technical data and provided technical assistance for the construction of dams projects; and a judicial track working towards a Comprehensive Framework Agreement (CFA) that, at Member States' government level unavoidably became a political process (Knaepen and Byiers, 2017).

The Nile Basin Initiative (NBI) is guided by a shared vision to achieve sustainable socio-economic development through the equitable utilization of the Nile River water resources and set the policy guidelines that provide a basin-wide framework for cooperative action. The key concept in the above statement is the concept of "equitable and reasonable utilization" and its counter sense of obligations not to cause 'significant harm' is the inclusion concept of the Nile Basin Initiative, and it was the first time that such a noble idea has been introduced (Adamnur, 2003: 76). The Nile Basin Initiative was developed with the assistance of UNDP and CIDA to help to reduce tension and create a framework for cooperative development of the Nile Water resources (Tesfaye, 2000)

The initiative has enabled all riparian states to establish the Nile Basin Strategic Action Program, which has two complementary sub-programs: the first one is the shared vision program, and the second one is the Eastern Nile Subsidiary Action Plan (ENSAP) (Girma, 2000). The Shared Vision Program mainly focuses on the issue of developing trust, cooperation, and an enabling environment for investment. And the Subsidiary Actions Programs focus on specific investment programs such as hydro-power generation, irrigation development, etc for the two sub-basins, i.e., the Eastern Nile basin and the Nile equatorial lakes basin (Cascao, 2009).

Despite the fact that this initiative has reached a ministerial level, the riparian states lack institutionalized political will. The NBI has solely served as a water authority so far. Because the issue of "equitable utilization" is central to the process, which stems from the 1997 UN non-navigational water law, political compromises must be reached among riparian states, as the downstream riparian lacks the willingness to adhere to the principles of equitable and reasonable water use (Oloo, 2007). Furthermore, the Nile Basin Initiative represented a paradigm shift from exclusive use towards a cooperative utilization of the Nile River; however, for Egypt, it seems to be a change of strategy rather than attitude (Adamnur, 2003).

The 2010 Cooperative Framework Agreement (Entebbe agreement): The NBCFA was at the heart of the Nile riparian cooperation transformations as it, for the first time, brought the fundamental question of equitable and reasonable reallocations of Nile Waters onto the cooperative agenda; it was such a bold step to turn a basin from unilateralism and competition into one governed body by a permanent legal institutions framework agreed upon by all riparian states., and in 1997 the draft of cooperative framework agreement was produced (Dereje, 2010; Tesfaye, 2011). The content of the CFA was developed over more than a decade of intensive work. The task of developing the text or working documents of principles, rights and obligations and institutions of the CFA was started by the Panel of Experts in 1997. It passed through a decade-long negotiation until it was placed for signature in May 2010. There is a major issue of disagreements during the development of CFA.

The major issues of disagreement that had been taking up most of the time of the negotiators were the following: Use of Terms (Nile River Basin vs. Nile River System); Seat of the Headquarters of the NBI; Notification on Planned Measures; and Fate of the existing agreements and Water Security (Essa, 2015). Article 14 of the document, which states: *(a) to work together to ensure that all States achieve and sustain water security (b) not to significantly affect the water security of any other Nile Basin State*" was the main source of disagreement throughout the negotiations process (Dereje, 2010: 428). The key point of contention in article 14 (b) is that "*member countries would work not to have a significant impact on the water security of any other Nile Basin States*"; and all Nile Basin states agreed on this proposal, however, Egypt and Sudan rejected this article and they propose their own proposal which read as *"member state should construct basin project not adversely affect the water security current uses and rights of any other Nile Basin States"* (Essa, 2015).

The CFA is based on principles of international water law, of equitable and reasonable utilization, of the obligation not to cause significant harm to other users, of protection and conservation of the river's ecosystem, as well as observation of equality of sovereignty and goodwill and sustainable development (Dereje, 2010). And now, according to current information, six countries have ratified the Cooperative Framework Agreement (CFA) on the Nile River Basin: Ethiopia, Rwanda, Tanzania, Uganda, Burundi, and South Sudan; this is the number required for the agreement to be instrumental or come into force (EBC, 2024). Where the CFA and the subsequent NRBC will not only allow for more equitable use of the Nile waters but will also deepen cooperation among riparian countries as well as the establishment of a permanent institutional framework that will take the achievements of NBI.

3. Features of Historical Agreements and Treaties According to the Ethiopian Perspective

The history of conflict management and negotiation among Nile Basin countries over the use of the Nile River dates back to 1891, as noted above. It is important to examine the nature and features of these processes, as well as their impact on the ongoing diplomatic negotiations. It can be classified into three major negotiation phases based on its features, as Kidane clearly states: exclusive existing agreements and treaties, inconclusive cooperation (attempts of establishing basin-wide instructions), and the inclusive negotiations process (the establishment of NBI, CFA, and DoP) (Kidane, 2012).

3.1. Exclusive Agreements and Treaties (1891-1959): A Resource Capture Strategy

The colonial treaties and agreements, which took place from 1891 up to 1959 mainly, were characterized by the deliberate exclusion of upstream states by Egypt and her colonial master, Great Britain (Owiro, 2004; Kidane, 2012). The impetus for the beginning of the negotiated apportionment of the Nile water was initiated from the European colonial power, particularly, Great Britain and Italy, which aimed at the shortage of cotton on the world market in 20th century, which put pleasure on Egypt and Sudan to turn the traditional flood-fed method of cotton production in to a perennial irrigation method of production to ensure cotton supply for world market (Kidane, 2012). Particularly, in 1929 and 1959, there was the first attempt at conflict management in the form of a bilateral agreement; these two treaties are the result of decades of negotiation process that took place between 1891 and 1959. The actors of the negotiations process from 1891 to 1959 and the agreements of 1929 and 1959 were European colonial powers, Egypt, and Sudan directly, and some riparian countries indirectly through their master colony, but it extremely excluded the upstream states, particularly Ethiopia (Yacob, 2007; Kidane, 2012).

The negotiations and agreements signed between 1891 and 1959 have become contentious and do not address the water conflict in the Nile region; rather, it is a grassroots source of tensions and disputes within the basin. Ethiopia, in particular, has officially made clear from the outset that it does not recognize the 1929 and 1959 agreements, to which it was not a party, and has stressed that there is no legal or moral basis for holding the agreements binding on Ethiopia. And the negotiations clearly recognizes the Egypt's historic and natural right in the Nile River; to attain its hegemonic influence in the Nile region (Beyen, 2016: 1). Exclusion of most of the riparian countries from participation in negotiations in relation to the issue of the Nile is, therefore, one of the major factors that have escalated the current struggle over the Nile waters and the result of unproductive diplomatic negotiations that are experienced between Ethiopia and Egypt on the single Great dam

3.2. Inconclusive Agreements and Treaties (1967-1993): A Resource Containment Strategy
After the 1959 Nile water treaties, there were various attempts at the negotiation process in relation to the use of Nile water, which were all initiated typically by Egyptians to preserve the historic dominance of water share over the basin. In 1967, the HYDROMET project was designed to collect Hydro-metrological information for the catchment of Lake Victoria, with the support of the United Nations Development Program and the World Meteorological Organization. When this project came to an end, the Technical Cooperation Committee for Promotions of the Development and Environmental Protections of the Nile Basin (TECCONILE) was formed by heads of nations' water ministers (Kidane, 2012).

The intention of the above cooperative initiatives was not in reality to share the benefits of the Nile waters across the basin, but to ensure that the water flow of the river was not obstructed by any upstream activities so that the status quo could be maintained. As a result, the various cooperative attempts are initiated from either Egypt or European colonial power, not from the riparian basin, which is why it remains an attempt rather than producing a clear-cut result (Yacob, 2007; Kidane, 2012). The downstream states, if the upstream countries unilaterally initiated water-resource renegotiations and development planning for hydroelectric power and irrigation, which exacerbated tensions in the region (ibid). So, it is safe to conclude that the negotiation process, which was attempted from 1967 to 1993, was inconclusive because the initiations of cooperation were not objective or factual, and thus could not help reach any agreement or treaties in the Nile basin states.

3.3. Inclusive Agreements and Treaties (1999-2011): A Waterer Diplomacy Platform
After a series of attempts of establishing basin-wide water cooperation, the Council of Ministers of ministers of water on the countries of Nile basin (Nile-COM) reached an agreement over the sharing and management of the Nile water in March 1998 at the meeting held in Arusha, Tanzania, which subsequently led to the establishment of the NBI in May 1999 (Dereje, 2010).

The NBI aims to promote equitable utilization of the Nile and the sharing of the benefits of its resources. Although a concrete agreement with all the riparian states' consent has not yet been reached, the NBI is at least the first initiative of its kind to include all the states in the basin in the consultative process (Kidane, 2012). The central principle of the NBI is, therefore, the shared vision jointly embraced by all member nations: to achieve sustainable socio-economic development through the equitable utilization of and benefit from the common Nile Basin water resources. Throughout the NBI process, priority has been placed on strengthening consultation among member states of the initiative to build trust and confidence, though the process has only resulted in the adoption of NBI's CFA by the majority of upstream riparian states (Kidane, 2012).

4. The construction of The Grand Ethiopian Renaissance Dam in 2011

According to the report of the United Nations' International Energy, 70 million Ethiopians lack electricity, which is the most in Africa. As a result, Ethiopia has committed to building the Grand Ethiopia Renaissance Dam sometimes known as "Hidase[4] Since 2011, the dam has been funded by its indigenous funding, in which 80% of the financing comes from tax collections and 20% from domestic bonding (Heggy, 2024). Africa's biggest hydroelectric and the world's 10th largest dam is located at Benishangul Gumuz, Guba, in the West region of Ethiopia, located 750 kilometers north-west of the capital city of Ethiopia, Addis Ababa, and about 45 kilometers from the border with Sudan (Tesfa, 2013). The dam reservoir area is 1,874 km^2 and the total storage volume is 74 billion cubic meters of water. Its wall is 145 meters high, 1, 708 meters wide, 180 meters long, and the dam will generate a mounted capacity of 6000 MW (Mehari, 2020). The locations of the Grand Ethiopian Renaissance Dam was based on a variety of studies over the years that four main locations ware identified by the United State of America Recommendations, which were adopted in 1964 on the regions of Blue Nile, including one which has now become the locations of Grand Ethiopian Renaissance Dam (GERD) (McCartney et al., 2012; Wheeler et al, 2016). In May 2010, Ethiopia announced that a multibillion-dollar Millennium Dam would be constructed on the Blue Nile River, following the signing of the Cooperative Framework Agreement by the Nile Basin States, with the exception of Egypt and Sudan. And in November 2010, Ethiopia announced the Millennium Dam's designs were finished. In February 2010, the Egyptian president Hosni Mubarak stepped down due to a mass uprising, and in March 2011, a five billion dollar Millennium Dam was made public with a contract awarded to the Italian company Salini Castrator. In April 2011, the dam's founding stone was laid by PM Meles Zenawi, and the Millennium Dam was renamed the Grand Ethiopian Renaissance Dam (GERD) (El-Gundy, 2021).

The primary goal of the $five billion cost dam is to generate electric power of 6000 MW, with annual energy production of 15130 GWh/year to cover the demands of the country and East African regions (Yildiz et al, 2016). The GERD will offer significant advantages and opportunities, including serving as a power hub for East and North Africa, regulating floods and water flows for Sudan and Egypt, controlling sedimentation for downstream states, and reducing water evaporation (Genevieve, 2024). The GERD is predicted to generate for home consumption and export over 6,000 megawatts of power, equal to the capability of virtually five Nuclear Power plants. The World Bank additionally states that, once the GERD is completed, Ethiopia will become the largest energy generator in Africa, which may bring $1 billion a year in exports.

5. Diplomatic Effort and the Completion of the GERD

Attempts of the negotiation process to enhance cooperation and trust among the riparian states took place in 1999, with the Nile Basin Initiative (NBI) (Dreje, 2010). The NBI was aimed at creating an inclusive framework and developing a "Cooperative Framework Agreement" (CFA) to replace the 20th unfair bilateral treaties and to formalize a permanent Nile Basin Commission. However, Egypt and Sudan rejected this framework because they assumed it

[4] "Hidase" a newly coined Amharic word linked with the Ethiopian initiative with wider Neo-pan Africanist idea of African revival for independence and development.

did not respect their historical and natural rights to the Nile River water (Yacob, 2007; Dereje, 2010). Ethiopia, on its part, considers the CFA as an unfair response to the earlier Nile treaty and creating new realities in the Nile region that should be accepted by both Egypt and Sudan. Therefore, the 1929, 1959, and 2010 Nile Basin treaties and agreements were the basis of challenges and tension for the current diplomatic negotiations between Egypt and Ethiopia. The following part of this paper is all about the practices and various efforts of the negotiation process to resolve the dispute over the GERD since its commencement in 2011.

The Establishment of International Panel of Experts (IPoE) in 2012: Following the official inauguration of the Grand Ethiopian Renaissance Dam in April 2011, the then-president of Egypt Mohammed Morsi warned Ethiopia that "*all options are open to stop the building of the dam*"; after that, fears and tensions were spread that there was a possibility of serious water conflict over the Nile, with Egyptian possessing the strongest military capabilities (Shay, 2018). Ethiopia however, initiate to form a tripartite committee by its good faith; in May 2011, the Egyptian Prime Minister Essam Sharif has visited Ethiopia, to communicate and agreed to form a committee from Egyptian, Sudanese and Ethiopian experts to study the future effects of the Ethiopian Great dam on the water flow and course of the Nile water to Sudan and Egypt (Shay, 2018). And then the Governments of Sudan, Egypt, and Ethiopia reached an agreement to form an International Panel of Experts (IPoE) to oversee the overall activities of the Grand Ethiopian Renaissance Dam. This panel of experts was assigned to conduct investigations over the Grand Ethiopian Renaissance Dam by focusing on two major issues: a hydrological issue on the Blue Nile watercourse and an economic, social, and environmental impact assessment of the dam on Egypt and Sudan (Yousif, 2018).

The Expert Panel was composed of two hydraulic experts from each of the three negotiated countries, and four international experts from Germany, South Africa, Britain, and France based on its respective disciplines: dam engineering, water resources planning, hydraulic modeling, environmentalist and socio-economist (IPoE final report, May 2013). The governments of Egypt, Ethiopia, and Sudan each nominated two national experts during December 15-23, 2011. And the final list of nominees was submitted on February 11, 2012, to three governments for approval. The launching of the meeting of the International Panel of Experts (IPoE) took place in Addis Ababa on May 15-18, 2012 (IPoE final report, May 2013). The panel investigates and reveals more than 153 design and study documents on the Grand Ethiopian Renaissance Dam.

The report of the International Panel of Experts shows that the design and construction of the GERD are based on the international standards of dam construction, and reveals that the dam has no negative impact on the downstream riparian states.

The Establishment of the Tripartite National Committee in 2014: The Tripartite National Committee (TNC) was established in August 2014. This committee was composed of twelve experts, who were carefully chosen from each of the three countries, whose task was to guide and follow up on the implementation of the two IPoE-recommended studies. The chosen members of the committee have held a meeting on a rotational basis in Addis Ababa, Khartoum, and Cairo.

The 2015 Tripartite Agreement of Declarations of Principles (DoP): The Declarations of Principle (DoP) signed by to officials of Egypt, Sudan and Ethiopia on March 23, 2015. The signing of the Declarations of Principles ensured that Egypt, for the first time, accepted that the Nile River is important for the upstream development project, and it also accepted that the construction of GERD has transformed the balanced water configurations of the basin from the existing status quo to a cooperation framework (Mahemud, 2019). The Declaration of Principles has ten principles signed by the three countries, four of which specifically address the issue of GERD and the rest of which are essentially part of the basic principles of international water law. It was the first of its kind, with the two countries sitting at a table to discuss the Nile River's utilization, which had not been done before (Bayeh, 2016). Unlike earlier bilateral and colonial agreements, the declarations of principle on the GERD ensure that all the three-country approves the construction of the dam (Shay, 2018).

The Hydrologist Meeting: The Establishment of National Independent Scientific Research Group (NISRG) in 2018: The establishment of the National Independent Scientific Research Group, composed of five scientists from Egypt, Ethiopia, and Sudan, on 05 February 2018, by the decisions of the Nine-party meeting at Addis Ababa. On May 15 in Khartoum, the National Independent Scientific Research Group was talking about the filling and operations of the dam. After conducting four meetings, the NISRG carried out modeling and scenario-based analysis and submitted its report to the Ministers of Water Affairs of the three countries in a meeting held on 25 September 2018 in Addis Ababa. The Ministers reviewed the report and agreed on the first filing and annual operation of the GERD. Ethiopia and Sudan were ready to sign the agreement, but Egypt, however, declined the agreement by citing the need to consult with higher authorities in Cairo.

Post-2018 Diplomatic Negotiation Process: Political reforms in Ethiopia in mid-2018 improved the construction process of the Grand Ethiopian Renaissance Dam (GERD), and the Ethiopians made a great determination to speed up the construction process. However, in more than a decade of the negotiation process, from the start of the Grand Ethiopian Renaissance Dam (GERD) in 2011 up to the immediate political reforms in Ethiopia in mid-2018, the trust of downstream countries, especially Egypt, was eroded; and tensions have been escalated into possible conventional conflicts and incidence of hydraulic wars. The nature of the GERD negotiation process in the post-2018 period has also changed slightly, which has increased the national interests of both riparian and non-riparian states (Yhdego, 2020). In this stage, the issue of third-party involvement in the negotiation process as an observer or mediator is a constant concern for the Egyptians to maintain their overwhelming water hegemony in the Nile basin, which has been blessed by the colonial power.

The Involvement of the US Department of the Treasury and the World Bank in 2019: From November 2019 to February 2020, twelve rounds of US-broker negotiations occurred, including the World Bank as observers; yet, attempts at the diplomatic negotiations process were aborted to reach a substantive matter because of biased conclusions in the United States draft proposal (Addisu, 2020). Particularly, after the first feeling was successfully achieved, the GERD issue became increasingly politicized and securitized. **The AU-led Negotiations Process in mid-2020:** From mid-2020, the African Union took the negotiation process to resume talks between the three countries, and the United States, the World Bank, and the

e-ISSN:2717-8277

European Union participated as observers. However, no agreement had been reached at the time this thesis was being finalized. Ethiopia and Egypt were never able to agree on critical details throughout the negotiation process, such as the timetable for filling the reservoirs, what to do during the drought season, dam safety management, data reciprocity, and other issues as mentioned in the discussions of areas of divergence or points of contention over the negotiations process of the GERD (Attia, 2021).

5.1. The Completions of the GERD: the Game-changer

The GERD, which is wholly funded by the Ethiopian people, was officially completed on September 9, 2025. The project was launched in 2011 with about a five billion dollar budget, and it represents Africa's largest hydro-electric power, stretching 1.8 km wide and 145 meters high, with a capacity to hold 74 billion cubic meters of water. The completion of the GERD remarks as a historic milestone for reshaping the broader Nile basin region, and a new approach to hydro-politics analysis. The accomplishment of GERD is a game-changer or shift of power dynamics that creates new emerging water-sharing by substituting the existing status quo in the region. The GERD has great potential benefits within the riparian states. This may push towards mutual cooperation, including the downstream state, Egypt (Gashaw, 2022). And know that GERD has become the center of development, a means of bargaining power and diplomacy. The office of the Prime Minister of Ethiopia reaffirms that "the dam is a symbol of regional cooperation and mutual benefits that the energy it will generate stands to uplift not just Ethiopia, but the entire *Nile region*.

Figure 1: The partial feature of the completed GERD

Source:https://www.ena.et/documents/d/eng/518361717_1163931335776212_1179395081938354289_n-1-jpg

6. Hydro-political Implications of the GERD on the Nile Region

6.1.. Cooperation and Conflict

Regional Cooperation: Ethiopia believes that the GERD is a matter of survival for millions of its people and serves as a water bank in the Horn of Africa during the drought season and facilitates energy integration for all riparian countries. As a result, Egypt may accepts the fact that Ethiopia has the right to construct the Grand Ethiopian Renaissance Dam (GERD) (Worku, 2024). The Egyptian's attitude and positions are therefore turned from opposing the construction of the dam and trying to persuade that the dam has to be undertaken under the applicable principles of international law. The Nile River Basin Initiative (NBI), founded in 1999, is the framework of the Blue Nile, and the GERD could be a great opportunity for cooperation and oneness between the eleven riparian countries, not just the three conflicted parties, if Egypt compromises and re-joins the initiative, and reaches a mutual agreement.

Africa plays for regional integrations in various developmental discourses, but the GERD is a practical means of regional integrations. The Grand Ethiopian Renaissance Dam creates an opportunity for interconnection among more than 11 African countries through a hydraulic energy system, known as the East Africa Power Pool, which links the African energy system; energy generated in Ethiopia could flow to any country in the Nile basin. And the Grand Ethiopian Renaissance Dam is one part of the great African power pool; the energy generated in Sudan, Egypt, or Kenya can be interconnected with this system (Firehiwot et al, 2025).

The Grand Ethiopia Renaissance Dam is a real opportunity rather than a source of water conflict, and it will be a catalyst for boosting the economy of the region as a whole. Therefore, GERD is the future source of cooperation and unity in East Africa.

Regional conflict: Grand Ethiopian Renaissance Dam as a threat for Conventional Hydraulic War between Egypt and Ethiopia. As we have seen over the past few years and the recent situation at hand, Egypt's position on the GERD negotiations process is linked to Ethiopia's internal politics (Almesafri, 2024). Considering that the current political turmoil in Ethiopia and the power struggle between the political forces will have a negative impact on Ethiopia's bargaining power in the negotiation process (Mahari, 2020). A peaceful and united Ethiopia has a better negotiation capability; a divided and fragile Ethiopia will weaken its negotiating position on the GERD (EBC Interview, 2021). The direct conventional war will be an impossible scenario, even if the Egyptian's belligerent and most bellicose rhetoric behavior continues (Sintayehu et al, 2025). There are some reasons that Egypt is not to engage a direct conventional war. The first reason is that Egypt will apply a proxy-war at a low cost by using insurgent groups that can easily destabilize and weaken Ethiopia and fulfill their interests. In fact, Egypt is still engaged in a proxy-war; it could be by supporting insurgent groups to disrupt the unity of the country. Egyptian insists that weakening Ethiopia is an important strategy to ensure Egypt's supremacy over the Nile. The second reason is the site of the dam that has been constructed is at the Ethiopian-Sudanese border, which is not attacked by any possible military actions of Egypt or Sudan. Thus, Egypt or Sudan would think twice before initiating any military action against the dam in case of tension escalation between the three countries (Whittington et al., 2014).

The third reason why the direct conventional war between Ethiopia and Egypt is the GERD dispute is an expansion of the historic tensions over the utilization of Nile watercourses, which, in turn, intensifies the problem of a lack of faithful communications among riparian states. Despite the escalating diplomatic crisis among Ethiopia, Sudan, and Egypt, the prospect of war over the GERD remains a plausible possibility. In addition to the above reason, Ethiopia's growing military capability to deter Egypt from considering war, and the current state of the dam, are important factors that contribute to the unlikely occurrence of conventional hydraulic war between Ethiopia and Egypt.

6.2. Geo-political Dynamics and its Implications

Grand Ethiopian Renaissance Dam as Possibly Became Cold Tensions in the Horn: Following the endless negotiations process over the Grand Ethiopian Renaissance Dam (GERD), both Sudan and Egypt claimed that the dam is a source of "national security threats (Almesafri, 2024). And Egypt has changed the negotiation process from technical talk to political negotiation by the strategies of regionalization and internationalization of the issue (Sintayehu et al, 2025). A frozen conflict in the region may persist due to geopolitical tensions between the United Arab Emirates (UAE) and Qatar, as both seek to advance their own interests, which may further fuel the conflict between Ethiopia and Egypt (Fenton-Harvey, 2021). While these regional powers may have their own interest to pursue on the horizon, the superpowers, such as the United States and European Union countries, on the one hand, and China and Russia, on the other hand, may intervene in the issue to seek their profit from the dispute. Thus, geopolitical competitions or a cold war over the Horn of Africa due to the Grand Ethiopia Renaissance Dam tensions will be another scenario (Matthews, Vivoda, 2023).

Conclusion

The GERD represents not only a pivotal shift in the hydro-political dynamics of the Nile region but also challenges the traditional narratives of Egypt's historical claims over it. The GERD serves as a historical narrative that must evolve to incorporate contemporary realities, fostering dialogue and collaboration rather than conflict.

Ethiopia and Egypt have been negotiating for more than a decade to reach an agreement on key technical and legal issues related to the GERD dispute. Some of the major attempts of the negotiations process are the foundations of an International Panel of Experts (IPoE) in 2013, and the establishment of the Tripartite National Committee (TNC) in 2014. The 2015 Declarations of Principles (DoPs) were a unique milestone in the negotiation process. Another milestone of the negotiation process was the establishment of the National Independent Scientific Research Group (NISRG) to discuss the filling and operation of the GERD. On November 6, 2019, as per the request of Egypt, the US Treasury group was a broker of the tripartite negotiations, with the presence of the World Bank (WB); however, Ethiopia rejected the US-biased draft proposal, and the negotiation process failed. In 2020, the failed negotiation process turned back to the African Union (AU); however, Egypt has rejected the AU-led negotiations process over the GERD by blaming the African Union (AU) for lacking institutional capacity and experience to resolve disputes over transboundary watercourses.

Finally, the paper looks into the geo-political implications of the GERD analysis from different perspectives or scenarios, one of which is from the optimistic view that Ethiopia and Egypt reach a comprehensive agreement on the GERD, and that the dam will be a milestone for the unity of the region. The second implication suggested that the Grand Ethiopia will possibly lead to cold tensions in the Horn. The third implication is that GERD would lead to the two countries entering into an active conflict and conventional war, which would become the first hydraulic war in the history of transboundary rivers.

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Received: October 27, 2025

Accepted: December 25, 2025

Issue: 8 2025
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

From Conflict to Cooperation? Lessons from the GERD for Transboundary Water Diplomacy in the Nile Basin

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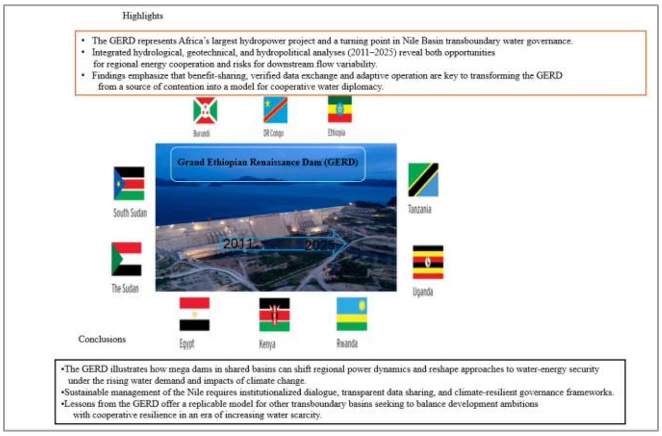
Abstract
The Grand Ethiopian Renaissance Dam (GERD) stands as one of the most ambitious hydropower projects in Africa, symbolizing both Ethiopia's developmental goals and the complex hydro-politics of the Nile Basin. Since its launch in 2011, the GERD has sparked intense debates between riparian states, specifically Ethiopia, the largest upstream source of the Nile, and Egypt, the principal downstream user, alongside Sudan, over issues of water security, energy needs, and regional economic development. While Egypt has expressed concerns over potential reductions in downstream flows, Ethiopia has emphasized the dam's critical role in addressing domestic energy shortages and regional power integration. This tension highlights the dual nature of large-scale water infrastructures as both sources of conflict and potential platforms for cooperation. Drawing upon the GERD case, this paper examines the evolving dynamics of transboundary water diplomacy in the Nile Basin. It explores the hydro-political, technical, institutional, and cooperative frameworks shaping management of transboundary waters, implications and the role of international actors, and the broader lessons for conflict transformation and mechanisms in shared river basins. Ultimately, the GERD experience underscores that the transition from conflict to cooperation is neither automatic nor linear, but contingent upon trust-building, inclusive dialogue, and adaptive governance.

Keywords: Grand Ethiopian Renaissance Dam (GERD); Nile basin; transboundary water diplomacy; hydro-politics, mega dam project



Graphical Abstract

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1. Introduction

The Nile River, the world's longest river, is the lifeline of over half a billion people across eleven riparian countries (Glada Lahn & Greg Shapland, 2022; Greg Shapland et al., 2025; Pacini & Harper, 2016). Approximately three-quarters of the basin's population live in rural areas, where livelihoods are closely tied to agricultural productivity and seasonal climate variability (Tront & Jägerskog, 2020). This deep reliance on the Nile's resources underscores its central role in sustaining life, livelihoods, and development across the region. Beyond its economic significance, the Nile Basin serves as the ecological and cultural backbone of northeastern Africa, underpinning food security, social stability, and regional identity for millions of people (Pacini & Harper, 2016b; World Bank, 2016)

At the heart of the basin's transformation lies the Grand Ethiopian Renaissance Dam (GERD), a mega-infrastructure that stands as Africa's largest hydroelectric facility. Located on the Blue Nile in northwestern Ethiopia, the GERD generates over 6,000 MW of renewable energy and creates a strategic foundation for regional energy trade and economic growth (Webuild, 2025). For Ethiopia, the dam symbolizes a path toward industrialization and energy self-reliance; for downstream countries, however, it represents a source of uncertainty and potential vulnerability. Egypt and Sudan, which depend almost entirely on Nile flows, have voiced persistent concerns that the GERD could alter established water use patterns and threaten water-energy security (Almesafri et al., 2024; Mohammed, 2025).

These apprehensions have escalated into one of the most significant hydro-political disputes in Africa. Egypt, describing the project as a potential threat to its national water security. Despite intense diplomatic exchanges, Ethiopia proceeded with construction and began reservoir filling in 2020, achieving major operational milestones by 2025 (Webuild, 2025). While regulated flows from the reservoir could help reduce downstream flooding, uncontrolled operation could disrupt established water allocations in the downstream riparian and raise the risk of mismatched expectations. The downstream riparian concerns about flows, navigation, and ecological sustainability challenges can be mitigated and transformed into opportunities for shared resilience through coordinated management(Walschot & Katz, 2022; Wheeler et al., 2018).

Beyond the immediate water-security debate, the GERD also represents a test of regional cooperation and adaptive governance in an era of climate change. Increasing climatic variability, population growth, and competing resource demands underscore the need for shared, science-based solutions. The Nile Basin Initiative and related multilateral frameworks provide essential foundations for dialogue, yet they remain underutilized (Nile Basin Initiative (NBI), 2025). Strengthening these institutions through technical data-sharing, early warning systems, and cooperative climate adaptation strategies could help transform the GERD from a point of contention into a driver of integration and resilience.

This study appraises GERD within the broader discussion on transboundary water diplomacy, analyzing how the project has influenced the Nile basin utilization and what lessons it offers for managing shared river basins under conditions of water scarcity and climate change. The paper links engineering performance with governance perspectives, evaluating its implications, and aims to identify actionable pathways through which mega dams' development can foster both sustainable resource management and cooperative stability in the Nile basin riparian.

2 Materials and Methods

This study adopts a qualitative and analytical research design integrating hydro-political analysis, document review, and comparative synthesis. It draws upon official technical reports, legal frameworks, and policy documents from Nile Basin countries, as well as studies from international institutions such as the African Union (AU), Nile Basin Initiative (NBI), United Nations Economic Commission for Africa (UNECA), World Bank, and FAO. These sources were systematically examined to understand the evolving institutional, technical, and diplomatic dynamics surrounding the Grand Ethiopian Renaissance Dam (GERD) and its implications for transboundary water governance.

The methodological framework (Figure 1) combines document analysis, secondary data synthesis, and comparative assessment. The study reviews key technical aspects, frameworks, and mechanisms, and evaluates negotiation frameworks, benefit-sharing mechanisms, and basin-level coordination initiatives. Qualitative analysis was used to assess ongoing disputes over the reservoir operation, understand management mechanisms and identify actionable pathways to dispute drivers, cooperation opportunities, and adaptive governance across the Nile Basin.

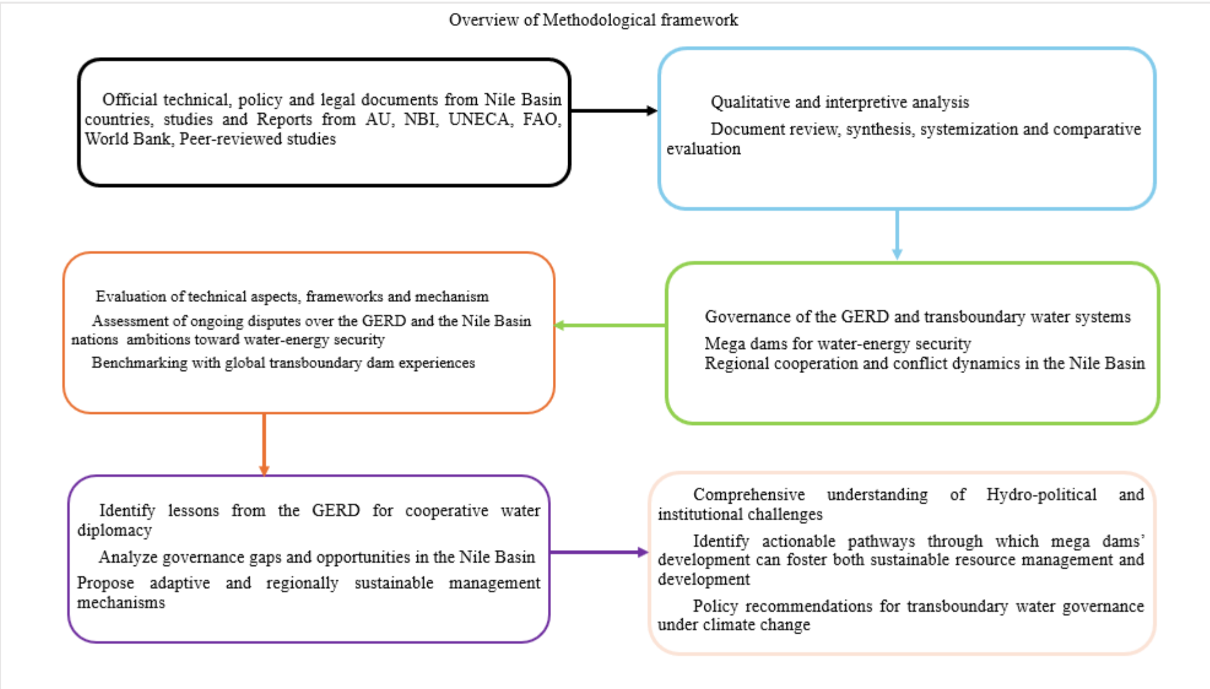

Figure 1. Conceptual framework of the research methodology

The approach emphasizes technical and policy interpretation rather than experimental analysis and the study identifies transferable lessons and strategic pathways for cooperative water diplomacy in transboundary shared river systems.

3. Mega-Dams and Transboundary Water Issues

Transboundary river basins (TRBs) are among the most critical and contested water systems on Earth, covering approximately 60% of the global freshwater supply and supporting the livelihoods of over three billion people(Jiang et al., 2025; Sahana et al., 2024; Zeitoun et al., 2013). The interdependence of nations sharing these basins creates both opportunities for regional cooperation and potential sources of political tension. Rapid population growth, economic expansion, and climate-induced hydrological variability have intensified competition over limited water resources, especially in arid and semi-arid regions (El Kenawy, 2024; Jewaro et al., 2025). In this context, the construction of large hydropower dams often intended to enhance national energy security has emerged as a defining feature of transboundary water politics in the 21st century.

While mega-dams offer substantial benefits in terms of renewable energy production, flood control, and economic growth, their transboundary implications are complex. Upstream developments can alter downstream flow regimes, sediment transport, and ecological balance, leading to heightened perceptions of risk among riparian neighbors. Studies have shown that (Sadoff, 2002; Sahana et al., 2024) . Climate change further complicates these dynamics by altering rainfall patterns and increasing drought frequency, thereby reducing predictability and intensifying water scarcity pressures. Without institutionalized mechanisms for data sharing, joint monitoring, and adaptive governance, such conditions may escalate into diplomatic disputes or protracted negotiations (Almesafri et al., 2024; Sadoff, 2002)

The Grand Ethiopian Renaissance Dam (GERD) exemplifies the multi-dimensional nature of these challenges. As one of the largest hydropower projects in Africa, it has redefined the hydropolitical landscape of the Nile Basin. For Ethiopia, the GERD is a national symbol of modernization and energy independence, designed to generate 6,450 MW of electricity and catalyze regional power trade (Webuild, 2025). For downstream states, particularly Egypt and Sudan, it represents a shift in the historical balance of control over the Nile's flow. These divergent perspectives underscore the persistent tension between upstream development rights and downstream high dependency. Yet, they also highlight a critical diplomatic opportunity: through transparent operation, equitable benefit-sharing, and joint climate adaptation initiatives, the GERD could evolve from a source of contention into a platform for regional cooperation.

Recent global analyses confirm that transboundary cooperation is the single most effective mechanism to mitigate water scarcity induced conflicts (Veldkamp et al., 2017). Modeling studies suggest that, without adaptive coordination, nearly 40% of TRBs could experience water-related disputes by mid-century (Jiang et al., 2025; Sahana et al., 2024; Veldkamp et al., 2017). However, sustained collaboration through treaties, basin organizations, and joint management frameworks can reduce that risk by more than half (K. Paisley & Henshaw, 2013; Wheeler et al., 2018). For the Nile Basin, where water, food, and energy systems are deeply interconnected, such cooperation is not merely desirable but essential for climate resilience and sustainable peace. The GERD thus provides a pivotal case for understanding how mega-dam diplomacy can transition shared basins from conflictual competition to cooperative governance under a changing climate.

4. Results and Discussion

4.1 The GERD in Context: Foundations and Development

The Grand Ethiopian Renaissance Dam (GERD), situated on the Blue Nile in northwestern Ethiopia near the Sudanese border, represents one of Africa's largest and most strategically significant infrastructure projects(K. Paisley & Henshaw, 2013). Construction began in April 2011, following the official declaration of the foundation, and has since advanced through successive engineering, hydrological, and diplomatic phases (Figure 2). The dam is designed with a total installed capacity of 6,450 MW and a storage volume of approximately 74 billion cubic meters, positioning it as a transformative pillar for Ethiopia's national energy policy and regional hydropower trade (Webuild, 2025).

The GERD project evolved alongside key political and institutional milestones. Early construction phases between 2013 and 2014 focused on site preparation, foundation stabilization, and roller-compacted concrete (RCC) placement. The Declaration of Principles, signed in 2015 by Ethiopia, Egypt, and Sudan, sought to establish a cooperative framework for equitable and reasonable utilization of the Nile waters (Kåresdotter et al., 2023; World Bank, 2016). Major civil works and structural progress followed between 2017 and 2018, leading to the first impoundment of the reservoir in 2020. Subsequent filling stages (2021–2024) progressively increased storage capacity, culminating in near-full operation by 2025 (Webuild, 2025).

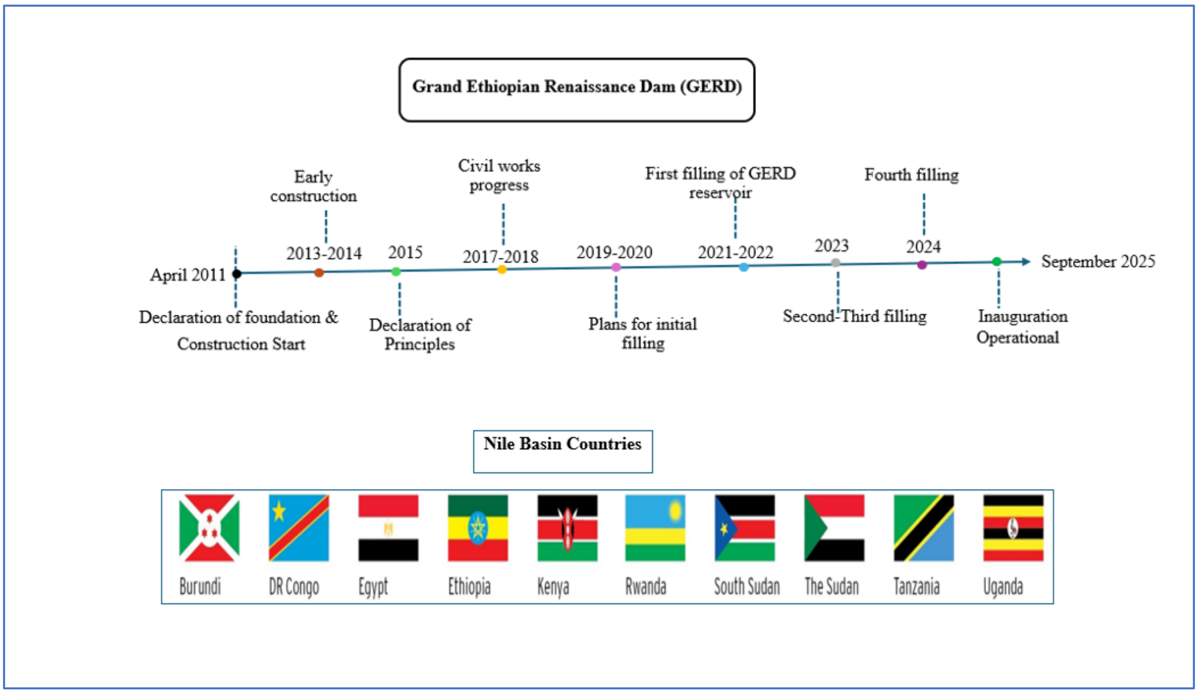

Figure 2. Timeline of the Grand Ethiopian Renaissance Dam (GERD) and the riparian states of the Nile Basin.

As illustrated in Figure 1, the GERD's development has unfolded in parallel with the evolving dynamics of Nile Basin cooperation. The eleven riparian states, Burundi, DR Congo, Egypt, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda, represent a diverse geopolitical and hydrological landscape with varying levels of dependency on the Nile's flow. The dam's successive filling cycles have had both symbolic and practical significance: symbolizing Ethiopia's growing capacity for self-sufficiency while testing the region's mechanisms for transboundary coordination and water diplomacy.

4.1.1 Hydrological characteristics

The Nile Basin is one of the world's most complex and climatically diverse transboundary river systems, extending across eleven countries and covering more than 3 million square kilometers (K. Paisley & Henshaw, 2013; Pacini & Harper, 2016c; Tayie, 2018). Two major tributaries the Blue Nile (known as the Abbay in Ethiopia) and the White Nile provide the majority of the river's total discharge. The origins of these tributaries are geographically and climatologically distinct (Pacini & Harper, 2016c; Vijverberg et al., 2009). The Blue Nile rises from Lake Tana in the Ethiopian highlands, reaching the Sudanese plains, where it joins the White Nile at Khartoum (Vijverberg et al., 2009). In contrast, the White Nile flows northwards from the equatorial lakes region, traversing a vast network of wetlands and floodplains, notably the Sudd in South Sudan (Pacini & Harper, 2016c). This combination of contrasting hydrological regimes makes the Nile Basin both hydrologically dynamic and politically sensitive, as rainfall variability, evapotranspiration, and topographic settings vary sharply between sub-basins. The basin's high climatic diversity, uneven precipitation, and spatially concentrated runoff contribute to its overall vulnerability to water scarcity and interannual variability.

The Blue Nile River, which contributes approximately 60-65% of the total Nile discharge reaching downstream, exhibits highly seasonal flow patterns, with nearly 80% of its annual runoff generated during the wet season under the influence of the Intertropical Convergence Zone (ITCZ) (Kim & Kaluarachchi, 2009; Taye et al., 2015). The average annual inflow at the GERD site ranges between 49 and 52 billion cubic meters (BCM), but this figure fluctuates substantially over the monsoon and periodic drought variability (Pacini & Harper, 2016c)

The GERD reservoir, designed with a gross storage capacity of 74 BCM and a surface area exceeding 1,750 km² at full supply level, can play a pivotal role in environmental transformation(Webuild, 2025). With its full operation, the dam is expected to regulate extreme flows, reducing flood peaks by 25-30%. However, evaporation losses (2-3 BCM annually) and sedimentation (120-150 million tons per year) may pose allocation arrangement and management challenges for long-term reservoir sustainability (Khairy et al., 2019)

The GERD can enhance Ethiopia's capacity for multi-renewable energy generation, while simultaneously necessitating coordinated operation with downstream users. The balance between domestic hydropower optimization and transboundary water allocation underscores the need for adaptive governance, particularly under future climate scenarios that project greater hydrological variability. Ensuring equitable and sustainable operation will depend on robust hydro-meteorological data sharing, real-time monitoring, and basin-wide planning that integrates the water-energy-climate nexus perspective.

4.1.2 Hydro-politics in the Nile Basin: Conflict Narratives

The hydro-political and diplomatic context surrounding the GERD has evolved as one of the most studied and emblematic cases of transboundary water governance in the Global South (K. Paisley & Henshaw, 2013; Walschot & Katz, 2022; Wheeler et al., 2018; Wolf et al., 2003). The project's announcement in 2011 marked a decisive assertion of Ethiopia's right to utilize the Blue Nile for national development, challenging a century-old status quo that favored downstream countries. Egypt, historically dominant in Nile utilization and management, perceived the dam as a potential threat to its water security, which depends on the Nile for nearly 90% of its freshwater supply.

Diplomatic tensions have fluctuated between periods of negotiation and confrontation. The Declaration of Principles (DoP) signed in March 2015 in Khartoum represented the first formal acknowledgment of shared responsibility among Ethiopia, Sudan, and Egypt, emphasizing cooperation, equitable utilization, and mutual benefit (Salman, 2017). However, divergent interpretations of "no significant harm" and "equitable use" principles have continued to fuel mistrust (Gari et al., 2023; Onencan & Van de Walle, 2018). While Ethiopia maintains that GERD operations are designed to optimize regional energy generation without causing considerable downstream harm, Egypt insists on binding water release guarantees to safeguard its historical allocations. Sudan's position has oscillated between support and caution, benefiting from flood control and cheaper energy imports, yet expressing concerns over dam safety and coordination.

The Nile Basin, extending across eleven riparian states, exhibits a unique diversity of hydrological conditions, development priorities, and national water interests (Gari et al., 2023; Onencan & Van de Walle, 2018). While Ethiopia views the river primarily as a source of hydropower and energy security, downstream countries such as Egypt depend almost entirely on its flow for irrigation and food production. Upstream states, including Kenya, Rwanda, and Tanzania, pursue mixed objectives, seeking to expand agricultural and hydropower infrastructure for socio-economic growth. The Democratic Republic of the Congo and Burundi, located in the upper reaches of the basin, prioritize navigation and local energy development, and Eritrea maintains an observer status and plays a subtle but important role in the region's hydro-political landscape. Understanding these differentiated interests is crucial for contextualizing the regional responses to the Grand Ethiopian Renaissance Dam (GERD) and the broader dynamics of cooperation and competition over Nile waters. Concurrently, the GERD illustrates that water-related tensions in shared basins are rarely zero-sum but hinge on institutional design, transparency, and diplomatic flexibility. In this sense, it serves as a laboratory of hydro-diplomacy where development ambition, environmental interdependence, and political negotiation intersect in shaping the future of the Nile Basin. Table 1 shows the Riparian countries' various interests over the Nile basin.

Table 1. The Nile basin riparian states and interests

Country	Primary interests
Ethiopia	Hydropower, Development
Egypt	Irrigation, Food security
Sudan	Hydropower, Irrigation
South Sudan	Irrigation, Hydropower
Uganda	Hydropower
Kenya	Irrigation, Hydropower
Tanzania	Irrigation
Rwanda	Hydropower
Burundi	Hydropower
DR Congo	Navigation, Hydropower

Following decades of limited utilization, Ethiopia's recent hydropower investments, particularly the GERD, have shifted the regional balance of water use. The project symbolizes the country's long-delayed aspiration to harness the Blue Nile for development and energy self-sufficiency. Historically, Ethiopia's contribution to Nile flows constitutes largest share yet its direct usage remained marginal due to economic and technological constraints. The GERD now provides a foundation for expanding national and regional energy access while maintaining commitments to equitable and cooperative utilization. Achieving this balance will require sustained dialogue, transparency, and technical collaboration to ensure that development gains in Ethiopia are aligned with downstream water security and shared basin resilience.

4.1.3 Frameworks, Mechanisms, and Diplomatic Pathways

The governance of the Nile Basin has long been guided by a mixture of historical treaties, evolving regional institutions, and emerging diplomatic mechanisms, reflecting both continuity and transformation in transboundary water management. The earliest arrangements allocated nearly the entire Nile flow to the two downstream states, leaving upstream riparian states, including Ethiopia, without recognized water rights. This asymmetrical control creates a legacy of distrust that continues to influence present-day negotiations.

Recognizing the limitations of these arrangements, riparian countries launched the Nile Basin Initiative (NBI) in 1999 as a transitional framework aimed at fostering cooperative development (Nile Basin Initiative (NBI), 2025; World Bank, 2016). The NBI's core principle, "Shared Vision for Sustainable Development," sought to replace unilateral action with basin-wide planning through three strategic pillars: equitable water utilization, regional economic integration, and environmental sustainability (Nile Basin Initiative (NBI), 2025). The initiative also provided a technical platform for data sharing, hydrological modeling, and capacity building. However, the Comprehensive Framework Agreement (CFA), designed to transform the NBI into a permanent legal entity, stalled due to divergent interpretations of "water security," with Egypt and Sudan withholding ratification. Despite this, the NBI remains a crucial institutional mechanism for dialogue and evidence-based decision-making in the basin.

The Declaration of Principles (DoP) on the GERD, signed in March 2015 by Ethiopia, Egypt, and Sudan, marked a significant diplomatic milestone (Onencan & Van de Walle, 2018). It reaffirmed key principles of international water law, including equitable and reasonable use, the obligation not to cause significant harm, and the pursuit of cooperation through mutual benefit. Article V of the DoP established the framework for dam filling and operation guidelines, while Article X called for dispute resolution through consultation and, if necessary, mediation (Mohamed & Abdalla, 2025). However, the absence of binding enforcement and the ambiguity of technical terms have limited its practical application. As a result, the DoP serves more as a political confidence-building instrument than a legally enforceable agreement.

Recent years have witnessed intensified mediation under the African Union (AU) and other regional and global platforms, with rounds of trilateral talks facilitated by the AU, United States, and the World Bank between 2019 and 2023 (UN SCR (UN Security Council Report), 2021). While no comprehensive accord has yet been reached, these processes have expanded the scope of technical cooperation and trust-building through shared modeling studies, reservoir operation proposals, and climate risk assessments. The involvement of the Eastern Africa Power Pool (EAPP) has also linked hydropower development with regional energy diplomacy, positioning electricity trade as a potential driver of cooperation(Eastern Africa Power Pool (EAPP), 2025).

Collectively, these frameworks demonstrate a gradual, albeit fragile, shift from treaty-based control toward adaptive, multilevel governance. The ongoing challenge lies in transforming declaratory commitments into operational cooperation supported by transparent data exchange and institutionalized joint management. For the GERD and the broader Nile Basin, success will depend on embedding diplomatic pathways within a basin-wide governance model that integrates technical, legal, and environmental dimensions, moving beyond zero-sum bargaining toward shared resilience under climate uncertainty.

Table 2. Conflict drivers and cooperation opportunities in the GERD case

Conflict Drivers	**Cooperation Opportunities**
Historic water rights claims (Egypt)	Declaration of principles (2015) as framework
Unilateral actions and mistrust	Regional-global negotiations platforms (AU, EU, US, Nile Basin Initiative, etc.)
Uncertainties over GERD filling and operation	Regional integration and energy export
Perceived threats to water-energy-food security	Shared benefits: development growth, flood control, technological, socio-economic cooperation
Weak enforcement of regional agreements	Joint climate adaptation initiatives and basin management

4.2 Lessons for Transboundary Water Diplomacy

The experience of the Grand Ethiopian Renaissance Dam (GERD) provides valuable lessons for strengthening transboundary water diplomacy in complex and politically sensitive basins. The GERD illustrates that large-scale infrastructure projects, when embedded within asymmetrical power relations and historical dependencies, can simultaneously act as drivers of conflict and catalysts for cooperation. The challenge lies not in the dam's physical scale, but in the governance frameworks and diplomatic mechanisms that determine how its benefits and risks are distributed among riparian states (UN Water, 2024; World Commission On Dams, 2000).

4.2.1 Institutional and Legal Lessons

One of the foremost lessons emerging from the GERD negotiations is the critical importance of institutionalized cooperation. The prolonged absence of a basin-wide legal framework has left decision-making fragmented, reactive, and heavily influenced by national priorities. While the Declaration of Principles (2015) marked a step toward codifying shared commitments, its non-binding nature exposed the need for stronger, enforceable mechanisms for dispute resolution, data exchange, and adaptive operation under variable hydrological conditions (UN SCR (UN Security Council Report), 2021). The Nile Basin Initiative (NBI) and the Comprehensive Framework Agreement (CFA) still hold potential as long-term cooperative platforms if reactivated through political consensus and strengthened with joint technical bodies capable of producing basin-level forecasts, reservoir simulations, and climate impact assessments.

4.2.2 Technical and Scientific Lessons

The GERD underscores that science-based dialogue is essential to depoliticize water negotiations. Multilateral modeling exercises, satellite monitoring, and hydrological forecasting, when transparently shared, can reduce uncertainty and build trust among stakeholders (Sowby et al., 2025). The use of remote sensing and GIS technologies has proven particularly effective in providing objective, real-time data on reservoir filling, water balance, and regional rainfall variability (Yalew et al., 2023). This technical transparency can bridge the gap between political perception and hydrological reality. Moreover, coordinated dam operation strategies and seasonal optimization models can help align upstream energy generation with downstream water needs, promoting a win-win framework that integrates energy, water, and climate resilience objectives.

4.2.3 Hydro-political and Diplomatic Lessons

Hydro-political issues over shared water systems in the Nile basin are addressed through hydro-diplomacy and persistent concerns about whether sufficient flows will reach downstream riparian states. Yet, despite these uncertainties, ongoing hydro-diplomatic engagements together with emerging regional energy-trade initiatives can create new pathways for dialogue, cooperation, and mutually beneficial negotiation among the riparian states. Linking hydropower generation to regional electricity interconnectors, such as the Eastern Africa Power Pool (EAPP), can transform the dam from a contested project into a shared asset (Eastern Africa Power Pool (EAPP), 2025). Similarly, benefit-sharing mechanisms, for instance, through joint investment funds, flood control services, or powerpurchase agreements, represent practical avenues for cooperation beyond volumetric water allocation.

The GERD also highlights the value of adaptive diplomacy under climate uncertainty. As rainfall patterns and runoff variability increase, rigid water-sharing arrangements become less viable. Instead, a flexible, data-driven, and climate-informed negotiation framework can help states adjust reservoir operations dynamically, ensuring both hydropower sustainability and downstream water security. In this sense, water diplomacy must evolve from static agreements toward continuous negotiation processes, supported by technical cooperation, scientific exchange, and regional solidarity.

4.2.4 Regional and Global Implications

Beyond the Nile Basin, the GERD case contributes to a broader understanding of how mega-dams in transboundary basins such as the Mekong, Indus, or Tigris-Euphrates reshape water diplomacy. It demonstrates that the pathway from conflict to cooperation is gradual, iterative, and often driven by shared crises such as droughts, floods, or energy shortage (De Stefano et al., 2017). These moments of vulnerability can be reframed as opportunities for collaboration through joint monitoring networks, early-warning systems, and climate-adaptation partnerships. Ultimately, the GERD shows that sustainable transboundary governance depends not only on legal agreements but also on the co-production of knowledge, mutual trust, and shared benefits among riparian states.

Table 3. Overview of the GERD dispute, impacts, and implications

Dimension	**Description / Key Insights**	**Implications**
The Dispute	Contestation over Nile water allocation, GERD filling schedule, and perceived control of flow. Downstream riparian countries, mainly Egypt, express water security concerns; Ethiopia emphasizes the sovereign right to development.	Highlights the need for shared rules on reservoir operation, environmental and water allocation management.
Hydrological Impact	Regulated flow reduces seasonal floods downstream but may alter sediment balance and water flow timing; potential ecological changes in lower floodplains.	Necessitates joint hydrological monitoring and adaptive mechanisms.
Socio-economic Impact	GERD enhances Ethiopia's power generation capacity (6,450 MW), supports sustainable development and regional power trade; downstream may face short-term water stress.	Promotes benefit-sharing through energy cooperation and regional infrastructure integration.

Diplomatic & Institutional Dynamics	Negotiations mediated by AU, UN, EU, and US; differences persist over equitable and sustainable water governance, legal enforcement, and dispute-resolution.	Calls for institutionalized dialogue, trust-building mechanisms, and verified data exchange platforms.
Climate & Environmental Dimension	Variability in rainfall and rising temperatures complicates reservoir management; potential for climate change induced water insecurity under conditions of demand increase, population growth, and poor basin management.	Strengthens the case for climate-adaptive governance and coordinated basin-wide planning.
Future Opportunities	Energy trade, joint environmental monitoring, climate adaptation funding, and Nile Basin Initiative reforms.	GERD can become a model for cooperative development and regional resilience.

The experience of the GERD offers valuable insights for the governance of shared river basins where resource scarcity intersects with regional interests. Five major lessons emerge from the GERD process. First, institutionalized dialogue is indispensable; the Khartoum Declaration of Principles (2015) demonstrated that even modest agreements can create frameworks for structured negotiation and reduce unilateralism. Second, benefit-sharing proves more sustainable than water-sharing, as cooperation in energy trade, flood control, and infrastructure development generates mutual gains beyond volumetric allocations. Third, trust-building through verified data exchange, joint technical committees, and transparent monitoring mechanisms is critical for overcoming entrenched mistrust. Fourth, regional ownership remains more legitimate and durable than externally imposed mediation-African-led mechanisms, particularly under the African Union, exemplify this. Finally, adaptive governance is vital in an era of climate variability; agreements must evolve to address drought, flood cycles, and shifting development needs. Collectively, these lessons underscore that the GERD is not merely a hydroelectric project but a test case for transboundary water diplomacy, with implications extending beyond the Nile Basin to other international river systems.

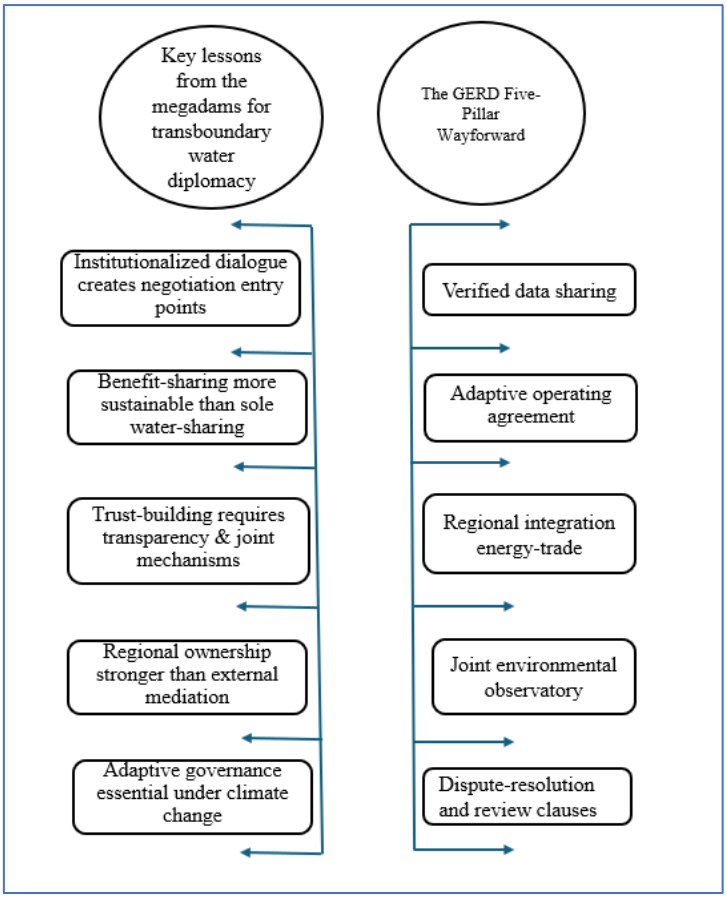

Figure 3. Linking key lessons from mega-dams to the GERD five-pillars way forward.

The GERD five-pillars way forward (Figure 3) synthesizes the study's main findings into a pragmatic framework for action. It connects the institutional and technical lessons of transboundary water diplomacy, such as dialogue, transparency, and benefit-sharing, to concrete measures, including verified data exchange, adaptive operation rules, regional energy cooperation, joint environmental monitoring, and dispute-resolution mechanisms. Together, these pillars outline a practical roadmap for transforming the GERD into a cornerstone of cooperative water governance and climate-resilient diplomacy in the Nile Basin.

5. Conclusion

The case of the Grand Ethiopian Renaissance Dam (GERD) optimizes the complex interplay between development ambitions, hydrological realities, and transboundary governance in a rapidly changing climate. As global and regional warming intensifies hydrological variability, the risk of surface water scarcity-induced conflicts in transboundary basins has grown considerably (De Stefano et al., 2017; Zeitoun et al., 2013). Climate projections indicate that, without coordinated adaptation and cooperation, nearly 40% of transboundary river basins worldwide could face conflict pressures by mid-century, with hotspots concentrated in Africa, South Asia, and the Middle East (Jiang et al., 2025). The Nile Basin, already characterized by climatic extremes, uneven resource distribution, and institutional fragility, stands as one of the most exposed systems to these pressures.

For Ethiopia, the dam symbolizes a transformative step toward energy security, industrial development, and regional integration. For other riparian states, particularly Egypt and Sudan, however, it has raised concerns over water security, food security, and economic development. These divergent perspectives illustrate how mega-dams in transboundary basins can serve simultaneously as engines of national development and triggers of hydro-political contestation.

In this context, the GERD serves as both a warning and a model. It demonstrates how the absence of comprehensive governance mechanisms can heighten hydro-political disputes, yet also how shared infrastructure can serve as a foundation for cooperation when underpinned by science-based diplomacy and transparent operations. The dam's evolution from a unilateral project to a subject of regional negotiation reflects a gradual shift toward recognizing the interdependence of water, energy, and climate security in the basin. Building on this trajectory requires sustained investment in joint hydrological monitoring, data exchange, and climate-resilient operational frameworks that can respond dynamically to hydrological shocks.

On a broader scale, the GERD illustrates the urgent need to reframe transboundary water diplomacy under climate change pressures. Future agreements must move beyond static water allocations toward adaptive, flexible, and knowledge-driven governance that accounts for changing hydrological baselines. Regional cooperation through platforms such as the Nile Basin Initiative and the African Union remains essential to institutionalize this adaptive diplomacy and reset it within broader continental resilience strategies.

Ultimately, the transition from conflict to cooperation in the Nile Basin and in transboundary basins globally will depend on the political will to align national development with regional sustainability. GERD's lessons underscore that climate change risks and competition for the limited water resources also offer an opportunity to reimagine shared governance through transparency, and collectively use and manage freshwater resources of transboundary river basins. Sustainable development in transboundary river systems will therefore hinge not only on managing water as a resource but on treating it as a shared common strategic resource and a catalyst for regional integration under a changing climate.

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Received: November 15, 2025

Accepted: December 25, 2025

Issue: 8 2025
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

Sustainable Rural Water Supply Management in Developing Countries: A Case Study of the Community Water and Sanitation Agency Reform in Ghana

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Abstract
The main management model for the National Community Water and Sanitation Program (NCWSP) in Ghana is the Community Ownership and Management (COM) model. This model entails training non-professional community members in the operation and management of water supply systems. The rural water supply in Ghana improved slightly from 27% to 62.13% between 1994 and 2017; however, the water systems have not been used to their full capacity. Again, a decrease in donor inflows of grants and loans to the sub-sector and Ministry of Finance policy announcements supporting sustainable initiatives call for Community Water and Sanitation Agency (CWSA) policy reform. The policy reform aimed to make CWSA a Utility Organization, directly in charge of delivering and overseeing piped water supply systems for small towns and supplying point water systems in coordination with Metropolitan, Municipal, and District Assemblies (MMDAs). However, the CWSA employees assigned to the various districts or special teams from the regional offices should be responsible for supervising and monitoring the Water and Sanitation (WATSAN) Committees and Water and Sanitation Development Boards (WSDB) to ensure the efficient operation and upkeep of the other water facilities. The current CWSA reform is the best course of action to guarantee a sustainable rural water supply in Ghana. It has the potential to significantly aid Ghana in achieving Sustainable Development Goal Six (SDG 6).

Keywords: Community Ownership Model; Sustainable Development Goal Six; Water Systems; Water and Sanitation Committee; Water and Sanitation Development Boards; Ghana

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1. Introduction
In 2010, the United Nations (UN) formally recognized access to potable water as a human right, stating that it is necessary for human life (UN, 2010). Five years later, SDG 6 of the 2030 Agenda for Sustainable Development, which aims to guarantee the availability and sustainable management of water and sanitation for everyone by 2030, once again emphasized this recognition (UN, 2015). The advancement of human society, environmental health, and economic well-being all depend on the quality of water availability (UN, 2018). In this sense, the 2030 agenda may be in danger if SDG 6 is not achieved. However, according to some

reports, countries around the globe are not on track to meet this objective (Ho et al., 2020). For instance, 1.8 billion people still had to drink water tainted by feces in 2015, and 80% of effluent from human activity was still being dumped straight into ecosystems that depend on water (UN, 2015).

The academic inquiry has been grounded in models, frameworks, and instruments (Corazza et al., 2022), providing an opportunity to develop locally relevant, action-oriented practices. The iteration of new and developing logic pertinent to the rural water sector can be supported by stakeholders, including engineering, health, education, planning, policy, housing, and urban development (Lang et al., 2017). In the rural water supply sector, problems related to limited resources and efforts can be overcome by the cross-cutting advantages of action, which is strengthened by new knowledge.

According to WHO/UNICEF (2015), one of the regions with the least water coverage is Sub-Saharan Africa (SSA). Like other least-developed regions, SSA made progress during the MDG period, but could not fulfill the target. Since 1990, 42% of the present population has had access to improved drinking water (WHO/UNICEF, 2015). There was about a 20% increase in improved drinking water sources in the region within the period (UNICEF, 2015). The MDG timeframe saw a doubling of the SSA population. There is little empirical data on the home-level factors that consistently and cooperatively affect access to improved water services across space and time, and on which of these factors extend across geopolitical borders.

The government of Ghana was exclusively responsible for providing safe water under the supply-driven system, and there were no requirements placed on communities to meet before water was made available. Water supply in rural areas was intended to provide universal access to services and equal socioeconomic development. The supply-driven strategy's primary concerns were the long-term viability of the water stations and the feasibility of achieving fast-passed coverage in remote communities (Adeenze-Kangah, 2022). These concerns diminished the impact of the government's effective implementation of this strategy and led to a shift from a supply-driven to a demand-driven approach. Beneficiary communities were required to contribute a portion of the water point's cost and participate in its construction and maintenance under a demand-driven, decentralized system.

Several Non-governmental organizations (NGOs) and donor agencies working in rural water delivery also switched from a supply-driven to a demand-driven approach in an attempt to support government initiatives. The COM model of rural water delivery is the outcome of this strategy (Kumasi, 2018). Over the years, rural water delivery coverage in Ghana has greatly improved due to the shift in strategy. As of 2019, the rural water supply coverage was approximately 60% nationwide (CWSA, 2020).

Achieving SDG 6.1, which calls for the "availability and sustainable management of drinking water for all" by 2030, depends on the rural water delivery infrastructure becoming significantly more sustainable (UN, 2015; Kumasi, 2020). The non-functionality figures of water points established in various studies over the last ten years have been consistently reconfirmed between 30% and 49%, despite governments and development partners investing approximately half a billion US dollars in infrastructure development over the past 20 years (Adeenze-Kangah, 2022).

When water supply systems are installed, they are not properly maintained and eventually malfunction, leaving them with unstable and interrupted systems (Kumasi, 2020). Boreholes and wells with hand pumps are examples of schemes that require efficient maintenance and are frequently costly. It is also essential to investigate the prospects for and barriers to the effective and efficient maintenance of rural water supply infrastructure in Ghana, especially given the high cost of these programs. The District Assembly (DAs) provides little to no assistance to the communities in managing the rural water systems. Effective water supply facility maintenance remains a significant difficulty in some communities, even after years of implementing the COM system. This frequently results in several water systems performing poorly. Communities revert to using their outdated, unclean water sources as a result of the poor conditions of the facilities. Such behavior undermines the socioeconomic and health goals that such rural water systems were implemented to achieve. The study aimed to examine the implementation of NCWSP under the COM & direct CWSA management models and propose a suitable model for sustainable rural water supply in Ghana. Table 1 shows the meaning of acronyms used in the study.

Table 1: used acronyms and their meaning

ACRONYMS	MEANING
NCWSP	National Community Water and Sanitation Program
COM	Community Ownership and Management model
CWSA	Community Water and Sanitation Agency
MMDAs	Metropolitan, Municipal, and District Assemblies
WATSAN	Water and Sanitation Committees
WSDB	Water and Sanitation Development Boards
SDG	Sustainable Development Goal
UN	United Nations
WHO	World Health Organization
UNICEF	United Nations International Children Emergency Fund
SSA	Sub-Saharan Africa
NGO	Non-Governmental Organization
DA	District Assembly
GWCL	Ghana Water Company Limited
LI	Legislative Instrument
EPA	Environmental Protection Agency
VRA	Volta River Authority
ECG	Electricity Company of Ghana
SMC	Supreme Military Council
GIDA	Ghana Irrigation Development Authority
WASH	Water Sanitation and Hygiene
MDG	Millennium Development Goal
CWSD	Community Water and Sanitation Division
GWSC	Ghana Water and Sewerage Corporation
IDWSD	International Drinking Water and Sanitation Decade
STWS	Small-Town Water System
GoG	Government of Ghana
HDW	Hand-Dug Wells
WSMT	Water System Management Team

2. Materials and Methods

2.1 Reform of the water sector in Ghana

National agencies charged with water resources management must lead policies toward resource preservation because, in recent decades, the appropriate management of water resources for maximum development and growth has become globally important. This is particularly important now because of climate change and vulnerability, and how it affects sustainable livelihoods. Therefore, for maximum development and sustainability, effective water resource management will undoubtedly need to be moderated (Yidana et al., 2014).

To overcome the obstacles to the sustainable development and management of the freshwater resources of the nation, a number of initiatives have been started. These include enhancing water resources information agencies, coordinating national water resources management, and reforming the water sector. Accordingly, the law was amended to reinterpret the roles and responsibilities of certain water-sector organizations (Dorm-Adzobu and Ampomah, 2013). The state-owned Ghana Water and Sewerage Corporation was restructured as the semi-autonomous Ghana Water Company Limited (GWCL). According to the Conversion of Company Act (2003), as modified by Legislative Instrument (LI) 1648, GWCL is responsible for urban water supply. According to the Act (1998), the Community Water and Sanitation Agency (CWSA) is responsible for rural water provision. The Act of 1994 mandates that the Environmental Protection Agency (EPA) to protect and preserve the environment. In addition, the Volta River Authority (VRA) was established to control the use of the Volta River or Volta Lake's water and to develop and produce electricity. By Supreme Military Council (SMC) Decree 85, the Ghana Irrigation Development Authority (GIDA) was also created as a semi-autonomous public body with the authority to regulate the use of any reservoir built for any irrigation project while taking the interests of the country into account.

2.2 Methodology

The study employed a comprehensive narrative review technique (Agodzo et al., 2023). It involved field experience, project reports, relevant published studies from reputable journals of the highest caliber, and other available material. The subjects discussed include the NCWSP implementation, the COM model, and the CWSA policy reform.

3. The National Community Water and Sanitation Program

The NCWSP was the Government's blueprint for improving access to safe water and sanitation and promoting hygienic behavior in rural communities and small towns in Ghana. The NCWSP was developed as part of the country's water sector reforms initiated in the early nineties, to address the low water and sanitation services in rural communities and small towns. The Program was officially launched in 1994. By promoting hygiene and providing safe water and related sanitation services, the NCWSP aimed to enhance the economic and public health of the people in small towns and rural areas. To guarantee sustainable service delivery, specific goals were to offer WASH services to small towns, rural communities, and institutions that support regular facility operations, maintenance, and repair expenses.

3.1 NCWSP and the Decentralization Policy

Over time, the organizational structure of the rural water sector has changed. From overseeing the design, building, and maintenance, the role of the central government has diminished and evolved into one of facilitation. In addition to co-financing the building and maintenance, the private sector, District Assemblies (DAs), and communities have become key partners with major responsibility for planning and implementation. The Local Government Law of 1988, the PNDC Law of 207, and currently certain clauses of the 1992 constitution support the NCWSP, which was also designed to operate under the national decentralization strategy framework since 1988 (CWSA, 2003). The NCWSP aimed to provide the DAs more power, accountability, and capability from the central government. Additionally, the strategy encouraged community-level involvement in the administration of water supply facilities.

3.2 The Community Water and Sanitation Agency

Access to clean drinking water is essential for improving health and lowering poverty. Nonetheless, over 50% of the rural population in Ghana lacked access to a dependable and safe water source. To focus resources on projects that would reduce poverty and advance sustainable development, the international community created the Millennium Development Goals (MDGs) in reaction to the lack of progress. One of these goals was to cut the number of people without access to secure and dependable water sources in half by 2015. The water sector, particularly the rural sub-sector, underwent reform in response to the global agenda on water and sanitation. The Community Water and Sanitation Division (CWSD), which was created within the Ghana Water and Sewerage Corporation (GWSC) and tasked with supporting the community water supply sector, took over management of rural and small town water supplies in 1994 from the GWSC.

Later, in 1998, an Act of Parliament changed the name of the Division to the Community Water and Sanitation Agency (CWSA Act). Act 564 gives CWSA the authority to support Ghanaian small towns and rural people in access to clean drinking water and associated sanitation services (CWSA, 2007a). To provide access to sustainable drinkable water, the same Act of Parliament that created CWSA also gave districts and communities ownership and implementation duties.

NCWSP reflects a policy movement from reliance on government for development toward reliance on user communities, based on the decentralization policy. By putting recipient communities first, the strategy aims to guarantee the sustainability of investments in water and sanitation. As a result, the NCWSP adopted the COM model, which assigns daily facility maintenance and repair tasks to community water and sanitation committees (CWSA, 2007a).

4. Community ownership and management (COM) model

In many countries, water was acknowledged as a public good and governments agreed to pay for all investment capital expenses (Maganga and Butterworth, 2002). These initial investments, however, were unsustainable, and numerous enterprises collapsed. These service delivery methods don't encourage community initiative. As a result, a shift toward community involvement occurred in the 1970s and early 1980s (Maganga and Butterworth, 2002). Simultaneously, it was demonstrated that communities with adequate support can manage their water systems (Evans & Appleton, 1993). This suggests that state funds used to maintain and deliver inefficient services may instead play a considerably more beneficial facilitating role, which would be more cost-effective and provide wider, long-lasting advantages (Evans & Appleton, 1993).

4.1 UN approval of COM model

WHO (1996) defines community management as giving the people who receive water supply services accountability, power, and control over how their services are developed. While authority suggests that the community has the right to make decisions regarding the system, responsibility indicates that the community assumes ownership of the system and all associated duties, benefits, and responsibilities. Control suggests that the community has the authority to carry out systemic decisions. McGarry (1991) said that the community will be more effective and efficient since it has the authority and responsibility for operation and maintenance, which will improve the sustainability of services. However, COM does not exclude outside assistance from being provided. Although the government or other organizations may provide the community with subsidies, technical assistance, and other forms of support, the community must be the one that owns the system, decides when to request this assistance, and controls access to it (WHO, 1996).

4.2 Adoption of COM for NCWSP implementation

Except for international contractors to drill boreholes and foreign consulting firms hired to oversee projects, the private sector was largely excluded from the planning, building, and maintenance of rural water supplies, which were handled by the central government and outside assistance organizations (Salim, 2002). This water management and supply system proved unsustainable. Hence, communities needed to be involved in building and managing the water facilities.

Accordingly, community involvement was one of the primary strategies of the 1981–1990 International Drinking Water and Sanitation Decade (IDWSD) (McCommon et al., 1990).

For operational purposes, the CWSA further separated Conyers's (1981) community concert into two categories: small town (population over 2000) and small community (population under 2000). Two categories of water systems were handed over to the communities to manage. They include CWSA-built water systems and those given to DAs for community management by Ghana Water Company Limited. The CWSA provided funding for the small-town water system (STWS), with community members and district assemblies contributing 5–10% of the capital cost.

In stark contrast to the previous perspective of communities, the community water entities now feel a sense of ownership over their new facilities (Hiroko, 2008). In the beginning, the implementers worked alone to choose locations and build the plans without the help of the community members. As a result, when the facilities malfunctioned, the people did nothing to fix them, ostensibly because they believed the implementer owned them. For this reason, Maganga & Butterworth (2002) highlighted that community ownership, especially the mechanism of community water committees, is a way to achieve sustainability through community investment and dedication to their systems.

In reality, the initial community contribution or a subsequent fee might grant membership in a pump community. Although the admission charge was not anticipated in the management rules, it is a creative institution established locally to address contributions that were not possible (Eguavoen, 2006). Each community formed a water and sanitation (WATSAN) committee with seven members under the COM. The WATSAN committee was in charge of managing the water facilities daily. Through the traditional leaders, the WATSAN committees addressed issues between themselves and the customers. Positive outcomes were thus facilitated by a feeling of ownership and affiliation among the populace (Bazaanah, 2019).

According to Well (1998), the effectiveness of COM of facilities is influenced by the composition and capabilities of water management organizations. The district Water and Sanitation Team at the district level, underwent various trainings to improve their performance. However, their supervisory functions were impacted by poor logistics. New members had not received any training because WATSANs were not regularly trained. Due to logistical issues, the new ones were not trained, and some experienced ones quit, moved, or passed away. According to Carter et al. (1999), this affected sustainability. The WATSAN committees in several localities lacked the required minimum of seven members. Some members played many roles because the membership spanned from two to five.

The facilitation role of the CWSA in guaranteeing fairness and broad coverage of water and sanitation facilities through targeted subsidies supporting basic service levels was one of the other components of the strategies implemented under the NCWSP. District assemblies played a major role in community management while the private sector provided goods and services. A special emphasis on women as the primary water users, planners, operators, and managers of water systems at the community level, and an integrated approach to sanitation, water, and hygiene promotion was encouraged.

4.2.1 Performance of WSDB/WATSAN under COM

While some communities reported strong WATSAN/WSDB performance, others reported poor performance. The low priority given to operation and maintenance, insufficient funding for these activities due to subpar fund-raising tactics, and a lack of operational guidelines led to subpar performance of the institution in most towns. This observation supported WHO's (1996) findings. It was discovered that one factor contributing to the committee's dysfunction was the nomination of committee members rather than their election, as was the case in several towns. In Mozambique, Kalyan and Kakebeeke (2001) discovered a similar phenomenon. In certain localities, non-payment and inadequate facility management were caused by a lack of openness in the financial administration of the WATSAN/WSDB (Adomako, 1998). Another factor contributing to the inadequate makeup and non-operation of WATSAN committees was the voluntary nature of their activity.

4.2.2 Management of Facility Sites

The WATSAN/WSDBs are in charge of managing the water and sanitation facilities. Unscheduled communal cleaning took place in certain communities. It was carried out whenever the location was unclean or weedy. Bylaws governing the administration and use of the facilities were nonexistent. Despite having received training on creating facility management plans, the WATSAN and WSDB members lacked action plans and conducted their operations without plans. While some thought they could get by without it, others had forgotten the process of creating an action plan. The WATSANs in most communities do not have action plans, primarily because they do not want to be held responsible. However, the viability of the facilities depends on the WATSAN/WSDB being accountable to the community. Therefore, to ensure the sustainability of facilities, COM must encourage accountability of these local-level institutions to the community people through education.

4.2.3 Consumer Satisfaction with Facilities Management

People were dissatisfied with management in some communities because of low water pressure for the Small Town Water Systems, inconsistent water flow without explanation, a lack of community interface, a lack of transparency in the use of public funds, and a lack of enforcement regarding the payment of repair fees. When it came to facility site administration, women were essential. Women held positions in WATSAN/WSDBs in most communities, in contrast to the findings of Laryea et al. (2008), who found that women were hesitant to join water and sanitation committees.

4.3 Advantages of the COM model

Numerous influencing elements that guarantee the sustainability of the water supply facilities were considered when choosing the COM model. Some of these concerns either supported or went against accepted ideas and methods. Below is an explanation of the factors.

4.3.1 Community Participation

Community leadership frequently decides to implement a specific practice, typically accepted or supported by the community (Yelbert, 1999). Community members participated in all stages of the water facility construction. In some communities, the people passively participated in the facility site selection, being deemed technical (Pretty, 1995). Nonetheless, it was customary for households to mutually define the boundaries of the areas where the facilities might be situated. In some situations, the indigenous people used their techniques to determine the proximity of the water table to dig wells before the invention of contemporary hydrogeological tools.

4.3.2 Willingness and Ability to Pay

In essence, the highest amount that recipients are prepared to pay for a service is the willingness to pay the water bill. Bin-Seraj (2007) asserts that aligning households' willingness to pay with their financial capacity was crucial in designing a tariff structure. Even if they could afford it, households in some communities refused to pay for repairs during the wet season. This resulted from the availability of substitute water sources.

4.3.3 Financing Arrangement for Water Services

Considering its small funding share in the NCWSP, community contributions are merely a policy tool rather than a financial requirement. Beneficiary communities pay 5% of the capital cost of facilities under the cost-sharing agreement established by the NCWSP between development partners and project beneficiaries. The 5% is paid by the government, and 90% is paid by External Support Agencies. In some communities, this beneficiary contribution works well, but in others, it becomes a limitation (Eguavoen, 2006).
According to Karikari (1996), the emphasis on community financial responsibility may make it more difficult to achieve the goal of supplying drinkable water to rural communities. Due

to their small populations, some communities could not pay the 5% capital contribution. It was not necessarily a barrier, though, as a study found that communities without water were willing to donate 5% (Braimah and Fielmua, 2011). Again, raising 5% of the total cost was to create awareness of the community's responsibility to ensure the sustainability of the water facility.

4.3.4 Fund-Raising Strategies for Water

It is generally acknowledged that suitable mechanisms for income collection towards operation and maintenance costs of water facilities must be incorporated into community funding strategies (Harvey and Reed, 2007). In certain rural communities, it is widely considered culturally unacceptable to sell "ordinary" water, not "iced" water, which is a sign of life and sustenance (Braimah and Fielmua, 2011). This belief persists in some communities. This makes revenue mobilization challenging in the communities.

4.3.5 Financial Management

Communities had to register bank accounts where their counterpart financing of 5% would be deposited before water supplies could be provided. It was anticipated that money would be saved in such accounts for operations and upkeep of the facilities. Nevertheless, some communities did not experience any financial savings after acquiring the facilities. This was because communities contributed to operations and maintenance only when necessary. The WATSAN committee chairman helped save the remaining funds (if any) following repairs. How the remaining funds were used was unknown to certain community members. When households had to foot the bill for later, this frequently led to strife.

4.3.6 Access to Spare Parts

Provision of spare parts for WATSAN/WSDB was delegated to CWSA-designated dealers and outlets in the districts to ensure accessibility. To stop consumer exploitation, the CWSA monitored these stores. A sustainable spare parts supply system must meet the needs of appropriateness, cost, accessibility, and availability (Harvey and Reed, 2006).

5. Improved rural water supply through NCWSP implementation

Since its establishment in 1994, the NCWSP has made some strides. Building or renovating water supply infrastructure is necessary to expedite the delivery of safe water. GoG (2009) reports that between 1994 and 2008, 3928 boreholes were restored and 12366 new boreholes were drilled and mechanized. In the same vein, between 1994 and 2008, 3,928 hand-dug wells were rehabilitated and 1,467 new ones were built. Since the NCWSP was established in 1994, 373 new pipe systems were built, of which 327 (87.7%) were small town pipe systems and 46 (12.3%) were small community pipe systems (mechanized systems with limited distribution serving a population up to 2000). When it comes to the storage and distribution of water, the piped systems in small towns are more capable than those in small communities. As part of its private sector capacity-building efforts to improve access to water, the CWSA trained 20,617 pump caretakers, 1,687 area mechanics, and 680 hand-dug wells (HDW) contractors between 1994 and 2006 (CWSA, 2007a).

6. Challenges of NCWSP implementation

CWSA facilitated the effective development of water delivery infrastructure in small and rural municipalities. Nonetheless, the Agency encountered two significant obstacles: the redraw of donor funds and poor management of the built water systems under COM.

6.1 Redraw of Donors of funding

Most of the funding for the Agency's projects came from non-governmental organizations (NGOs) and foreign donors; the Government of Ghana made a relatively small contribution (CWSA, n.d.). Until the nation achieved middle-income status in 2011, the Agency had ample funding, and projects were constantly underway. Nearly all the large contributors left when the country reached middle-income status since they were concentrating on low-income countries. The Agency lacked sufficient resources to complete its mission due to the limited support for such actions from the GoG (CWSA, n.d). Everything froze as a result. The management decided to take over the current water supply system to guarantee effective revenue mobilization for system maintenance and new system construction. Since the proceeds are used to maintain the water systems in optimal operating condition, it's proven reliable.

6.2 Poor maintenance of built systems

In 2017, management assumed additional responsibilities, including managing the agency's built-out water infrastructure. Due to the community members' poor maintenance practices and incapacity to operate the sophisticated, modern technology, which frequently resulted in system breakdown under the COM, this was required (CWSA, n.d.). The slight increase in improved water access in rural communities from 27% to 62.13% between 1994-2017 was ascribed to unsustainability caused by inadequate management of the constructed water systems. The factors explained below are among the causes of the poor sustainability of water facilities under the COM.

6.2.1 High dependence on supervision

The WATSAN/WSDBs, organizations created to support the COM model, need additional support and supervision from the district assemblies and the Community Water and Sanitation Agency due to the lack of qualified human resources at the community level. To make sure they use the training they have received and are accountable and open to the community, they need to be closely watched. However, there is a knowledge gap about water management at the district and community levels. Water supply, operation, and maintenance are technical processes that call for the employment of skilled people and the application of sophisticated technology and innovation. For instance, even when water quality tests were performed, several municipalities and districts had trouble interpreting the results.

6.2.2 Limited human resources for advancement level of operation

Without outside funding, some villages were able to maintain their water infrastructure. Most communities' belief that "water is life and cannot be borrowed continually" reflects a growing feeling of accountability for maintaining local water infrastructure. This fundamental knowledge offered COM a bright future in maintaining water facilities. However, when community water supply levels rise, hand-dug wells or boreholes fitted with hand-pumps give way to advanced pumping, treatment, and measurement systems, which require human resources with professional training in all aspects of water supply in small town water supply systems (STWS). The management of the STWS requires a management model other than the COM due to limited technological know-how.

6.2.3 High non-revenue water

The non-revenue water proportion of rural piped water systems had progressively increased from 45 to 60 percent, increasing the water tariff and the cost of production per unit. Reaching the desired 10% upper limit will require significant effort. Illegal connections, frequent pipe bursts, inaccurate meter readings, etc. are the main causes of the growing non-revenue water.

6.2.4 Poor Revenue Mobilization

One of the key issues was the WATSAN/WSDB's inability to provide consistent funding for the upkeep and operation of the water facilities in the communities. Community members anticipate receiving free water until there is a breakdown; therefore, they help with that issue after paying the 5% capital cost contribution. The sustainability of facilities is adversely affected by the "pay as and when repairs are required" approach that communities use to fund operations and maintenance. Many rural communities lack robust institutional frameworks, and the dispersed settlement pattern makes revenue mobilization difficult (Yanore, 1994). When there are no other options, people are generally more inclined to pay for water, followed by perceived convenience, dependability, and quality (Yanore, 1994). Understanding the risks of drinking contaminated water is a prerequisite for willingness to pay. Regrettably, there remains a high level of illiteracy and limited awareness of the risks of using contaminated sources in some communities (Yanore, 1994).

6.2.5 Poor financial management

One of the biggest challenges of community-managed water systems is a lack of financial management (Kativhu et al., 2018). Therefore, while effective management and mobilization techniques are important, communities can raise sufficient funds for pump maintenance through collective fund management and improved bookkeeping. Nonetheless, there have been instances of customer payment default for maintenance and financial mismanagement (Manu, 2015).

It was nearly impossible for community-managed water systems to deliver water continuously due to their high debt to electrical corporations. Before CWSA's intervention, 90 water systems across the country owed VRA and ECG a total of GHS 3,322,900.71 in unpaid electrical bills. Inadequate funding for post-construction operation and maintenance prevented district assemblies and CWSA from regularly checking, repairing, and maintaining the water infrastructure. The lack of willingness to pay for maintenance in some communities was caused by the WSMTs' and Private Operators' inadequate accountability for the money they brought in.

6.2.6 Accessibility of potable water

Safe water is defined by the CWSA Act, 1998 (Act 564) as water that meets certain quality standards and is intended for human consumption. The CWSA defines access to clean drinking water in rural communities as having at least 300 people within 500 m of residences serviced by supplies from boreholes that provide at least 20 liters per person per day (CWSA, 2007a). Due to frequent failures, several water systems could not offer communities continuous service. Additionally, water quality in most systems was not checked since it was assumed that groundwater, the most popular water source, would always have a consistent quality. However, high concentrations of fluoride, arsenic, manganese, iron, hardness, and salinity are typical common water quality issues in most communities.

6.2.7 Poor operation and maintenance

The WATSAN/WSDB is ineffective for a variety of reasons, including lack of interest or low community participation in the selection of committee members; lack of transparency in operations; failure of the committees to answer to the community; the committees' perception that the water facility belongs to the government; the lack of clarity in the committee's role; the fact that members of the committee also serve on political committees; the lack of training for management bodies; the lack of actual authority for water committees to act within the community; and, in cases where traditional structures are in place, women interested in water management are excluded. There was limited knowledge of community ownership and responsibilities to ensure effective community management in some communities (Kelly et al., 2017; Rautanen, 2018).

6.3 Effects of NCWSP implementation challenges on CWSA operations

The loss of donor funds and poor maintenance of built infrastructure resulted in poor water quality, reduced output, and inefficient reactivity. Due to a lack of funding, the Agency was unable to efficiently maintain its current water infrastructure and construct new water infrastructure. Inadequate management and operation of the community-owned water system resulted in reduced productivity. In most communities, monitoring and treatment of the water quality failed. One of the main problems the CWSA is facing is inadequate finances.

7. The need for CWSA reform for sustainable NCWSP implementation

A decrease in donor inflows of grants and loans to the sub-sector was caused by changes in the country's funding landscape following the country's achievement of lower-middle-income status in 2011. Furthermore, the Ministry of Finance's policy pronouncements indicate a rising preference for sustainable initiatives. These changes posed a major medium- to long-term danger to the Water, Sanitation, and Hygiene (WASH) sub-sector's sustainability. To help the sub-sector stay on course to meet SDG 6, CWSA commissioned an organizational evaluation to realign the Agency in light of these issues. Therefore, from May 8–12, 2017, a review conference with the title "Rural Water and Sanitation Services Provision: Current Role of CWSA, Gaps, and the Way Forward for Effective and Sustainable Delivery" was conducted at the Noda Hotel in Fumesua in the Ashanti Region.

7.1 Objectives of the reform

The ultimate objective of the policy reforms was to turn CWSA into a Utility Organization that would be directly in charge of providing and managing point water systems (boreholes with hand pumps) and piped water supply systems for small towns in collaboration with the MMDAs. This was to ensure dependable, reasonably priced, and high-quality water services for rural and small towns. The reforms' specific goals are; to make the piped water system management and operation more professional. Boost the water systems' operational effectiveness; gather water system management money to fund facility upkeep, expansion, and building. Expand access to water to achieve the SDG 6. Provide decent employment for jobless water management specialists. Utilize the right technology to cut down on non-revenue water. Use cutting-edge technologies to solve issues with water quality, optimize health benefits, improve access to sanitation and hygiene services, and establish a support system for the long-term upkeep and operation of point water systems.

7.2 Achievements of the reform

The rural water supply sector has significantly improved due to the reform, which has allowed the CWSA to effectively maintain the operation of some operational water systems and repair several that were not. The Agency has made great strides in several areas, including employment for young professionals, rehabilitation of Brokendown piped water systems, and the direct control of piped water systems across the country by professional staff. In the sixteen (16) Regions, the CWSA is currently in charge of 125 Piped Water Systems. Some water system rehabilitation projects have been finished and others are ongoing to improve the rural water supply.

The change has helped to reduce unemployment by creating new jobs. The 834 professional staff members who have been deployed include revenue officers, community relations officers, water safety specialists, engineers, technician engineers, and accountants. Also, 269 auxiliary Staff are employed nationwide to support the professional staff managing 269 pipe water systems.

Plans for water safety have also been developed for ninety (90) piped water systems. Ghana can now provide data to the WHO as part of its pledges to achieve SDG 6. The CWSA reform has had several effects on water services, including increased revenue from water sales for all water systems without a tariff increase, greatly improved efficiency in the operation and management of piped water systems, improved reporting and performance tracking, increased capacity for technical and financial audit of the water systems due to the employment of professionals, and an overall improvement in the amount of safe, high-quality water that regularly flows in the communities.

7.3 Challenges with CWSA reform

Every organization has challenges while implementing a change. How these challenges are handled will determine how well the modification is executed. The execution of the change must be planned to ensure its success. Implementing the goals of the CWSA reform has been challenging. Among the difficulties are the elements listed below.

7.3.1 Legal / Community issues

Since the CWSA's legislative instrument has not been changed, community ownership and management is now a recognized legal practice. In some communities, it is challenging for CWSA to take over the water systems. While some communities reclaimed the water facility after turning it over to CWSA, others refused to give it to them. To guarantee the change in the LI, the Agency has made progress in collaborating with the relevant government agencies.

7.3.2 Technical

The Agency still has to deal with inadequate water supplies in some areas because of their low groundwater potential. Additionally, the poor groundwater quality in some communities renders it unfit for use as a community water supply without expensive treatment. For instance, because of the high salinity content, the communities within the saline belt in the Central region cannot use groundwater. The cost of producing the water is high due to its poor quality.

7.3.3 Human Resource

The reform altered the duties of the Agency's current employees, requiring them to relearn outdated skills and receive training in new, pertinent ones. Additionally, the recently hired employees in charge of managing the water systems in the different towns are not equipped with the necessary abilities to run and maintain the systems efficiently. Joining the water system management teams gives regional and head office employees leadership and supervisory responsibilities, which require specialized skills to be successful. This calls for different leadership, team-building, and professional training to develop and acquire skills. Unfortunately, this has not been as effective as it should have been, resulting in less-than-optimal results for the agency's work. Once more, since the reform's adoption in 2017, a significant number of new staff members have been hired. However, most of these people have left due to poor working conditions, which make it easy for them to resign to other companies when better offers are presented. In addition to improving service conditions, the Agency must ensure that staff members at various levels receive efficient training for tasks.

7.3.4 Financial Resource

The redraw of funds by major donors from 2011 has affected the Agency's capacity to raise sufficient money for the significant expenditures required to rehabilitate the current water systems. Some systems are outdated and need repair and expansion, but the Agency cannot carry out these tasks because of financial constraints.

8. Proposed model of rural water supply management in Ghana

In Ghana, water supply services are available for rural water provision, such as hand-dug wells, boreholes with hand pumps, limited mechanized systems, and small-town water supply systems. Given the financial commitment required, the various operational levels require varying human resource skills for efficient operation and management. Depending on the population of the recipient communities, CWSA makes it easier to construct all of these kinds of water infrastructure. Even when effective, the WATSAN/WSDB capabilities may be restricted to hand-dug wells; boreholes equipped with hand pumps, and limited mechanized systems.

However, the many phases of water pumping, treatment, distribution, and efficient revenue mobilization associated with managing Small Town Water Supply Systems require properly qualified human resources. As a result, management becomes ineffectual when the entire system is placed under the COM model. Additionally, in light of SDG 6's mandate that everyone has access to drinkable water in their residence, CWSA concentrates on constructing more and larger small-town water supply systems, which call for a different management approach than the COM to ensure sustainability and efficient operation.

Therefore, it is now urgently necessary to implement a significant policy direction focusing on the professional management of such rural water systems. The CWSA should directly manage the STWS and closely supervise and monitor the WATSAN/WSDB to ensure effective management of other water facilities. The supervision and monitoring of the WATSAN/WSDB may be done by either the CWSA staff deployed to the various districts to manage the STWS or special teams from the regional offices. This policy reform will ensure that the CWSA leaves no one behind in the effective implementation of the NCWSP, which is the core mandate of the CWSA. It will be challenging to meet the demand for water supplies in smaller communities if CWSA solely concentrates on STWS management and does not support WATSAN/WSDB in managing the other facilities.

9. Conclusion

The main management model for the NCWSP in Ghana is the COM model. This model entails training non-professional community members in the operation and management of water supply systems. The rural water supply in Ghana improved slightly from 27% to 62.13% between 1994 and 2017; however, the water systems have not been used to their full capacity. Again, limited donor inflows of grants and loans to the sub-sector and Ministry of Finance policy announcements, ensuring sustainable initiatives, call for CWSA policy reform. The policy reform aimed to make CWSA a Utility Organization, directly responsible for delivering and overseeing piped water supply systems for small towns and for supplying point water systems in coordination with MMDAs. However, CWSA employees assigned to districts or special teams from the regional offices should be responsible for supervising and monitoring WATSAN/WSDB to ensure the efficient operation and maintenance of other water facilities. The current CWSA reform is the best course of action to guarantee a sustainable rural water supply in Ghana. It has the potential to significantly aid Ghana in achieving SDG 6.

10. Recommendation

Considering the rural water supply situation in Ghana, the following recommendations are suggested to meet SDG 6 and guarantee a sustainable water supply.

- The CWSA policy should be amended to allow direct management of STWS and supervision and monitoring of WATSAN/WSDB.
- The government must spend significant money to repair the current water system and increase its efficiency as it is now sustainably managed by professionals.
- Because CWSA management ensures sustainability, domestic and foreign donors and development partners are encouraged to fund the construction of new water systems and the rehabilitation of the current ones.

- A policy should be in place to guarantee that all rural water supply interventions are carried out by, in conjunction with, or after being verified by CWSA before handing over to communities.
- It should be mandatory for recipients of rural water interventions to receive education on their responsibilities for maintaining the sustainability of the water facilities. This will assist in raising awareness and enforcing accountability to guarantee the sustainability of the water systems.

Statements and Declarations

Funding: No funding was received by the authors.

Conflict of Interest: The authors declare that they have no conflict of interest.

Availability of data: All data used for this study are included within the manuscript.

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Received: December 6, 2025

Accepted: December 25, 2025

Issue: 8 2025
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

Implementation of Water Safety Plan for Adequate Water Supply: A Case Study of The Afigya Kwabre District of Ghana.

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Abstract
The assessment of the potential toxicological effects of long-term groundwater consumption in the Afigya Kwabre District, without prior treatment, identified potential health risks. To ensure that inhabitants have access to safe water, this study aimed to outline the processes required to develop and implement water safety plans appropriate for the study area. To protect public health, effective implementation of a water safety plan is needed. Adopting a comprehensive risk assessment and management strategy that analyzes all stages of the water supply, from the catchment to the point of use, is the most effective way to ensure the safety of drinking water. A Water Safety Plan (WSP) is an effective instrument that drinking water companies can use to control the flow of potable water. Implementing the plan across various components of the water supply system ensures the provision of safe water to consumers. Drinking water quality can be improved by focusing more on source selection and input control, but this strategy should be applied to all system components. Collaboration among the parties involved is necessary for more reliable implementation of this strategy, as is the use of measures such as staff training, online resources, and the enforcement of directives and legal pressure.

Keywords: Afigya Kwabre district, Drinking water, Groundwater, Public health, Water safety plan

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1. Introduction
Humans rely on water for numerous purposes, including drinking, food production, sanitation, and industry (Yousefi et al., 2018). Water is essential for all facets of a healthy life on Earth. Acute watery diarrhea and other severe illnesses, such as typhoid, acute bloody diarrhea, and Guinea worm disease, can, however, occur if pathogenic organisms contaminate water resources, particularly in children under five (Bidkhori et al., 2019). Additionally, various illnesses, including skeletal disorders, hypertension, Alzheimer's disease, and infertility, may arise as a result of the excessive chemicals (fluoride, heavy metals, etc.) in water (Yousefi et al., 2019). Although the body can absorb an element like fluoride from other substances, drinking water may contain fluoride because of its high solubility in water (Faraji et al., 2014). The World Health Organization (WHO) estimates that water-related diseases

claim the lives of approximately 3.4 million people annually (Berman, 2009). Thus, clean and healthy drinking water should be a priority for governments' health promotion initiatives and has been an aim of sustainable development (Yousefi, 2019).
In drinking water supply systems (DWSS), access to safe drinking water is essential for human health and a fundamental human right (Bidkhori et al., 2019). A third of people in cities in poor countries do not have access to safe drinking water, according to WHO reports (Akbari, 2018). All populations are affected by endemic and pandemic diseases caused by contaminated drinking water (Davison, 2005). Therefore, health promotion initiatives require monitoring of water supply, risk assessment, and risk management. To this purpose, several measures have been established to guarantee both the safety of DWSS and access to healthy water, including the water safety plan (WSP), hazard analysis critical control point (HACCP) (Tsoukalas, 2018), and qualitative microbiological risk assessment (QMRA) (Hamilton, 2016). WHO launched the WSP, a methodical preventive risk assessment approach for drinking water quality, in 2004 (Rondi, 2015). Preventing water pollution during storage and water supply management, minimizing the pollution of water resources, and eliminating or reducing contamination through treatment processes are its primary goals (Ferrero, 2018).

Critical control points are taken into account in the WSP, including monitoring, management plans, identification and control mechanisms, and evaluation of the hazards to water quality from the inland to the point of use (Hamilton, 2006; Baum, 2015). While this approach covers the entire system of the water supply chain from the catchment to the consumer, water supply organizations in many countries only concentrate on particular parts of the system and do not evaluate system risk or pay attention to the entire system (Sean, 2005; WHO, 2017; Aghaei, 2017). Although WSP has been implemented by several European nations for urban drinking water supply (Dewettinck, 2001), there are not many studies or global data on its application (Ye, 2015). To develop a methodological guide for actual use, the current study examined the WSP's principles and applications. It also sought to characterize the program's efficacy in improving the quality of drinking water supplies in the Afigya Kwabre district.

One of the most significant environmental problems at the moment is groundwater pollution. Because of their severe toxicity, even at low concentrations, heavy metals and microbial pollutants are of particular concern among the many contaminants that influence water quality (Mahipal & Rajeev, 2019). Heavy metals can cause a range of symptoms and serious health issues, depending on the type and amount consumed (Mahipal & Rajeev, 2019). Groundwater is used for residential, commercial, and agricultural purposes in many parts of the world. These days, our land and water resources are under greater strain due to the growth of industrial development, increased water use, and pollution. Contamination problems include leaching from landfills and wastewater leakage practices. The global growth in water contamination has become more evident, leading to significant environmental problems (Mahipal & Rajeev, 2019).

According to earlier research by Agyemang (2019), the study area's groundwater types include Na-Cl, Mixed, and Na-HCO3. Additionally, the study found that the groundwater quality in the area is impacted by anthropogenic activities, ion exchange, mixing processes, silicate weathering, and carbonate weathering. Low pH and high amounts of Fe, F-, and Pb in specific samples are among the groundwater quality problems in the area (Agyemang, 2019). Agyemang (2020) conducted a follow-up study to assess the level of heavy metal contamination in the district's groundwater. According to the study, there was a possible carcinogenic risk because the mean amounts of Pb and Fe were higher than those recommended by the WHO (2012) in some samples. Once more, Agyemang (2022a) assessed local groundwater contamination using geostatistical techniques to determine how human activities were affecting groundwater quality. The study found that human activities, including the use of agrochemicals on farmland and improper waste disposal, as well as natural processes such as ion exchange and rock mineral weathering, had impacts on groundwater quality.

Therefore, Agyemang (unpublished article) assessed the potential toxicological effects of long-term drinking of groundwater without prior treatment. The study found possible effects on public health. To ensure that inhabitants have access to drinkable water, the author suggested that decision-makers, medical professionals, and water specialists work together effectively. The author also suggested incorporating medical geology into Ghana's public health delivery system. To provide a sustainable potable water supply for the residents of the Afigya Kwabre district, this study sought to outline the processes required to create and execute water safety plans appropriate for the study area. To protect public health, effective implementation of a water safety plan is needed.

2. Materials and methods

2.1.Study area

With a population density of 263 persons per km², the Afigya Kwabre district is expanding at a pace of 4% annually. Residents of the District rely on groundwater for the majority of their water needs. Latitudes 6 5' N and 7° 1' N and longitudes 1 4' W and 1° 25' W are the boundaries of the district (Fig. 1). There are two seasons of rainfall in the equatorial climate of the research area: little rain falls between September and November and a lot between March and July. With isolated hills in the south, near Buoho village, rising to 1,200 m above mean sea level, the topography is a scattered plateau with altitudes between 800 and 1200 m above sea level (Yidana et al., 2015). The most famous rivers and streams that drain the region are the Offin, Oyon, and Abankro Rivers.

Rocks of the Voltaian Supergroup and Birimian granitoids underlie the district, and their hydrogeology is controlled by secondary features such as weathering, fissures, and fractures (Yidana et al., 2015). According to Kesse (1985), the Voltaian sandstones were significantly affected by Pan-African tectonic processes, leading to a marked decrease in primary porosity. Semi-confined Voltaian aquifers are among the most difficult to investigate in Ghana, according to Yidana et al. (2015), with drilling success rates for productive wells in the terrain rarely exceeding 60%. Birimian aquifers are more productive than Voltaian aquifers in terms of groundwater occurrence (Yidana et al., 2015). The restricted granitoids are found in the Crystalline Basement Aquifer Province, where groundwater is typically found in fractured bedrock, saprock, and saprolite (Obuobie et al., 2016; Banoeng-Yakubo et al., 2010).

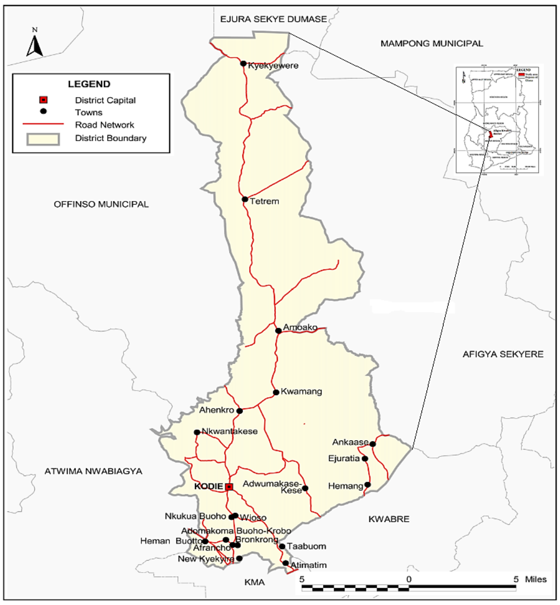

Fig.1 Map of Afigya Kwabre District (Ghana Statistical Report, 2010)

2.2 Extensive narrative review technique

The study used a thorough narrative review to present the available data on water resources management within the district (Davison, 2005). The study used field experience, project reports, published studies from top-tier, respected journals, and other relevant information.

3 Development of the WSP

Safe drinking water delivery is essential for maintaining public health and encouraging more stable livelihoods. However, the evaluation of water supplies is frequently limited to sporadic water-quality testing; proactive water safety management receives little attention (Davison et al., 2004). In the past, water quality testing at the distribution system entry point, delivery point, or point of use has been necessary to ensure the delivery of safe water (WHO/IWA, 2023). Water quality monitoring has typically been handled by the service provider rather than the customer. Checking that the water meets water quality standards or recommendations established for technical, aesthetic, and health reasons has been the foundation of this method (WHO/IWA, 2023).

The third version of the World Health Organization's drinking water quality (GDWQ) recommendations was introduced in 2004, and the fourth edition was released in 2011. These primary documents on water quality, international standards, describe a significant shift in the strategy for controlling drinking water quality (Gelting et al., 2012). The GDWQ encourages the adoption of water safety plans (WSPs), which emphasize comprehensive risk assessment to enable efficient risk management. They also employ fundamental indicators to track process control, with microbiological indicator audits being used for periodic verification (WHO/IWA, 2023).

In addition to preventing water contamination from the source to the point of consumption, WSPs' water safety plans aim to increase consumer participation and control over water quality maintenance (WHO/IWA, 2023). Water safety strategies can be applied to piped urban utility supplies as well as rural or peri-urban community supplies in both new and existing

water supply schemes. Plans for water safety are only as good as the information they contain and as the design and execution (Gunnarsdottir et al., 2020). Improvements to water safety plans using better methods for detecting drinking water quality, Sci. Total Environ., 698 (2020). Water safety plans address water quality issues, but they cannot address additional problems such as water quantity or prioritizing different water users (WHO/IWA, 2023).
The WSP is typically created by ongoing collaboration, encompassing everyone with a stake in the community's water supply, the ability to take action to support it, and knowledge of water supply and quality. The water system should be sufficiently understood by every member of the team (Davison, 2004). The WHO guidelines (WHO, 2009) may be followed in developing the WSP. Based on current evaluations, one-fifth of the population lacks access to proper excreta disposal (Karamia, 2019), and one-sixth lacks access to safe, healthy water within 1 kilometer of their residence (Fallahati, 2020). The WSP is an effective strategy for reducing the burden of waterborne illnesses and increasing access to clean drinking water (Davison, 2004; Gunnarsdottir, 2020).

3.1 WSP team formation

According to WHO/IWA (2023), the WSP team is a multidisciplinary group that collectively understands all aspects of the water supply, from catchment to user. For a WSP to be developed and implemented successfully, the WSP team must have the necessary administrative, technical, and leadership skills (Hamilton et al., 2006). This involves advocating for the organizational adjustments required by the WSP process. The team is essential to ensuring that everyone involved in the safe management of drinking water understands and accepts the WSP method (Li et al., 2020).

3.1.1 Identify the required expertise and establish the team.

Select WSP team members who, taken as a whole, possess the expertise needed to evaluate and control risks along the water supply chain. The WHO/IWA (2023) states that the WSP team should be aware of how the entire drinking water supply is operated and managed, the threats to the safe management of the water supply at different stages, the effectiveness of the barriers in place to manage these threats, the drinking water quality targets to be met, the extent to which the system can meet these targets and the implications for public health if it cannot, the challenges faced by the full diversity of users, potential future challenges that could affect the water supply, how to maintain management and financial commitment to sustain the WSP process (Muoio et al., 2020).
To accomplish this collective knowledge and experience, the WSP team usually consists of representatives from the water supplier and a few chosen external stakeholders, such as technical staff involved in daily system operations and maintenance representing the entire water supply chain; engineers with expertise in design, construction, and planning; management staff; staff with technical knowledge of the public health aspects of drinking-water safety; staff involved in water sampling and testing; representatives of the health authority, including those in charge of consumer education and/or water quality compliance monitoring; and representatives of user groups (Setty et al., 2017; WHO/IWA, 2023).
WHO/IWA (2023) states that for the WSP team to carry out the suggestions, they must have the support or authorization of those in charge. This could entail allocating financial and

human resources to implement the WSP, reporting to the appropriate authorities, or approving system or management changes that may result from the WSP process. The WSP team will frequently need to look for focused feedback from advisors outside the team who possess the necessary skills and background. To identify potential stakeholders who can assist with water safety planning, consider conducting a stakeholder analysis. Consider who might affect or be affected by the water supply at each level when identifying stakeholders (Shafiei et al., 2017; WHO/IWA, 2023).

3.1.2 Define the roles and responsibilities of team members.

To ensure each team member understands their responsibilities regarding water safety planning, clearly identify and document their roles and responsibilities within the WSP framework (WHO/IWA, 2023). Select a competent team leader to oversee the WSP procedure. This individual must possess the interpersonal and organizational abilities necessary to guarantee the successful implementation of the WSP. Usually, team members continue to do their other activities in addition to their WSP obligations (Sorlini et al., 2017). Nevertheless, it is crucial that every member of the WSP team actively participates in the process and supports the water safety planning strategy.

3.1.3 Maintaining an appropriately sized WSP team

WSP teams that are too big may impede development and decision-making effectiveness (WHO/IWA, 2023). The size and complexity of the water supply, as well as the water supplier's management structure, will often affect the ideal team size. It may be appropriate in some situations to designate individuals as core WSP team members, who are in charge of the day-to-day implementation of the WSP and usually attend all WSP team meetings, and extended WSP team members, who are less involved in day-to-day WSP implementation and may only need to attend key meetings, to ensure a functional team and effective decision-making (Tsoukalas & Tsitsifli, 2018).

Instead of becoming full members of the WSP team, external stakeholders who offer assistance may simply need to be involved in specific technical concerns (WHO/IWA, 2023). This will also help keep the WSP team at a manageable size, promoting efficient decision-making. The WSP team and its operations ought to be included in current teams, groups, and organizational structures whenever feasible (WHO/IWA, 2023). This could increase the WSP's adoption and acceptance. Frequent personnel changes might hinder WSP teams' progress and cause them to lose steam. This is especially true in situations where there are no legal obligations for planning for water safety. The water supplier could create a company-wide water safety planning strategy that integrates the WSP as a fundamental business function and maintains focus on water safety planning across the entire organization (Sorlin et al., 2017). Even when higher-level organizational staffing changes take place, this can help keep focus. Creating a training kit and an induction program for water safety planning can help sustain momentum, educate new hires, and increase understanding of the value of WSPs. Both regular employees and upper management can benefit from these training kits (WHO/IWA, 2023).

3.1.4 Identifying stakeholders who may contribute to water safety planning

To identify potential internal and external stakeholders who can assist with water safety planning, consider conducting a stakeholder analysis. These stakeholders may include those working in customer service, human resources, organizational management, information technology, procurement, maintenance, asset management, finance, system design and construction, and system operation and maintenance (WHO/IWA, 2023). Land users in the catchment area, environmental protection and catchment management, public health professionals, drinking water quality regulators, independent drinking water quality monitors, user groups and civil society, experts in public health and climate change, users of urban infrastructure, and researchers or academicians are examples of potential external stakeholders (Tsoukalas & Tsitsifli, 2018; WHO/IWA, 2023). Identifying which stakeholders can participate in the planning process for water safety and how they can do so may be aided by a stakeholder analysis. This process might reveal that some stakeholders merit a full-time spot on the WSP team. The roles and duties of these stakeholders on the team should be documented in the WSP team table (WHO/IWA, 2023).

3.1.5 Planning and conducting regular WSP team meetings

The WSP team should meet regularly to review how the WSP is working and make any necessary updates. The WSP should continue to be actively implemented, as ensured by the meetings; data from operational monitoring and verification are regularly reviewed to identify trends, outliers, and any regular occurrences of non-compliance; improvement plans are regularly reviewed; contact lists are kept current; the WSP objectives and related key performance indicators are regularly reviewed; and the WSP is regularly updated to reflect the impacts of any changes in the water supply and its wider organization (Gelting, 2012; WHO/IWA, 2023). The results of WSP team meetings should be reflected in the WSP as needed.

3.2 Describing the system

The catchment evaluation usually comes first in the system description, and the water quality check at the point of use comes last. Additionally, standard knowledge is necessary to identify interventions in this step (WHO, 2009). It is easier to identify the hazards associated with the water supply system when the system is defined from the raw water source to the point of consumption (Amézquita, 2014). Water quality is ensured using the WSP quality assurance (QA) tool. WHO and IWA, as editors, created the tool based on the WSP Manual (WHO, 2009). The user can add more questions to the assessments, in addition to the existing ones.

3.2.1 Gather, document and update system information

Compile the pertinent data for your system description, revising any existing information as needed. The water supply description should be brief but accurate enough to assist the WSP team in identifying the weakness of the water supply. Specialized considerations for desalination system treatment and source management are covered by WHO (2011b). Also known as the abstraction point or off-take point, this is the location where the source water is extracted for the water supply.

Summaries of the following should be included in the system description: the water supply and supplier; the WSP boundaries; the intended uses of the water; the full diversity of water users; catchment characteristics, such as the amount of vegetation cover, topography, soil types, condition, protection areas, groundwater recharge zones, land uses, and activities; all current water sources for the water supply and their typical yields; raw water intake, storage, and conveyance to the water treatment plant(s); water treatment processes, such as pre-treatment, coagulation/flocculation, clarification, filtration, and disinfection, including any chemicals used to treat the water and an overview of their treatment performance; distribution systems, including piped distribution network and treated water storage; Water supply user interfaces; user practices, including the need to use alternative sources of drinking water; water demand; water quality targets; historical water quality, with a focus on non-compliances; known or potential system problems; uncertainties regarding specific system components; history and trends of extreme weather events; future trends, including potential impacts from climate variability and change and changes in water demand; potential future or alternative water sources and any possible drinking-water safety issues associated with these sources (Gunnarsdottir et al., 2020; WHO/IWA, 2023).

3.2.2 Development of a system diagram

To bolster the written system description, create a system diagram. An essential component of the system description is the system diagram. They capture the essential components of the water supply and offer a visual representation of how the system works (WHO/IWA, 2023). The following stages for risk assessment and management will benefit from a system diagram. The leading equipment and assets of the system, potential sources of hazards and the main routes by which these hazards may reach users, the main stages of the water supply process, such as the source, water treatment, distribution, and storage, user levels, the directions of water flow throughout the water supply, the types of chemicals used for drinking water treatment, and the main points where water control is currently managed or is required to be managed should all be identified in system diagrams (Hamilton et al., 2006; WHO/IWA, 2023).

3.2.3 Developing a succinct system description

WHO/IWA (2023) states that WSP teams often include excessive, comprehensive information in the system description. This is frequently superfluous and can obfuscate crucial data that could help pinpoint water supply issues. The team must reduce information redundancy and avoid data "dumping" without analysis to create a concise, focused system description. Customers may use different sources of drinking water in certain circumstances (Liljequist et al., 2019). These alternate sources might be challenging to locate and record, and they are typically outside the purview of the water supplier.

However, because the water from these sources may be unsafe to drink, it is crucial to include them in the description of the WSP system. Talk to the appropriate parties to gain a better understanding of the types of alternative water sources used, the factors that influence their use, and usage trends. Addressing and managing significant vulnerabilities in later WSP modules, especially for underprivileged user groups, might be facilitated by including these alternate sources in the system description (Lockhart et al., 2014; WHO/IWA, 2023).

3.2.4 Considering equity in the system description

It may be possible to miss significant vulnerabilities that affect marginalized users if all users are treated as a single homogeneous group (WHO/IWA, 2023). To ensure the needs of vulnerable groups are met, it is crucial that the WSP system description explicitly account for the variety of user groups. This can be accomplished by identifying various user groups during the system description step. Differences in sex, gender, age, wealth, health, and service level are all examples of diversity. To guarantee that every user benefits from the WSP, it is necessary to comprehend this variety (WHO/IWA, 2023). Hazardous incidents that affect specific disadvantaged groups may be unintentionally missed during the risk assessment if it is not seriously evaluated early in the WSP process. When the water supply does not serve the entire community, it is crucial to identify and remove barriers to access, as well as to take non-users of the system into account (Mälzer et al., 2010). Examine various user experiences with water once more. Exploration of various water experiences is made possible by knowledge of the wide variety of water user groups. To ensure that everyone benefits equally from the WSP, this will assist the WSP team in systematically identifying all risks and hazardous events, developing more effective control measures, and prioritizing enhancements (WHO/IWA, 2023).

3.2.5 Confirm the accuracy of the system description

Use field visits to verify that the system description is accurate. The accuracy and correctness of the system description are crucial. Otherwise, erroneous assumptions regarding the dangers, vulnerabilities, and operation of the system might be formed. Examine the entire water supply; larger supplies may require multiple visits. Although technical tools like satellite imagery and drones may be used for large catchment areas and for areas that are risky or difficult to access, a thorough in-person assessment is always preferred. To verify the accuracy of the information, speak with pertinent field personnel, operators, or stakeholders. Verify that the data and reports are accurate and match the system description. Revise the system description in light of the findings from the staff interviews and field trips (Rickert et al, 2016; WHO/IWA, 2023).

3.3 Defining the boundary of the WSP

WHO/IWA (2023) states that the WSP's "boundary" is the extent of the water supply under its management. Ineffective management of significant water supply hazards may result from unclear roles and duties arising from poorly defined WSP boundaries. To help guarantee efficient management and operations, including emergency responses, the WSP's limits should be precisely established (Rondi et al., 2015). Planning for water safety can be implemented in a variety of ways for large and intricate water supplies. Examine the following factors regarding the WSP border.

3.3.1 Catchment boundary

Catchments are frequently defined areas predetermined by external organizations. Adopting these recognized catchment boundaries for the WSP might be practical (Rickerte et al., 2016; WHO/IWA, 2023)—interfaces in the distribution chain between bulk suppliers. Ensure the interfaces between agencies are well-defined when working with multiple systems or when a different agency manages the bulk water supply.

3.3.2 User boundary

Indicate the WSP's perimeter at the users' location. The user's water meter is often the boundary in situations where there is a continuous pressurized water supply and every property is fully plumbed; this may also align with the water supplier's legal obligations (WHO/IWA, 2023). In some situations, such as informal settlements or systems with sporadic supplies, it may be appropriate to incorporate user components outside the water meter, as they affect public health. To ensure that priority hazards within the water supply are controlled, the WSP team should collaborate closely with relevant stakeholders for locations within the WSP boundary, even if the water supplier is not legally responsible for them (Schmoll et al., 2011).

3. 4 Identifying hazards and hazardous events

Determine the dangerous situations that could cause the hazard to enter the water supply or fail to be sufficiently removed from it. A single incident or a sequence of incidents might be referred to as a hazardous event (WHO, 2017; WHO/IWA, 2023). When explaining dangerous situations, be specific. It is challenging to evaluate hazardous events that are excessively broad and poorly defined in the risk assessment, and as a result, they are less likely to be handled successfully.

3.4.1 How to describe hazards

Typically, a danger is described as a noun or noun phrase, such as a chemical contamination, a microbiological infection, or a water deficit. To identify and manage significant risks in later modules, the WSP team must have a thorough awareness of what could go wrong throughout the entire water supply (Aghaei et al., 2017; Abolli et al., 2019; WHO/IWA, 2023).

3.4.2 Identifying hazards and hazardous events

List and explain the risks and potentially dangerous situations that could arise at each stage of the water supply. Identify the hazardous situations associated with the hazard, such as how the hazard may enter or be inadequately removed from the water supply. One incident or a sequence of events can be characterized as a hazardous event (Amézquita et al., 2014; WHO/IWA, 2023).

- Short-term exposure to microbiological risks may affect one's health. They are usually linked to drinking water that has been tainted by human or animal waste. The most prevalent and pervasive health hazards linked to drinking water are infectious diseases brought on by microbial infections. For this reason, the WSP team should prioritize their assessment and control.
- Chemical components that, usually after prolonged contact, can have a negative impact on health.
- Radionuclides are radiological compounds that contain unstable atoms that produce radiation and may pose a health concern to humans, usually after prolonged exposure. Regretfully, these metrics are not checked by the majority of water systems in Ghana.

- Aspects of acceptability that influence users' acceptance of the water. Acceptability-related risks might have indirect detrimental effects on health as well as erode user confidence.
- Aspects of quantity that may adversely impact the amount of water accessible to users. Users may turn to less safe alternate sources or have insufficient water for cooking, hydration, or basic hygiene, among other quantity-related risks that could compromise user confidence and have an impact on public health.

3.4.3 How to describe hazardous events

WHO/IWA (2023) states that the following convention is a clear and succinct method to write a hazardous event: X occurs as a result of Y, where Y is the cause and X is the impact on the water supply. For instance, Unhygienic pipe repair methods (Y) allow microbiological contaminants to enter distribution pipes (X). X will frequently explain not only what happens but also the stage of the water supply at which it takes place. The hazard type may also be included in X. The WSP team can comprehend and evaluate the related risk and determine suitable management measures by identifying X and Y.

3.4.4 Comprehensively identifying hazards and hazardous events throughout the water supply

For early-stage WSP teams in particular, creating a comprehensive inventory of dangers and hazardous events for the water supply can be a difficult undertaking (WHO/IWA, 2023). However, this is a crucial stage to guarantee that all risks are evaluated and that the WSP manages the priority concerns. Three important questions must be addressed to methodically compile an exhaustive list of risks and dangerous incidents: what has gone wrong in the past, what is wrong now, and what might go wrong in the future? The historical data gathered for the system description is then used to comprehend patterns, extremes, and problems pertaining to the system's dangers. As needed, add to these data, and maintain a record of any information that is missing or unavailable so that pertinent data can be gathered later. Go through the entire water supply to examine the system and find any weaknesses. This task can be coupled with the field inspection that was done to create the system description for increased efficiency. Inspections can be carried out methodically over a number of visits for bigger systems.

With internal and external stakeholders who are knowledgeable about the water supply, such as water supply operators, engineers, maintenance personnel and contractors, catchment managers, farmers, fishermen, and non-governmental organizations, discuss and identify water supply risks. To thoroughly identify the entire spectrum of risks and dangerous occurrences in the water supply, workshops involving a variety of stakeholders with the requisite expertise are frequently required. Since this may call for professional experience and knowledge sharing, this method can be particularly helpful when determining what might go wrong in the future.

When preparing the WSP, take into account all user groups. Because of their position within the water supply network, the type of collection point they use, or water consumption and management habits, certain users may be more likely than others to experience unsafe water. The entire spectrum of water user experiences, including those unique to underprivileged populations or those living in informal settlements, should be taken into account by the WSP team; otherwise, these risks and dangerous incidents can go unnoticed.

3.5 Validating existing control measures and assessing risks

There are several dangerous occurrences in every water supply, each with a unique degree of risk (WHO/IWA, 2023). These dangers can be ranked by an impartial risk assessment, which enables the water provider to concentrate their efforts and resources on the dangerous situations that pose the greatest threats to the drinking water supply's safety. Finding and verifying any current control measures to determine their efficacy in preventing the associated hazardous occurrence is the first stage in risk ranking. This makes it possible to identify and prioritize the need for either enhancing current control mechanisms or implementing new ones. Plans for operational monitoring can then be created to make sure that crucial control measures keep working as intended (WHO/IWA, 2023).

Find out what controls are in place for each of the dangerous situations. Make sure to properly record in the WSP any hazardous events for which there are currently no control mechanisms in place. Physical infrastructure, like fencing around a source water intake or a filtration unit at a water treatment plant, can be used as a control measure. Other non-infrastructural measures include policies, regulations, management procedures, staff or contractor training, and user behaviour change programs (WHO/IWA, 2023).

Verify that each of the specified current control measures is successful in reducing the related hazardous event (WHO/IWA, 2023). This entails proving that the control measures can effectively manage the related hazardous event through the use of evidence or expert judgment. The evaluation of current water quality monitoring data, focused research or investigations, field visual inspections, and published scientific literature or technical reports are some of the sources of evidence for the validation of control measures. It is best to assess each control measure's efficacy in relation to its placement within the water supply rather than separately. This is due to the fact that the effectiveness of one control measure might affect the effectiveness of others.

3.5.1 Assess the risks

Evaluate the risk involved in each potentially dangerous situation. When identifying and validating current control measures, take the validation results into account when assessing risk (WHO/IWA, 2023). A WSP team can identify which issues require the greatest attention by conducting risk assessments. Planning for water safety may involve the use of various risk assessment techniques. To make sure that a suitable risk assessment method for the local environment is selected, WSP teams should give it some thought. Techniques for semi-quantitative risk assessment are frequently employed.

Define the risk levels—low, medium, and high—as well as the associated risk scores in detail. Because every system is different, risk evaluations should be tailored to each drinking water source. Water supply data, investigative monitoring, the expertise and experience of the WSP team and other stakeholders, industry best practices, scientific literature, and technical reports should be used to inform the risk assessment, which will typically be based on expert judgment (WHO/IWA, 2023). The risk assessment should be informed by the data collected and documented in the system description.

3.5.2 Prioritizing risks effectively

It may be challenging to efficiently prioritize these risks and concentrate scarce resources where they are most needed if the WSP team discovers that the risk assessment yielded numerous substantial risks (WHO/IWA, 2023). Such a result could suggest that the WSP team was too cautious in its initial risk assessment, that the risk definitions and/or risk matrix chosen are inappropriate for the local context, or that there are actually a lot of important risks that need to be properly handled. The WSP team can review the likelihood and severity scores assigned to (i) and (ii) to ensure that they appropriately reflect the true risk that the hazardous occurrence poses. This may include looking for outside assistance. The team should also think about whether the risk definitions and risk matrix are suitable for effectively distinguishing between the various risk categories.

When evaluating risks and validating control measures, a WSP team will frequently have information gaps. Progress should not be hampered by this. Note the assumptions used in the lack of this knowledge as well as the information gaps. Until the required data is available to show otherwise, it may be prudent to presume that the risk is significant and/or the control measure is ineffective when there are substantial ambiguities surrounding the validation or risk assessment (WHO/IWA, 2023). Proof of a safe drinking water supply in typical circumstances is insufficient to prove safety. WSP teams should evaluate the likely efficacy of the control mechanisms in the event of prior extraordinary events or predicted future situations. When taking climate risks into account, it is especially important to assess control measures under various scenarios, especially if an existing control measure has been validated for less difficult conditions in the past (WHO/IWA, 2023).

4.0 Planning for improvement

The goal of improvement planning is to continuously raise the degree of control to lower the risks associated with the water supply. It identifies areas in need of improvement. An improvement plan outlines the water supply enhancements that have been given priority for implementation, along with deadlines and accountability for doing so (WHO/IWA, 2023). To make the best use of the limited resources, improvement planning should aim to improve risk management gradually and progressively, paying special attention to the most significant risks. Priority improvements may be implemented with the help of improvement planning, which also makes it possible to incorporate activities into budgets and financial planning cycles (WHO/IWA, 2023).

4.1 Select the hazardous events needing additional control

Determine which hazardous events call for an improvement strategy based on the results of the risk assessment. WSP teams only need to use their collective judgment to choose which dangerous events need more management (WHO/IWA, 2023). To determine if an improvement is required for the control of a hazardous occurrence, the team may also begin with the risks classified as "high" or employ a risk score cut-off point (WHO/IWA, 2023). Any method used to identify risky occurrences that need further control should be approved by the WSP team and recorded in the WSP.

4.2 Develop a plan for improvement

Determine what new or enhanced control measures are needed for the hazardous events that have been chosen for improvement, then create an improvement plan. The improvement action that is required, the issue that the improvement is a result of, the people or parties in charge of the improvement, the estimated cost of the improvement, the suggested funding source, the completion date, and the improvement's current state should all be covered in the improvement plan (WHO/IWA, 2023). Think about the potential effects on equity outcomes of the suggested improvement activities. Get the community's opinion on the best control strategies and gain their support. To prevent any unintended injury or discrimination against vulnerable groups, think about changing a control measure, choosing an alternative, or considering compensating measures if they potentially affect equity (WHO/IWA, 2023).

4.3 Implement the improvement plan

Follow the designated timelines for implementing the improvement plan. Keep an eye on the improvement plan's execution to make sure the changes are being made or have already been finished (WHO/IWA, 2023). If there are any delays, note them in the improvement plan along with the updated schedules. The WSP team should periodically assess the progress of the improvement plan and update top management as necessary. Update the relevant portion of the risk assessment table as soon as an improvement is put into practice. Evaluate the risk again while considering how well the new or improved control mechanisms are working. Incorporate any enhanced or new control mechanisms into the strategy for operational monitoring.

5.0 Monitoring control measures

WHO/IWA (2023) states that control mechanisms are essential to managing safe drinking water and must always operate efficiently to reduce risk. Control measure monitoring alerts operators when a control measure is not operating within predetermined bounds and gives quick feedback on how well it is working. This makes it possible to take prompt corrective action to avoid jeopardizing the safety of drinking water.

5.1 Select the control measures to be monitored

The team should determine which control measures need an operational monitoring strategy based on the identified existing control measures. Make sure the operational monitoring plan and the current control measures in the risk assessment table are clearly connected. If a control measure is deemed by the WSP team to be a crucial obstacle to maintaining the risk at a level that is acceptable, it should at the very least have a matching operational monitoring plan (WHO/IWA, 2023).

5.2 Develop an operational monitoring plan

Create a customized operational monitoring strategy for each control measure that is currently in place and needs to be monitored (WHO/IWA, 2023). Record the parameters to be monitored, their location, the time, method, and personnel of the monitoring, as well as the critical limit that establishes the upper limit of acceptable performance for the control measure and the corrective action to be taken in the event that performance limits are exceeded. In the operational monitoring plan, provide a summary of this data. To provide operational staff with guidance on how to carry out operational monitoring and corrective measures, more comprehensive standard operating procedures can be created.

5.3 Implement the operational monitoring plan

As part of regular operations, carry out the operational monitoring plan (WHO/IWA, 2023). Monitor at the designated intervals and make sure that remedial measures are implemented as soon as possible. Regularly review monitoring data to learn more about the water supply's performance and areas that need improvement. Analyze and evaluate operational monitoring results on a regular basis, and take appropriate action if they deviate from established patterns. These variations could be a sign that an issue is about to arise, necessitating preventive maintenance. Validation of control measures and WSP reviews should be continuously informed by the outcomes of operational monitoring. Additionally, historical patterns in water quality can be developed using these data. The information might also help establish sensible and useful critical boundaries.

6.0 Verification of the effectiveness of water safety planning

For WSPs to be implemented successfully and sustainably, verification is essential. Compliance monitoring, user satisfaction monitoring, and WSP auditing are its three equally crucial pillars (WHO/IWA, 2023). Verification as a whole offers proof of the water supply's sufficiency, acceptability, and safety. When taken as a whole, the three components guarantee that risks are sufficiently addressed and the water supply is handled securely. To make sure that water safety planning is operating well, it is essential to have established procedures for verification (WHO/IWA, 2023).

6.1 Conduct compliance monitoring

To ascertain if the water provided to customers satisfies laws and drinking-water quality standards, establish a system-specific compliance monitoring program (WHO/IWA, 2023). The parameters, frequency, and locations for monitoring, as well as the analytical and reporting processes, are often outlined in regulations and standards. These ought to serve as the foundation for creating the program for compliance monitoring. The surveillance agency, the water supplier, or both the surveillance agency and the water supplier working together can monitor compliance (WHO/IWA, 2023). Improvement plans and/or modifications to current control mechanisms must be put into place if compliance monitoring reveals that the water is not frequently or consistently suitable for its intended uses or does not satisfy the norms and regulations. Regular compliance monitoring should be carried out at sites that reflect all varieties of water collecting stations and user groups. Make sure the monitoring program includes the network's most vulnerable users and segments (WHO/IWA, 2023).

6.2 Conduct user satisfaction monitoring

Create a tool to track user satisfaction to make sure people are using and enjoying the water supply. A mechanism for handling daily user notifications or grievances and a regular program for aggressively requesting user feedback should be part of this. Keep track of and record user comments and grievances, and follow up as necessary (WHO/IWA, 2023). Make certain that every complaint and notification is investigated fairly. Always look at complaint clusters or patterns. Early detection of departures from standard service or quality can be greatly aided by this kind of verification, especially when it comes to acceptability concerns that might be connected to distribution system water quality issues.

6.3 Conduct WSP auditing

To objectively and methodically verify that the WSP is comprehensive, suitably implemented, and efficient, conduct WSP audits (WHO/IWA, 2023). By offering accountability and incentives to adhere to WSP requirements over time, WSP implementation for better safe drinking-water management, and ongoing WSP improvement, WSP auditing can directly support the verification that WSPs are in compliance with any regulatory requirements and the sustainability of the WSP (WHO/IWA, 2023). Make every effort to have someone who is not directly involved in the creation and execution of the WSP conduct the WSP audit. Potential conflicts of interest will be avoided in this way. Drinking water quality rules may include the need for WSP audits. Create an internal audit program in addition to the required regulatory audits to make sure the WSP is current and consistently used in practice. The water supply may benefit from this as it helps it ready for external regulatory audits. The degree of confidence that the water supply requires and the WSP's development stage will determine how frequently internal audits are conducted (WHO/IWA, 2023). Strengthen water safety planning procedures and evaluate the WSP's efficacy critically using audit feedback.

7.0 Strengthening management procedures

Instructions on how to operate all drinking water supplies are necessary (WHO/IWA, 2023). These guarantee that all workers properly understand their obligations, and know when to act and what to do. Management practices guarantee that every employee has the necessary resources to run the water supply efficiently in any situation. To prevent the loss of valuable knowledge and experience, build operator confidence regarding what to do and when to do it, ensure that important tasks are performed consistently and correctly, serve as training tools for staff, provide standard ways of taking corrective action in the event of an incident, and achieve efficiency and uniformity of performance, it is crucial to develop procedures that must be followed during normal operations, incident conditions, and emergency situations. By employing the operational monitoring plan and adhering to standard operating procedures (SOPs), automated systems and/or trained system operators can handle the majority of corrective measures for problems in the operation of WSPs, which are quite routine (WHO/IWA, 2023). ERPs are necessary to make sure that the water supplier has clear instructions on how to react in a methodical and efficient manner in the event that an unforeseen circumstance arises or if the standard corrective action fails to restore system control.

7.1 Develop and implement SOPs

Determine which procedures or activities currently have SOPs and where any gaps might exist by methodically evaluating and documenting them (WHO/IWA, 2023). Review current SOPs and regular operating duties, critically evaluate risks and vulnerabilities, and anticipate the kinds of deviations that may result in an incident. For each of the circumstances that have

been identified, create new SOPs or evaluate and improve existing ones that outline how to carry out normal duties efficiently in order to lower risks. The SOPs should be so thorough that, even without supervision, someone with only rudimentary training and comprehension can carry out the procedure properly. Think about mentioning crucial safety details, roles and duties, and the level of expertise or training needed to complete the task. Create SOPs outlining the corrective measures that employees should take in the event of an issue so that they can react to it quickly and efficiently.
After SOPs are created, make sure that staff members are properly taught to follow them and that they comprehend the entire process (WHO/IWA, 2023). Regularly retrain as needed, always after an update to an existing SOP. Make sure copies are easily available for reference in the work areas of those carrying out the activity to encourage the usage of SOPs. Management, ideally the immediate supervisor of the employees performing the task, should review and enforce the application of SOPs. Review, test, and update SOPs on a regular basis. Involve the appropriate operational personnel in these reviews to guarantee successful results. SOPs should be updated and approved whenever procedures change. Verify that the related SOPs are still sufficient after any risk reassessment. To guarantee that the most recent versions of SOPs are distributed to the appropriate internal and external personnel, establish strong document control and distribution mechanisms.
After emergency response plans (ERPs) have been created, evaluate their efficacy and the organizations and employees' preparedness to handle crises by holding regular and refresher training sessions. Plan emergency drills that include all key employees and external parties at appropriate intervals. Review and update the ERPs on a regular basis. Create reliable processes for document delivery and control. Keep a record of every emergency and "near miss" incident, and consider how it affects planning for water safety (WHO/IWA, 2023). After an emergency has happened, critically evaluate the ERPs and amend the WSP in light of the lessons discovered.

8.0 Strengthening WSP supporting programmes

By generally promoting the provision of clean drinking water, supporting programs aid in maintaining water safety planning (WHO/IWA, 2023). They offer a helpful and encouraging atmosphere for the implementation of WSP. Supporting initiatives can increase awareness, enhance communication, and fill in knowledge and skill gaps. In order to use WSP effectively, they assist an organization in integrating the water safety planning strategy. Supporting programs might focus on developing the water supplier's and external stakeholders' capability, assessing particular risks, and providing general organizational support (WHO/IWA, 2023).

8.1 Develop programmes that support WSP implementation

Determine whether more supporting programs are required by conducting an evaluation of current programs from the standpoint of water safety planning (WHO/IWA, 2023). To close these gaps, create new supporting programs or bolster current ones in light of the results (WHO/IWA, 2023). To satisfy WSP standards, operators and others must participate in training programs. There may be formal operator training programs that include standardized proficiency tests. If not, create internal operator education and training programs that are specific to the company and its systems. Determine the needs for operator training first, then build the curriculum and training goals around the intended results. Make sure that the frequency of refresher training is sufficient. Create programs to address user behaviours and practices that are found to be high-risk factors. This is significant because human behaviour is a major factor in maintaining the safety of the water once it is delivered or collected. To provide safe drinking water, a water supply cannot rely just on technology and the services offers (WHO/IWA, 2023).

8.2 Implement supporting programmes

About whether the supporting program needs to be delivered on a regular basis or as a one-time event (WHO/IWA, 2023). When applicable, analyze the intervention's efficacy, evaluate the learning outcomes' efficacy, and make any necessary modifications. Examine and update the WSP as needed, taking into account the impact of the supporting programs' results (WHO/IWA, 2023). Over time, supporting programs that were meant to be a one-time event might need to be reviewed.

9. Reviewing and updating the WSP

By monitoring progress and routinely analyzing operational monitoring and verification data, regular WSP reviews serve to guarantee that the WSP is operating efficiently (WHO/IWA, 2023). This makes it easier to guarantee that the WSP procedure will continue to be supported once it is first developed. Staff and stakeholders' trust and motivation in the water safety planning process will be preserved with the support of an updated, pertinent WSP. As conditions, improvement plan implementation, processes, procedures, staff and stakeholder contact information, organizational changes within the water supplier or external bodies, new information on existing or emerging parameters of concern, and regulatory requirements change, a WSP can quickly become outdated, necessitating planned WSP reviews (WHO/IWA, 2023).
The system description, risks and hazardous events, risk assessments, improvement priorities, and regular WSP operations can all be impacted by these (WHO/IWA, 2023). The WSP team has the chance to improve the WSP and its practical application with each cycle of review and revision, particularly by incorporating equality and climate change factors. Significant events, near-misses, or emergencies, system modifications, audits, and the experiences of the WSP team, operators, general staff, management, contractors, users, and other stakeholders may also present opportunities for WSP improvement. As part of an ongoing cycle of improvement, these ought to be included in the WSP to make sure it is current and functional (WHO/IWA, 2023).

9.1 Conduct regular WSP reviews

To make sure that events and developments that potentially jeopardize the WSP's effective implementation are routinely evaluated and addressed, schedule frequent, dedicated WSP review sessions (WHO/IWA, 2023). Think about additional situations that might occasionally lead to complete or partial evaluations in addition to scheduled review meetings. Before making any major alterations to the water supply, proactively examine the WSP. Perform WSP reviews according to the agreed-upon review triggers or at the frequency specified in the WSP. During a thorough review, go over every facet of the WSP to make sure it remains true. Involve local operators in the assessment process and conduct site visits as needed. Examine the findings of operational monitoring and verification to see if any patterns indicate any WSP operation areas that could need to be strengthened. Evaluate any specified WSP goals, targets, and KPIs to see how they are doing. Update the WSP as necessary in light of the review, making sure that future iterations of the WSP have sufficient document control for auditing and traceability reasons (WHO/IWA, 2023).

10. Conclusion

Adopting a thorough risk assessment and management strategy that incorporates an analysis of every stage of the water supply, from the catchment to the point of use, is the most efficient way to guarantee the safety of drinking water. WSP is an effective instrument that drinking water companies can use to control the flow of potable water. The implementation of the plan in various water supply system components ensure supply of safe water to the consumers. Drinking water quality is improved by focusing more on the source and controlling inputs, but this strategy should be applied to all system components. The collaboration of all parties involved is necessary for a more dependable implementation of this strategy, as is the employment of strategies like staff training, online resources, and the enforcement of directives and legal pressure.

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Received: December 6, 2025

Accepted: December 25, 2025

Issue: 8 2025
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

Integration of Water Quality Indices and GIS For Groundwater Suitability Assessment: A Case Study of Afigya Kwabre District, Ghana

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Abstract
To evaluate groundwater suitability for drinking, domestic, and irrigation purposes in the Afigya Kwabre district, this study used the PIG, IRCA, and IWSI methods. The PIG revealed excellent (37.5%), good (10%), poor (5%), abysmal (2.5%), and unsuitable (45%) water quality types. The IRCA estimates show that 90% of the samples contain water safe for human consumption, 7.5% contain low-risk water, none contain medium-risk water, 2.5% contain high-risk water, and none contain water unfit for human consumption. Groundwater is generally suitable for drinking, but poor water quality in some communities highlights potential public health risks when groundwater is consumed without prior treatment. For irrigation use, none of the groundwater types were found to be excellent; 12.5% were good, 25% were poor, 30% were abysmal, and 32.5% were unsuitable according to the IWSI technique. This implies that groundwater is generally unsuitable for irrigation due to its relatively high Na% content.

Keywords: Groundwater suitability; Water quality indices; Pollution index of groundwater; Water quality risk index for human consumption; Irrigation water suitability index

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1.0 Introduction

One of the vital components of the life support system is water. Because of its significant impact on human well-being, researchers are always trying to understand the variables that govern its quantity and quality. Because it combines with air gases and both organic and inorganic components as it enters the atmosphere, water, as a natural resource, does not exist in its purest form. Water dissolves a variety of compounds as it moves across the Earth's surface and beneath it; some of these substances are beneficial to human health when they fall within a specific range, while others are detrimental even at low concentrations (Raju, 2007). Public health issues may arise when the concentration of inorganic elements in water exceeds permissible limits (Raju, 2012a). To detect groundwater contamination early and implement preventive measures to safeguard the groundwater resource, it is crucial to evaluate groundwater quality regularly.

Because surface water bodies are contaminated and villages and small towns lack access to clean water, Ghana relies primarily on groundwater for residential use in rural communities (Gyau-Boakye et al., 2008). The contamination of surface water sources by human activities, such as illicit mining known locally as "Galamsey," partially accounts for Ghana's rising groundwater demand. As a result, numerous studies on groundwater quality in Ghana have been conducted.

Globally, groundwater is mainly utilized for agricultural purposes, according to UNESCO (2004). Because of the growing demand for food production, there is a greater need for groundwater for irrigation. In contrast to the conventional farming system, which relies solely on rainfall, irrigated farming enables farmers to grow a variety of crops year-round. Given the growing population and the resulting need for food security, the adverse effects of climate change on surface water bodies, advancements in farming technology, and the proximity of groundwater to the point of need, it is likely that groundwater use for irrigation will continue to rise over time.

Groundwater quality studies have historically involved the laboratory examination of specific parameters; however, the use of Geographic Information Systems (GIS) today enables the integration of various data for efficient evaluation. Bridging the communication gap between researchers and other stakeholders is a significant benefit of using GIS in research (Goodchild, 2000). The degree of groundwater contamination and human exposure to it can be determined using GIS. For instance, Aral and Maslia (1996) used GIS to identify public exposure to contaminated groundwater. They used GIS methods to estimate the extent of pollution and the locations of the exposed population.

For all their water needs, the district's residents mainly rely on groundwater. However, two significant issues affecting groundwater use in the district are the salty taste and the frequent failure of metallic borehole pumps in specific neighborhoods. The district's growing groundwater demand requires measures to ensure that groundwater supplied for public use meets drinking, household, and agricultural water-quality criteria. As a result, routine analysis is necessary to monitor changes in water quality. In addition to helping identify potential changes in the groundwater system that could explain sources of contamination, such analysis would ensure that the groundwater's suitability for the various intended purposes is evaluated.

To ensure the supply of safe water, several professional organizations, including those in water, the environment, engineering, politics, public health, social science, and policymaking, must work together. Unfortunately, not every professional understands the concept of water quality. The gap between the other stakeholders and the water experts grows as a result. To bridge that gap, an effective technique known as the water quality index is employed (Shah and Joshi, 2017). To evaluate the suitability of groundwater for domestic, drinking, and irrigation purposes, this study used the pollution index of groundwater (PIG), the water quality risk index for human consumption (IRCA), and the irrigation water suitability index (IWSI).

2.0 Materials and Methods

2.1 Study Area

The Afigya Kwabre District is located in the central part of the Ashanti Region, between latitudes 6 5′ N and 7 1′ N, and longitudes 1 4′ W and 1 25′ W (Fig. 1). With a land size of about 409.4 sq. km (GSS, 2021). The District has an equatorial climate and two rainfall periods. The minor rainfall period is from September to November, while the significant rainfall period is from March to July. According to Dickson and Benneh (1995), the mean annual rainfall ranges between 855 mm and 1500 mm. Additionally, Yidana et al. (2015) noted that there are typically 110–120 rainy days in a year. The area's terrain consists of a divided plateau that rises between 800 and 1200 m above sea level. The Mampong-Gambaga scarp includes the plateau. According to Yidana et al. (2015), isolated hills in the south around the Buoho village can reach elevations of 1,200 m above mean sea level. The water flows easily because of the area's undulating relief. The area is drained by numerous rivers and streams, with the Offin, Oyon, and Abankro Rivers standing out.

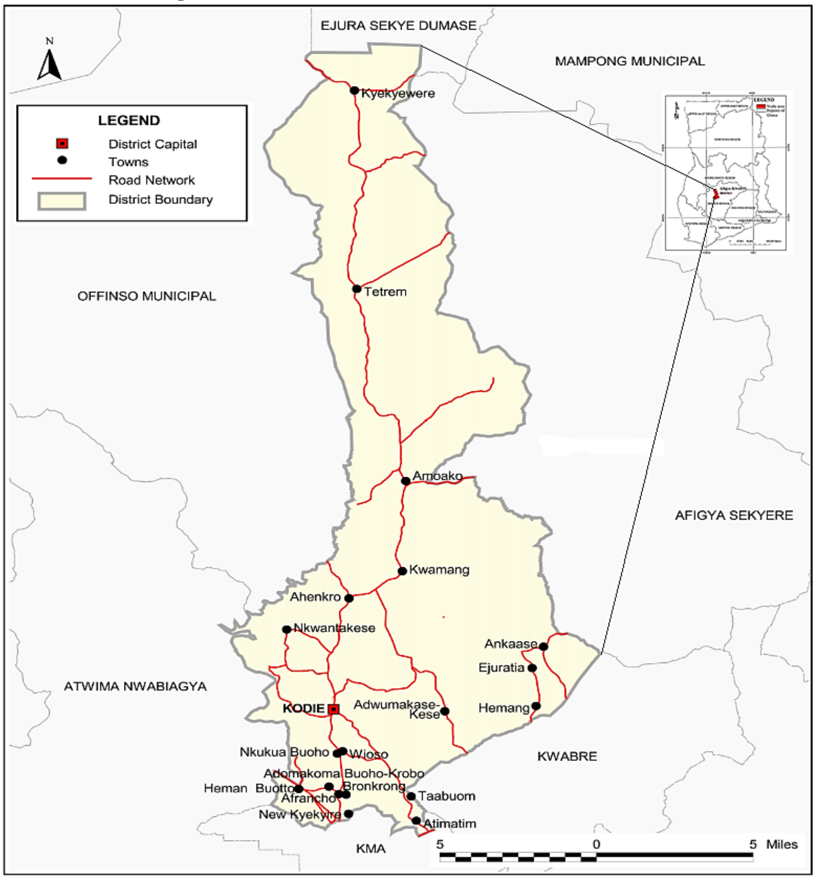


Fig. 1 Map of Afigya Kwabre District (GSS, 2021)

Rocks from the Voltaian Supergroup and granitoids from the Birimian Supergroup underlie the research area. Secondary hydrogeological characteristics, such as weathering, fissures, and fractures, govern the area's hydrogeology (Yidana et al., 2015). Kesse (1985) claims that the Voltaian sandstones' fundamental porosities are significantly lower due to partial metamorphism induced by Pan-African tectonic activity. The semi-confined Voltaian aquifers are among the most challenging to research in Ghana, according to Yidana et al. (2015), and drilling success rates for numerous boreholes in the terrain rarely exceed 60%. Again, the authors stated that the amount and presence of clay in the weathered zone affect the hydraulic capabilities.

The rock's hydrogeological conditions are greatly improved, providing substantial water to wells where the clay content is low and the weathered zone is significantly thick. They found that where the clay content is high, hydraulic conductivities are reduced considerably, resulting in a reduced capacity to deliver water into wells. It has been observed that the Birimian aquifers are generally superior to the Voltaian in terms of groundwater occurrence (Yidana et al., 2015). According to Obuobie et al. (2016) and Banoeng-Yakubo et al. (2010), the confined granitoids are part of the Crystalline Basement aquifer Province, where groundwater is found chiefly in the saprolite, saprock, and fractured bedrock.

2.2 Methodology

In November 2015, forty (40) boreholes were sampled for the investigation of nutrients, microorganisms, and trace metals. The coordinates of every borehole were recorded using a Global Positioning System (GPS). Water for bacteriological analysis was collected in sterilized high-density polyethylene sample bottles, whereas samples for physicochemical analysis were collected in unsterilized bottles. The bottles had a capacity of 500 ml. Before sample collection, the groundwater outlets were flushed for 10 to 15 minutes to remove any accumulated water in the pipes. Two drops of 69% nitric acid were added to the samples collected for trace metal analysis to preserve them.

In the field, pH, TDS, and EC were measured using a portable meter (Hanna instrument) in compliance with the guidelines and protocols of the American Public Health Association (APHA) (1995) and the World Health Organization. After that, the samples were placed in an ice chest filled with ice packs. After that, they were taken to the University of Ghana's Ecological Laboratory for additional examination. Because of the distance, the samples arrived at the lab within 3 days of collection. Groundwater samples were analyzed in the lab using standard techniques (APHA, 1995). TDS, conductivity, pH, and temperature were all measured using the probe method. Fluoride, chloride, sulfate, nitrate, bromide, phosphate, carbonate, silicate, and sulfate were all analyzed using ion chromatography. Metals such as lead, copper, manganese, cadmium, magnesium, calcium, zinc, and iron were analyzed using Flame Atomic Absorption Spectrometry (AAS).

Hem's (1985) formula was used to convert bicarbonate, expressed as alkalinity (mg $CaCO_3$/l), to HCO_3^-. The photometric method 8006 (Non-filterable residue) was used to analyze total suspended solids (TSS), the titrimetric method was used to analyze total hardness (TH), the titration method was used to analyze alkalinity, the turbidity method was used to analyze color, the electrical conductivity method was used to analyze salinity, the flame photometer was used to analyze sodium and potassium, the 5-day BOD test and acid modification were used to analyze biochemical oxygen demand (BOD) and dissolved oxygen (DO), and the pour plate method was used to analyze total coliform, fecal coliform, and pathogenic coliform. The ionic balance technique was used to assess the validity of the lab data, and all were within the permissible range of ±10 % (Celesceri et al., 1998). The Texas Water Development Board (TWDB), the American Public Health Association (APHA), and the Association of Official Analytical Chemists (AOAC) all prescribe different standard procedures for use.

2.2.1 Pollution index of groundwater (PIG)

Subba Rao (2012) developed the PIG, which has been effectively applied in many locations for monitoring and evaluating fluctuations in drinking water quality (Subba Rao and Chaudhary, 2019). Equations 1-4 were used in the PIG evaluation of drinking water quality.

$$Wp = \frac{R_W}{\sum R_W} \quad (1)$$

$$Sc = \frac{C}{D_S} \quad (2)$$

$$Ow = Wp \times Sc \quad (3)$$

$$PIG = \sum Ow \quad (4)$$

Where R_w is the relative weight on a scale of 1–5; Wp is the weight parameter for the water quality variables; Sc is the status of concentration; C is the water quality variables' content; Ds is the water quality standard limits; PIG is the pollution index of groundwater.

2.2.2. The water quality risk index for human consumption (IRCA)

One of the water quality indicators used to assess drinking water quality is the IRCA, which ranges from 0 to 100. Like all water quality indices, it simplifies complex information about the quality of drinking water samples into a numerical value that professional groups can readily understand. The index uses variables assigned risk scores based on their potential impact on human health. The IRCA values are grouped into five ranges, according to MAVD (2021). Equation (5) was used to calculate IRCA using the parameters in Table 1 (García-Ubaque et al., 2018).

$$\%IRCA = parameters * 100 \quad (5)$$

Table 1: IRCA's risk scores (MAVD, 2021).

Parameter	Unit	Risk score
pH	pH unit	1.5
TH	mg/l	1
Ca^{2+}	mg/l	1
Mg^{2+}	mg/l	1
Na^{+}	mg/l	1
Cl^{-}	mg/l	1
TDS	mg/l	1
F^{-}	mg/l	1
NO_2^{-}	mg/l	1
NO_3^{-}	mg/l	1
SO_4^{2-}	mg/l	1
Fe	mg/l	1.5
PO_4^{3-}	mg/l	1
Turbidity	mg/l	15
Colour	CPU	6
TOTAL		**34**

2.2.3 Irrigation water suitability index (IWSI)

An attempt was made to incorporate the effects of six parameters often used to evaluate irrigational water to establish IWSI, which measures the suitability of groundwater for irrigation usage. Using equations (6) to (11) and expressing all ionic concentrations in meq/l, the six irrigational water quality assessment parameters, including EC, Sodium Absorption Ratio (SAR), Sodium Percentage (Na%), Kelly Index (KI), Permeability Index (PI), and Magnesium Hazard (MH) were calculated to create IWSI. Following that, each of the six parameters was given an equal weight of 5. The criteria were categorized as they currently are, and the classes were assigned scores of 1-5 based on their impact on water quality. Once the weights and ratings for each factor were assigned, the IWSI was computed using equation (11). A higher probability of appropriate groundwater quality for irrigation is indicated by higher values obtained using this method.

$$SAR = \frac{rNa^{+}}{\sqrt{(rCa^{2+}+rMg^{2+})/2}} \quad (6)$$

$$\mathrm{Na\%} = 100 * \frac{\mathrm{rNa^{+}}}{\mathrm{rCa^{2+}+rMg^{2+}+rNa^{+}+rK^{+}}} \quad (7)$$

$$\mathrm{MH} = \frac{\mathrm{rMg^{2+}}}{\mathrm{rCa^{2+}+rMg^{2+}}} * 100 \quad (8)$$

$$\mathrm{PI} = 100 * \frac{\mathrm{rNa^{+}} + \sqrt{\mathrm{rHCO_3^{-}}}}{\mathrm{rCa^{2+}+rMg^{2+}+rNa^{+}}} \quad (9)$$

$$\mathrm{KI} = \frac{r\mathrm{Na^{+}}}{\mathrm{rCa^{2+}+rMg^{2+}}} \quad (10)$$

$$IWSI = \sum_{j=1}^{m} \sum_{i=1}^{n} (W_i * r_j) \quad (11)$$

Where n is the total variables, m is the total variable classes, W_i is the weight of the ith desired variable, r_j is the weight of the jth variable class, and IWSI is the irrigation water suitability index. Table 2 presents the weights assigned to the different parameters and the rating of their subclasses.

Table 2: Weights assigned to different parameters and rating of their subclasses

Parameter	Classified after	Weight (W)	Classes	Rate (r)	W*r
EC	Wilcox, 1955	5	<1000	5	25
			1000-2000	4	20
			2000-3000	3	15
			3000-4000	2	10
			>4000	1	5
SAR	USSL, 1954	5	<2	5	25
			2-10	4	20
			10-18	3	15

			18-26	2	10
			>26	1	5
Na%	Wilcox, 1955	5	< 60	5	25
			>60	1	5
KI	Kelley, 1940	5	<1	5	25
			>1	1	5
PI	Doneen, 1962	5	<25	1	5
			25-75	3	15
			>75	5	25
MH	Paliwal, 1972	5	<50	5	25
			>50	1	5

3.0 Results and Discussion

The statistical summary of the result is displayed in Table 3. The average pH of the groundwater is 5.16, with a range of 4.26 to 6.62. The high dissolved carbon dioxide concentration in the groundwater, which forms carbonic acid, may be the cause of the groundwater's low pH in the studied area. The EC values fall below the WHO (2012) standard of 1000 µS/cm for drinkable water supplies, ranging from 93.33 µS/cm to 700.28 µS/cm. The EC and TDS of the groundwater are typically low (56.00 to 420.17 mg/l). This observation can be ascribed to the study area's high rainfall. This short residence time hinders the water's ability to react with the host rock and reach equilibrium, potentially leading to a low rate of rock weathering (Kortatsi, 2004).

Table 3: Statistical summary of the groundwater data

Parameter	Unit	Minimum	Maximum	Mean	Std. Deviation	WHO (2012)
TDS	mg/l	56.00	420.17	159.45	95.17	1500.00
EC	µS/cm	93.33	700.28	265.75	158.61	1000.00
Temp.	°c	23.00	33.00	29.47	1.65	15.00
pH	pH unit	4.26	6.62	5.16	0.54	6.5-8.5
Fe	mg/l	0.00	13.26	0.35	2.10	0.30
Zn	mg/l	0.00	0.13	0.01	0.02	5.00
Pb	mg/l	0.00	0.36	0.03	0.07	0.01
Cu	mg/l	0.00	0.43	0.03	0.07	2.00
Mn	mg/l	0.00	0.21	0.07	0.06	0.10
Cd	mg/l	0.00	0.02	0.00	0.00	0.00
TSS	mg/l	0.00	20.00	1.10	3.26	500.00
Turbidity	mg/l	0.00	7.00	0.78	1.48	5.00
Salinity	mg/l	0.00	7.10	0.27	1.11	1000.00
Colour	PCU	0.00	4.00	0.50	0.91	15.00
F^-	mg/l	0.00	2.26	0.15	0.47	1.50
TH	mg/l	12.00	272.00	67.60	76.89	500.00
Br^-	mg/l	0.00	0.10	0.01	0.02	0.01
PO_4^{3-}	mg/l	0.01	3.06	0.25	0.52	0.10

Ca^{2+}	mg/l	0.06	36.46	3.92	6.78	75.00
Mg^{2+}	mg/l	0.02	17.75	3.24	3.91	150.00
Na^{+}	mg/l	12.20	60.90	30.10	14.09	200.00
K^{+}	mg/l	4.00	154.00	18.70	27.02	30.00
HCO_3^-	mg/l	9.53	270.66	50.38	46.40	
Cl^-	mg/l	5.22	170.72	51.80	39.02	250.00
SO_4^{2-}	mg/l	0.05	10.49	1.32	1.78	250.00
NO_3^-	mg/l	0.01	2.94	0.44	0.69	50.00

About 10% of the K^+ samples (4.00–154.00 mg/L) exceeded the WHO permissible range (2012). The Ca^{2+} values ranged from 0.03 to 6.46 mg/L. The Mg2+ concentration range in groundwater was 0.02-17.75 mg/L. The range of bicarbonate concentrations in the study was 9.53-270.66 mg/L. The groundwater's SO_4^{2-}concentration varies between 0.05 and 10.49 mg/l. The Fe values ranged from 0 to 13.26 mg/L. Except for two samples with fluoride concentrations above the WHO (2012) guideline threshold of 1.5 mg/l, fluoride concentrations were generally low (0–2.26 mg/l). Pb concentrations ranged from 0 to 0.36 mg/L, and the southern, densely populated portion of the research area had the highest groundwater Pb content. The PO_4^{3-} concentration ranges from 0 to 3.06 mg/l, with 30% above the 0.10 mg/l allowable limit (WHO, 2012). A cadmium quantity of 0.02 mg/l was found in one of the samples, exceeding the WHO (2012) recommended threshold of 0.01 mg/l. Household garbage discharge could be the cause of elevated cadmium levels (Santos et al., 2002). Agyemang (2019) states that silicate and carbonate weathering, ion exchange processes, and human activity primarily regulate the geochemistry of the study area. The water types include Na-HCO_3, Na-Cl, and Mixed (Agyemang, 2019).

Table 4 Water quality indices

NO.	LOCATION	LATITUDE	LONGITUDE	PIG	IRCA	IWSI
1	Kyekyewere	7.141435817	-1.640882855	1.18	7.35	75.00
2	Kyekyewere Zongo	7.141719125	-1.642445661	0.19	5.88	80.00
3	Kyekyewere Abofrem	7.138646571	-1.638682103	4.44	51.47	110.00
4	Tetrem Besease	7.039625281	-1.637061043	2.01	4.41	95.00
5	Tetrem Kondeso	7.041952936	-1.628853567	0.09	4.41	110.00
6	Tetrem Zongo	7.041954948	-1.628867397	0.34	11.76	80.00
7	Soko1	6.971057625	-1.619272549	150.16	4.41	105.00
8	Soko 2	6.970435269	-1.618727725	0.67	4.41	70.00
9	Boaman Abase	6.947394423	-1.616458073	0.52	4.41	90.00
10	Boaman Police Station	6.945581082	-1.616866523	1.02	4.41	90.00
11	Boaman Kokoado	6.94421106	-1.616046438	0.77	4.41	115.00
12	Kwaman Bonglo	6.891376404	-1.613192987	0.77	4.41	95.00
13	Kwaman Zongo	6.886210553	-1.619522329	0.44	4.41	110.00

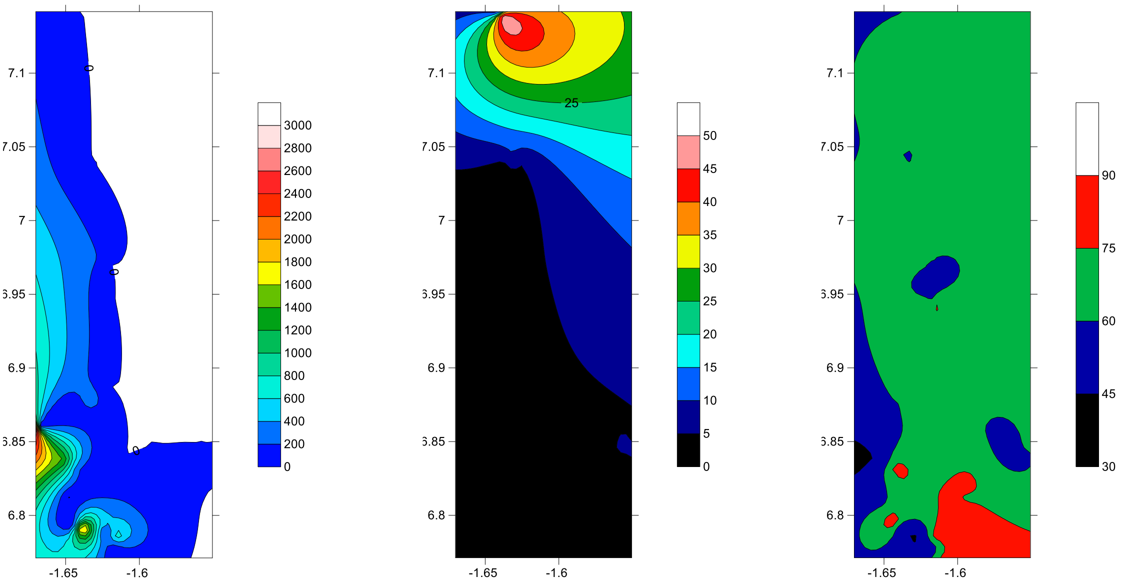
14	Ahenkro New York	6.87733856	-1.63581809	382.70	4.41	100.00
15	Ahenkro 2	6.875151051	-1.639032802	19.61	4.41	90.00
16	Denase	6.837235596	-1.650843574	1393.04	4.41	70.00
17	Kodie Zongo	6.813526796	-1.647468433	0.52	4.41	100.00
18	Kodie Masalachie	6.813199986	-1.649056468	1.51	4.41	70.00
19	Bouho Da School	6.792423092	-1.645157123	26.60	4.41	120.00
20	Buoho Glotto	6.795901665	-1.641564388	540.48	4.41	120.00
21	Atimatim Taabuom	6.771158623	-1.612188164	1.01	4.41	115.00
22	Maase Essen	6.777240951	-1.617112365	1.14	4.41	70.00
23	Maase Edwenase	6.786254263	-1.615636814	776.65	4.41	125.00
24	Agyarko Buoho	6.788124768	-1.623551762	29.82	4.41	70.00
25	Nkukua Buoho	6.791540729	-1.639072867	2231.62	4.41	70.00
26	Nkwantakese 1	6.860441146	-1.667460864	2.50	4.41	70.00
27	Adwumakase Kese	6.814881815	-1.594529171	2.52	4.41	110.00
28	Nkwantakese	6.858773064	-1.670207949	3206.98	4.41	70.00
29	Aduamoa	6.832553465	-1.642715475	296.25	4.41	120.00
30	Aduman	6.823105887	-1.631168816	2.53	4.41	110.00
31	Aboabugya Eboom	6.840143362	-1.612216495	1.64	4.41	90.00
32	Aboabugya Beposo	6.84006541	-1.610564254	0.41	4.41	90.00
33	Adwumakase Kese	6.819784222	-1.59583943	93.61	4.41	125.00
34	Ankaase Ohenedaho	6.850359226	-1.5505106	0.22	4.41	105.00
35	Wawase 1	6.846760372	-1.591728693	0.48	4.41	105.00
36	Wawase 2	6.85123438	-1.590983542	0.59	4.41	95.00
37	Mpobi Sunroase	6.849174947	-1.562365964	0.17	4.41	75.00
38	Ankaase	6.847561514	-1.552574141	0.59	8.82	100.00
39	Ejuratia	6.841042237	-1.554200146	151.22	4.41	80.00
40	Heman	6.819310393	-1.552104671	1.08	4.41	100.00

Table 5 Groundwater quality indices classification

Index	Classification	No. of samples	Percentage (%)	Interpretation	Code
PIG	<0.1	15	37.5	Excellent	1
	1.0-1.5	4	10	Good	2
	1.5-2.0	2	5	Poor	3
	2.0-2.5	1	2.5	Very poor	4
	>2.5	18	45	Unsuitable	5
IRCA	0-0.5	36	90	Excellent	1
	5.1-14.0	3	7.5	Good	2
	14.1-35.0	0	0	Poor	3

e-ISSN:2717-8277

	35.1-80.0	1	2.5	Very poor	4
	80.1-100.0	0	0	Unsuitable	5
IWSI	>90	0	0	Excellent	1
	90-75	6	15	Good	2
	75-60	22	55	Poor	3
	60-45	12	30	Very poor	4
	<45	0	0	Unsuitable	5



a b c

Fig 2. Spatial distribution of a) PIG, b) IRCA, c) IWSI

3.1 Groundwater pollution assessment

The possible level of groundwater contamination in the area was assessed using the PIG. The relative contributions of the chemical variables from each groundwater sample were investigated in the PIG evaluation. Excellent (37.5%), Good (10%), Poor (5%), Very poor (2.5%), and Unsuitable (45%) were the results. Approximately 47.5% of groundwater samples are suitable for human consumption due to their low levels of contamination. Nevertheless, 52% of the samples are unfit for human consumption due to the high contamination levels. The samples from the southern portion of the area, which were determined to be unsuitable for human consumption, were most likely affected by anthropogenic activities. High values were found near the southwest portion of the area (Fig. 1a).

3.2 Drinking water suitability assessment

The IRCA estimates show that 90% of the samples contain water safe for human consumption, 7.5% contain low-risk water, none contain medium-risk water, 2.5% contain high-risk water, and none contain water unfit for human consumption. This suggests that groundwater is generally suitable for drinking and that most samples pose no hazardous risk to human consumption. However, the bulk of the samples typically had low pH values and high observed levels of turbidity, color, Mn, Fe, and PO4 compared to the WHO (2012) recommended values, indicating poor water quality in several boreholes. The observation aligns with Agyemang's (2019). Agyemang (2019) evaluated the suitability of groundwater for drinking and household use in the district using the water quality index method. About 87.5% of the samples were fit for human consumption, while 12.5% were unfit. Low pH and elevated Fe, F-, and Pb levels were noted as groundwater quality issues in the district (Agyemang, 2019).

According to García-Ubaque et al. (2018), water quality monitoring in Colombia from 2008 to 2012 revealed that the computed IRCA value was approximately 13.4%, indicating low risk. After conducting an investigation, Duarte-Jaramillo et al. (2021) concluded that the water sources in the towns of Sincern and Gambote pose a serious risk to human health and should not be used for drinking. Garcia-Avilla et al. (2022) assessed the home water supply network in Azogues, Ecuador, and discovered that the samples had IRCA levels ranging from 0 to 5%. The water that was being supplied was therefore judged safe to drink and given the water type label "No-risk." The IRCA values increased from south to north, as shown in the regional distribution (Fig. 2b).

The generally good groundwater quality revealed by the IRCA approach confirmed observations of people drinking groundwater without prior treatment. However, the fact that the groundwater samples were raw, untreated, may account for the poor drinking quality of the selected samples. The presence of such water types indicates potential public health risks associated with drinking groundwater without prior treatment. Hence, groundwater in the area must be treated before it can be used for drinking water to safeguard public health.

3.3 Irrigational water suitability assessment

It is essential to keep in mind that determining groundwater quality is challenging, as it depends on several factors, including the intended use of the water and its specific characteristics. This intricacy makes it difficult for scientists and water experts to explain their findings to decision-makers who may lack technical knowledge of water science. The water quality index approach can help close the communication gap in this situation. Based on specific water quality parameters, it provides an overall water quality value at a given time and place (Yogendra and Puttaiah, 2008). None of the groundwater types were found to be excellent; 15% were good, 55% were poor, 30% were abysmal, and none were unsuitable according to the IWSI technique. In general, groundwater can be used for irrigation. However, the quality of irrigation water is impacted by the high MH and Na% in some samples.

Samples with high magnesium and sodium contents are unsuitable for irrigation. Both water availability and management of soil salinity and alkalinity are essential for irrigation projects to succeed (Haritash et al., 2008). Since the reaction between soil and Na+ reduces soil permeability, the sodium concentration in irrigation water must be taken into account. The maximum sodium concentration in irrigation water should be 60%, according to Ramakrishna (1998). The spatial distribution of the IWSI revealed no exceptional groundwater type. The good water type is located in a particular spot in the south-eastern section and in other specific locations. The poor water type covers about 55% of the whole area. Specific areas have inferior water quality, whereas none showed unsuitable water quality (Fig. 2c). According to the United States Salinity Laboratory (USSL, 1954), 97.5% of water samples of the area fell into the C1-S1 category, whereas 2.5% fell into the C1-S2 category (Agyemang, 2019). The author indicated that the use of the Wilcox diagram revealed an "Excellent to good" category irrigation water type. This implies that the groundwater is generally suitable for irrigation (Agyemang, 2019).

4.0 Conclusion

To evaluate groundwater suitability for drinking, domestic, and irrigation purposes in the Afigya Kwabre district, this study applied PIG, IRCA, and IWSI. The PIG revealed excellent (37.5%), good (10%), poor (5%), abysmal (2.5%), and unsuitable (45%) water quality types. This means about 47.5% of the groundwater samples are fit for human consumption due to their negligible contamination levels. Nevertheless, 52% of the samples are unfit for human consumption due to the high contamination levels. The IRCA estimates show that 90% of the samples contain water safe for human consumption, 7.5% contain low-risk water, none contain medium-risk water, 2.5% contain high-risk water, and none contain water unfit for human consumption. This suggests that groundwater is generally suitable for drinking, but poor water quality in some communities highlights potential public health risks when used without prior treatment. Hence, groundwater in the area must be treated before it can be used for drinking to safeguard public health, especially for parameters such as low pH and high levels of Fe, Pb, and Mn. Again, regarding irrigation use, none of the groundwater types were found to be excellent; 12.5% were good, 25% were poor, 30% were abysmal, and 32.5% were unsuitable according to the IWSI technique. This implies that groundwater is generally unsuitable for irrigation due to its relatively high Na% content. Hence, it is necessary to treat the Na+ concentration before using groundwater for irrigation.

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Received: December 6, 2025

Accepted: December 25, 2025

Issue: 9 2026
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

Deconstructing the Anatomy of Water Conflict: A Six-Layer Framework for Transboundary Water Issues

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Abstract
In an era of intensifying water scarcity and geopolitical tensions, transboundary water disputes present complex challenges to international peace and security. This paper proposes a novel, multidimensional analytical framework to dissect these disputes across six interdependent layers: hydrological, institutional, socio-cultural, geoeconomic, geopolitical, and global engagement. Developed through a mixed-methods approach—including comparative case studies of eight major international basins, qualitative content analysis, and expert workshops—the framework integrates and extends beyond existing models by explicitly addressing power asymmetries, socio-cultural identities, and the role of external actors. It moves beyond the conflict-cooperation dichotomy to reveal how these factors co-evolve and interact across scales. The framework's application to hotspots like the Nile and Mekong basins demonstrates its utility in diagnosing leverage points and prescribing tailored interventions, such as adaptive trigger mechanisms and binding dispute-settlement institutions. This power-sensitive architecture offers a comprehensive tool for scholars, policymakers, and diplomats to foster resilient and cooperative transboundary water governance.
Keywords: Transboundary Water Disputes, Analytical Framework, Hydro-Politics, Water Diplomacy, Conflict and Cooperation, Geopolitical Drivers

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1. Introduction

Water is a finite and essential resource, critical not only for human survival but also for economic development, food security, and ecological balance. As global demand for freshwater increases—driven by population growth, urbanization, and climate change—competition over shared water resources has intensified (Ghosh, 2023). This is particularly evident in transboundary water systems, where rivers, lakes, and aquifers cross political boundaries and become sources of tension between nations (UN, 2021). According to Wolf and Hamner (2000), over 250 international watersheds span more than half of the Earth's land surface and affect 40% of its population, making transboundary water governance a cornerstone of international peace and security. In these shared systems, political boundaries offer no barrier to hydrological flow, yet they often become fault lines for diplomatic

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tensions and strategic maneuvering, threatening regional stability and cooperative governance (Rai et al., 2017).

Media narratives also play a significant role in shaping public perception and political discourse around water disputes. Mianabadi et al. (2025) argue that media coverage can either escalate tensions or foster cooperation, depending on how issues are framed and which stakeholders are given voice. Beyond quantity and quality debates, media narratives powerfully shape public perceptions and policy responses in transboundary contexts. Framing by national and international outlets can either inflame nationalist sentiment or foster cooperative discourse, as seen in divergent coverage of the Teesta River negotiations between India and Bangladesh (Mianabadi et al., 2025). Understanding these narrative dynamics is critical for designing water diplomacy strategies that mitigate conflict rather than magnify it.

The geopolitical significance of shared water resources has grown in recent decades. In regions such as the Nile Basin, Indus Basin, Mekong River, and Euphrates–Tigris system, water has become a strategic asset—used for leverage, development, or even coercion (Zawahri, 2008). For instance, Ethiopia's construction of the Grand Ethiopian Renaissance Dam (GERD) has triggered diplomatic standoffs with Egypt and Sudan, both of which depend heavily on Nile waters (Azizi & Leandro, 2025). Similarly, India's threats to revise the Indus Waters Treaty in response to regional tensions have highlighted the increasing weaponization of water in geopolitical rivalries (Zeitoun et al., 2019).

These disputes are not merely about water quantity or quality—they are deeply embedded in broader political, economic, and historical contexts. As Kåresdotter et al. (2025) note, water conflicts are increasingly shaped by climate variability, governance failures, and socio-political instability. The United Nations and other international bodies have repeatedly warned that without robust, science-based, and cooperative water governance, the world could see a rise in water-related conflicts in the coming decades (Silvis, 2025). Since the 1980s, comprehensive chronologies such as the Pacific Institute's Water Conflict Chronology have documented water's multifaceted role as a trigger, casualty, and weapon in an increasing number of violent conflicts, underscoring the stakes of weak or contested water governance (Pacific Institute, n.d.). High-profile disputes illustrate how infrastructure development and unilateral actions can rapidly inflame geopolitics and exacerbate resource insecurity (Azizi & Leandro, 2025).
This paper proposes a novel analytical framework for examining transboundary water disputes through twelve crosscutting themes, organized into environmental-structural, institutional-legal, socioeconomic-cultural, and geopolitical-strategic driver categories. Employing a mixed-methods approach—including systematic thematic coding of case-study literature and comparative analysis of eight major international basins—this study integrates quantitative hydrological data with qualitative policy documents and media content to capture the multilayered drivers of cooperation and conflict.

While existing interdisciplinary models emphasize hydro-social cycles and hegemony dynamics, their effectiveness in addressing contemporary water tensions remains debated due to limited incorporation of power asymmetries, socio-cultural identities, and global actor engagement (Azizi & Leandro, 2025). This gap underlines the need for a layered, power-sensitive framework that situates immediate hydrological stresses within broader geoeconomic and geopolitical contexts.

The remainder of the paper is structured as follows. Section 2 surveys global hotspots of transboundary water disputes. Section 3 presents a thematic analysis of the twelve common factors driving conflict and cooperation. Section 4 introduces the proposed analytical framework and its visual representation. Section 5 applies the framework to selected case studies, and Section 6 derives policy implications for riparian states, international mediators, and researchers. Section 7 concludes with reflections on future research directions.

2. Objectives and Methodology

This paper pursues three interrelated objectives:

1. To review and synthesize major transboundary water disputes worldwide, emphasizing their geopolitical, environmental, and institutional driver categories.
2. To identify and analyze twelve recurring factors—spanning scarcity, climate variability, legal regimes, power asymmetries, socio-cultural identities, and external engagement—that shape these disputes.
3. To propose a multilayered analytical framework that integrates these factors into a coherent model for assessing dispute dynamics and cooperative opportunities in diverse basin contexts.

To achieve these aims, the study adopts a mixed-methods, multi-scalar approach grounded in:

- *Comparative Case Study Design:* Eight emblematic basins are selected—Nile, Indus, Mekong, Euphrates, Tigris, Ganges, Brahmaputra, Meghna, Colorado, Jordan, and the Aral Sea—through purposive sampling to capture variation in hydrology, governance, and geopolitical stakes (Yin, 2014).
- *Qualitative Content Analysis:* Treaty texts, policy reports, peer-reviewed articles, and international legal instruments are systematically coded using NVivo, following the phases of thematic analysis outlined by Braun and Clarke (2006). This generates a codebook of factors that recur across basins.
- *Media Frame Analysis:* Major regional and international outlets (e.g., Al Jazeera, The New York Times, China Daily, The Tribune) are mined via LexisNexis for portrayals of key disputes. Discourse patterns—such as securitization, developmentalism, and environmentalism—are identified to assess narrative impacts on state behavior (Mianabadi et al., 2025).
- *Quantitative Hydrological and Socioeconomic Indicators:* Time-series data from the Transboundary Freshwater Dispute Database (Azizi & Leandro, 2025), GRDC streamflow records, FAO AQUASTAT water-stress indices, and GRACE satellite-derived storage anomalies are statistically analyzed to link physical stressors with treaty actions and conflict/cooperation events (NASA JPL, 2023; FAO, 2024).
- *Integrative Synthesis:* Combining qualitative themes with quantitative correlations enables the construction of a layered framework. Iterative expert workshops with basin specialists and water diplomats refine the model's driver categories and weightings, ensuring both theoretical robustness and practical relevance (Mirumachi, 2015; Yuan et al., 2023).

This methodology balances depth—through rich case narratives and expert validation—with breadth—via cross-basin comparisons and statistical patterning—thereby providing a holistic tool for scholars and practitioners.

3. Literature review: analytical frameworks for transboundary water disputes

To scope established and widely used frameworks for analyzing transboundary water disputes, I ran targeted searches (July–August 2025) on Google Scholar and publisher databases (AGU/Wiley, IWA Publishing, Taylor & Francis/Routledge) using combinations of keywords such as *"transboundary water conflict framework," "Basins at Risk," "hydro-hegemony," "TWINS Mirumachi," "water diplomacy framework,"* and *"Transboundary Freshwater Dispute Database."* I prioritized (i) peer-reviewed or publisher-vetted sources, (ii) foundational/seminal works with high citation counts or sustained policy uptake, and (iii) global applicability beyond a single basin. This yielded five core frameworks plus the TFDD as the principal empirical backbone: (1) Basins at Risk (BAR), (2) Hydropolitical Resilience/Vulnerability, (3) TWINS, (4) Hydro-hegemony, (5) Water Diplomacy Framework (WDF), and (6) TFDD as data infrastructure (Wolf et al., 2003; Yoffe et al., 2004; Zeitoun & Warner, 2006; Mirumachi, 2015; Islam & Susskind, 2012; TFDD, n.d.). These were retained because they each offer distinct logics (risk mapping, resilience diagnostics, power-sensitive interaction analysis, negotiation/benefit-creation, and treaty/event data) that together cover the main analytical needs for a new integrative framework.

3.1 Basins at Risk (BAR): Building on the International Water Event Database, BAR codes historical conflict–cooperation events on a −7 to +7 scale and links them to biophysical and political covariates to identify "basins at risk" over a 5–10-year horizon (Wolf et al., 2003; Yoffe et al., 2004). Its strengths are global coverage, replicable coding, and early-warning orientation. Limits include event-reporting biases and a focus on inter-state interactions that underplay sub-national dynamics or informal power (Yoffe & Larson, 2001/2002 coding manual).

3.2 Hydropolitical resilience/vulnerability: Wolf and colleagues extend BAR by pairing hydrological stress (e.g., flow variability, scarcity) with institutional capacity (treaties, river-basin organizations) and socio-political context to ask whether basins are resilient to shocks or vulnerable to conflict (UNEP/OSU program monographs). The Africa volume exemplifies how mixed indicators profile risks and institutional buffers (UNEP et al., 2005). This lens captures institutional quality as a moderator but still leans on state-centric indicators and formal cooperation architectures.

3.3 TWINS (Transboundary Waters Interaction NexuS): Mirumachi reconceptualizes conflict and cooperation as co-evolving rather than mutually exclusive, mapping their simultaneous intensities and how power relations shape the quality of cooperation (i.e., whether it is equitable or merely diplomatic) (Mirumachi, 2015). TWINS has proven useful for unpacking "cooperation under asymmetry," but it requires careful operationalization and longitudinal evidence to score interaction trajectories.

3.4 Hydro-hegemony: Zeitoun and Warner foreground asymmetric power (material, bargaining, and ideational/discursive) to explain how dominant riparians achieve preferred outcomes via coercion, control strategies, and narratives, often without overt conflict (Zeitoun & Warner, 2006). The framework surfaces "quiet" forms of conflict and compliance and helps explain why some treaties mask inequity. Its main critique is diagnostic tilt: it can illuminate domination better than it prescribes feasible institutional remedies, though later work addresses contestation and change (Zeitoun et al., 2017).

3.5 Water Diplomacy Framework (WDF): Islam and Susskind treat water disputes as complex adaptive problems where value can be created, not just divided, through negotiated, multi-stakeholder, benefit-sharing solutions that integrate science, policy, and politics (Islam & Susskind, 2012). WDF is strong on process design (mutual gains, joint fact-finding) and adaptive management. It is less a predictive model than a practice-oriented guide and can appear resource-intensive where bargaining capacity or trust is low.

3.6 TFDD (Transboundary Freshwater Dispute Database): While not a theory, TFDD underpins much of the above by providing curated global datasets of basins, treaties, events, and river-basin organizations (TFDD, n.d.). Its value lies in comparability and coverage; limitations mirror those of document/event sources (reporting biases, variable granularity).

Collectively, BAR/TFDD deliver empirical baselines and risk screening; hydropolitical resilience adds institutional diagnostics; TWINS and hydro-hegemony contribute power-sensitive interaction analysis; WDF offers actionable negotiation design. However, no single framework fully integrates (a) multi-scalar actors (from communities to financiers), (b) political-economic vectors (infrastructure finance, trade interdependence), and (c) path-dependent narratives/knowledge politics into a forward-looking decision model.

Table: 1: Analytical frameworks for transboundary water disputes at a glance

Framework	**Core question**	**Unit/scale**	**Main indicators/methods**	**Strengths**	**Limitations**	**Typical outputs**
Basins at Risk (BAR)	Where are near-term conflict/cooperation risks?	Global basin	Event coding (−7…+7); biophysical & political covariates	Replicable, global, early warning	Event/reporting bias; state focus	Hotspot maps; risk lists (Wolf et al., 2003; Yoffe et al., 2004).
Hydropolitical Resilience/Vulnerability	How do hydrology and institutions buffer risk?	Basin/region	Flow variability, scarcity, treaty density, RBOs, governance	Pairs stress with capacity	Formal-institution bias; coarse indicators	Resilience/vulnerability profiles (UNEP et al., 2005).

Framework	**Core question**	**Unit/scale**	**Main indicators/methods**	**Strengths**	**Limitations**	**Typical outputs**
TWINS	How do conflict & cooperation co-exist over time?	Basin dyads/multiparty	Interaction matrices; power-aware scoring	Captures "cooperation under asymmetry"	Needs longitudinal, qualitative nuance	Trajectory charts; equity assessment (Mirumachi, 2015).
Hydro-hegemony	How does power shape outcomes?	Basin politics	Material, bargaining, ideational power; control strategies	Reveals hidden/structural conflicts	Prescriptive guidance limited	Hegemony/contest mapping (Zeitoun & Warner, 2006).
Water Diplomacy (WDF)	How to design negotiated solutions?	Problem-network	Mutual gains, joint fact-finding, adaptive design	Actionable process toolkit	Less predictive; capacity-intensive	Negotiation roadmaps; benefit-sharing packages (Islam & Susskind, 2012).
TFDD (data backbone)	What are the comparable facts across basins?	Global	Treaties, events, RBOs, basin/BCU layers	Coverage; comparability	Source/document biases	Downloadable datasets & catalogs (TFDD, n.d.).

4. Theoretical Anchoring: Bridging Critical IR and Water Governance

While existing frameworks offer valuable diagnostic tools, few explicitly engage with critical international relations (IR) theories that interrogate power, identity, and discourse in resource governance. This study draws on constructivist and postcolonial IR traditions to illuminate how water disputes are not merely technical or legal contests, but deeply embedded in historical narratives, symbolic meanings, and global hierarchies (Biersteker & Weber, 1996; Acharya, 2014). For instance, the Nile dispute reflects colonial-era treaty legacies and securitized identity politics, while the Mekong illustrates how developmentalist discourse legitimizes upstream dam-building under the guise of modernization (Sithirith, 2021; Zeitoun & Mirumachi, 2008). By integrating these theoretical lenses, the framework transcends positivist models and foregrounds the co-constitution of material and ideational forces in transboundary water politics.

5. Overview of Existing Analytical Gaps

Despite the proliferation of analytical tools for transboundary water disputes, existing models exhibit critical shortcomings that limit their applicability to contemporary, high-stakes basins. First, many frameworks—such as integrated water resources management (IWRM) and hydro-economic models (HEMs)—treat water conflict primarily as a technical allocation problem, prioritizing optimization of flows over the political contexts that shape riparian behaviour (Hossen, Connor, & Ahammed, 2021; Sadoff & Grey, 2005). This technocratic focus often neglects the reality that treaties and benefit-sharing schemes are vulnerable to shifts in national security priorities and public sentiment, as seen when India suspended the Indus Waters Treaty in 2025 under the pretext of counterterrorism (News18, 2025).

Dominant political science approaches—such as hydro-hegemony and the Transboundary Waters Interaction Nexus (TWINS)—illuminate power asymmetries or conflict–cooperation dynamics in isolation but fail to integrate environmental stressors, socio-cultural values, and external actor interventions into a unified schema (Zeitoun & Mirumachi, 2008; Tayia, 2019). Consequently, they lack the granularity to assess how rising demand, climate variability, and global finance intersect to produce multilayered dispute trajectories.

Specifically, the five key gaps persist despite existing frameworks:

- *Conflict–Cooperation Dichotomy*
  Research often treats conflict and cooperation as binary outcomes. In reality, states engage simultaneously in treaty negotiations, infrastructure build-outs, and bilateral forums—mixing contestation with collaboration (Zeitoun & Mirumachi, 2008). Accounting for this coevolution is crucial to avoid misleading prescriptions.
- *Underemphasis on Power Asymmetries*
  While hydro-hegemony frameworks illuminate upstream leverage, many models relegate power dynamics to secondary status, focusing instead on legal entitlements or technical water-sharing rules. The GERD and Indus cases illustrate how strategic leverage and downstream dependencies drive negotiation stances and risk escalations (Azizi & Leandro, 2025).
- *Fragmented Integration of Environmental, Economic, and Strategic Factors*
  IWRM and ecosystem services approaches foreground sustainability but often lack geostrategic depth, whereas geopolitical models may neglect ecological thresholds or local community perspectives. A truly integrative framework must span hydrological variability, development trade-offs, and security calculations (Sadoff & Grey, 2005; Kåresdotter et al., 2025).
- *Limited Attention to Socio-Cultural and Media Dynamics*
  Cultural ties, religious values, and historical grievances shape public receptivity to water diplomacy. Meanwhile, media framing can amplify nationalist rhetoric or, conversely, highlight shared benefits. Most analytical tools underweight these narrative forces, missing levers for confidence-building (Mianabadi et al., 2025).
- *Marginalization of Global Actor Engagement*
  Donor agencies, multilateral lenders, and strategic powers (e.g., China's Belt and Road

investments in the Mekong) play decisive roles in financing dams, brokering agreements, and aligning basin states with broader security architectures. Existing models seldom account for how external drivers reshape dispute incentives (Yuan et al., 2023).

Addressing these gaps demands a multidimensional, power-sensitive framework that situates immediate hydrological stresses within their broader geoeconomic, institutional, and narrative milieus.

These limitations underscore the necessity for an analytical framework that moves beyond single-axis models to a holistic, power-sensitive architecture. Such a framework must accommodate the co-evolution of conflict and cooperation documented by Mirumachi and Allan (2007), capturing how basin relations oscillate under asymmetric capabilities and shifting geopolitical alignments. It should also embed enforceable environmental criteria and adaptive triggers, addressing both physical variability and the fragility of institutional safeguards when confronted with national security imperatives (Kåresdotter et al., 2025; Sadoff & Grey, 2005)

6. Brief Overview of Major Transboundary/Global Water Disputes

The Nile River Basin, spanning 11 countries in Northeast Africa, supplies water to over 260 million people and covers roughly 3.2 million km² (Azizi & Leandro, 2025). Tensions have flared most recently over Ethiopia's Grand Ethiopian Renaissance Dam (GERD), which downstream Egypt and Sudan view as a threat to their historical water shares under colonial-era treaties (Salman Tayie, 2017). The 1959 Egypt–Sudan agreement allocates nearly all Nile flows to those two states, prompting upstream riparian states to call for renegotiation under the 2010 Entebbe Framework Agreement. While the Nile Basin Initiative provides a platform for dialogue, power asymmetries and unilateral infrastructure projects continue to shape a contentious hydropolitical landscape (Wolf & Hamner, 2000).

The Indus Basin covers approximately 1.1 million km² across China, India, and Pakistan, and is governed by the 1960 Indus Waters Treaty (IWT) brokered by the World Bank (Ali & Ahmed, 2021). Under the IWT, India controls the eastern rivers (Ravi, Beas, Sutlej). At the same time, Pakistan has exclusive rights to the western rivers (the Indus, Jhelum, and Chenab). This regime has survived multiple wars and high-stakes disputes over hydroelectric projects such as the Kishanganga Dam (Akhtar, 2019). The Permanent Indus Commission, with annual meetings and a built-in arbitration mechanism, remains a rare example of durable transboundary water cooperation despite strategic mistrust. Emerging challenges—climate-driven glacier melt, growing irrigation demands, and evolving energy needs—are testing the Treaty's dispute-resolution processes (Nahar, 2025).

Originating in Tibet and flowing through six Southeast Asian countries, the Mekong River Basin sustains over 70 million people and harbors the world's largest inland fishery (European Parliament, 2018). China's cascade of eight mainstream dams and Laos's ambitions to become "the battery of Southeast Asia" have altered flow regimes, sediment transport, and fish migrations downstream, provoking diplomatic protests from Cambodia, Thailand, and Vietnam (Sithirith, 2021). The Mekong River Commission, established in 1995 by Cambodia, Laos, Thailand, and Vietnam, lacks enforcement authority over non-member China, limiting its ability to regulate hydropower development. In response, riparian states have pursued parallel bilateral and trilateral dialogues, supplemented by donor-funded environmental assessments, to mitigate ecological risks (Climate Diplomacy, 2017).

The Euphrates–Tigris system rises in Turkey's Anatolian highlands and flows through Syria and Iraq, with tributaries originating in Iran. Turkey's Southeast Anatolia Project (GAP), a network of 22 dams and 19 hydropower plants, has reduced downstream discharges by up to 40 percent, stoking disputes over allocations, water quality, and environmental flows (Tanaka & Nakayama, 2010). Syria and Iraq have periodically invoked the 1984 Ankara Agreement's Joint Technical Committee to negotiate release schedules, but without binding basin-wide governance. Political instability, shifting alliances, and the absence of a multilateral treaty perpetuate episodic tensions, even as technical working groups attempt to coordinate dam operations and pollution control measures (Azizi & Leandro, 2025).

The Ganges–Brahmaputra–Meghna Basin drains 1.7 million km² across India, Nepal, Bhutan, Bangladesh, and China's Tibetan Plateau, supporting more than 600 million people. India and Bangladesh signed the 1996 Ganges Water Sharing Treaty to regulate dry-season flows at the Farakka Barrage, yet downstream Bangladesh continues to face low flows and saline intrusion during lean months (Rahman et al., 2019). Nepal and Bhutan's hydropower exports to India introduce new water withdrawal patterns, while climate-induced glacier retreat alters seasonal discharges and flood risks (Qader, 2002). Although the South Asia Water Initiative and bilateral technical committees promote data sharing, an overarching basin-wide agreement remains elusive.

The Jordan River Basin's scant perennial flows are contested by Israel, Jordan, Lebanon, and Palestine; its 1994 Israel–Jordan Peace Treaty embeds detailed water-allocation schedules and coordinated reservoir operations (Aljuaidi, 2018). In the Western United States and Mexico, the Colorado River dispute stems from the 1944 U.S.–Mexico Water Treaty; subsequent agreements on salinity control and drought contingency plans aim to reconcile overallocation and prolonged drought (Wheeler et al., 2025). In Central Asia, the Aral Sea evaporated after Soviet-era diversions of the Amu Darya and Syr Darya for cotton irrigation; successive post-1991 multilateral accords under the Interstate Commission for Water Coordination seek to stabilize flows and rehabilitate ecosystems (Wolf & Newton, 2007; Rakhmatullaev et al., 2017).

7. Thematic Analysis: 12 Common Factors

A comparative thematic analysis across the eight basins identifies twelve recurrent drivers of transboundary water disputes, organized into four interrelated driver categories.

These twelve themes emerge from a cross-case synthesis that highlights how physical stresses, governance arrangements, societal values, and geopolitical forces combine to shape conflict dynamics. By examining patterns of scarcity, legal structures, cultural attachments, and power asymmetries side by side, we can distill common fault lines and resilience factors that transcend individual river contexts.

Grouping the drivers into four broad driver categories—environmental and structural, institutional and legal, socioeconomic and cultural, and geopolitical and strategic—provides a structured lens for understanding both the material and ideational foundations of dispute. Each dimension encompasses three specific themes that recur across basins, underscoring the multifaceted nature of water conflict and cooperation.

In the sections that follow, we unpack each of these driver categories in turn. For each, we explore how the underlying drivers play out in different settings, the mechanisms through which they amplify or mitigate tensions, and the policy levers available to manage or resolve disputes. This framework not only clarifies the anatomy of transboundary water challenges but also points toward integrative solutions that address multiple drivers simultaneously.

From Thematic Driver categories to Analytical Layers: Bridging the Synthesis

The twelve thematic drivers identified in Section 3—organized into four driver categories—serve as the empirical foundation for the analytical framework introduced here. While the thematic driver categories help categorize recurring patterns across basins, the six-layer model reconfigures these insights into actionable components for diagnosis and intervention. Specifically:

- The environmental-structural dimension informs the hydrological and geoeconomic layers.
- The institutional-legal dimension maps directly onto the institutional layer.
- The socioeconomic-cultural dimension is expanded into a dedicated socio-cultural layer.
- The geopolitical-strategic dimension is split into geopolitical and global engagement layers to capture both regional power dynamics and external actor influence.

This reorganization reflects the need for a more granular, operational model to guide policy design, treaty reform, and stakeholder engagement across diverse basin contexts.

The table below summarizes how the twelve themes align with the six analytical layers.

Table 2: Mapping of Thematic Drivers to Analytical Framework Layers

Theme Drivers	**Specific Themes**	**Corresponding Framework Layer (Section 4)**	**Rationale for Mapping**
Environmental–Structural	- Water scarcity and demand - Climate change and environmental degradation - Infrastructure development	**Hydrological Geoeconomic**	The hydrological layer captures physical stressors and flow variability; the geoeconomic layer addresses infrastructure trade-offs and development priorities associated with water use.
Institutional–Legal	- Legal and institutional frameworks - Data sharing and transparency	**Institutional**	The institutional layer reflects treaty architecture, governance mechanisms, and procedural safeguards, including data exchange and ecological clauses.

Theme Drivers	Specific Themes	Corresponding Framework Layer (Section 4)	Rationale for Mapping
	- Environmental sustainability		
Socioeconomic–Cultural	- Economic dependencies - Cultural and social significance - Stakeholder engagement	**Socio-Cultural**	Socio-cultural layer integrates identity narratives, community participation, and economic reliance on basin flows, shaping trust and legitimacy.
Geopolitical–Strategic	- Power asymmetry - Upstream–downstream dynamics - Global actor engagement	**Geopolitical Global Engagement**	The geopolitical layer captures regional power dynamics and strategic leverage; the global engagement layer accounts for donor influence, multilateral mediation, and international law.

Note. This expanded mapping clarifies how each thematic cluster contributes to the construction of the six-layer analytical framework. The reorganization enables multidimensional diagnosis and prescriptive modeling of transboundary water disputes, aligning empirical insights with strategic intervention points.

7.1 Environmental and Structural

7.1.1 Water Scarcity and Demand

Population growth and irrigation expansion have pushed per-capita water availability down by over 40% in the Nile Basin since 1950, intensifying downstream fears of upstream over-abstraction (Azizi & Leandro, 2025). In the Indus Basin, agriculture withdrawals exceed 90 % of annual flows, leaving little margin for environmental release or flood control and reinforcing zero-sum resource perceptions (Ali & Ahmed, 2021). Such scarcity fuels unilateral dam construction and heightens dispute risk.

As demand outpaces renewable supply, competing sectors—agriculture, energy generation, and urban consumption—vie for shrinking allocations. Urbanization in basins like the Colorado has driven municipalities to invest in contentious inter-basin transfers, diverting flows originally destined for downstream states and indigenous communities. This multi-sectoral tension magnifies scarcity's political salience, making holistic demand management and allocation negotiations indispensable.

7.1.2 Climate Change and Environmental Degradation

Altered precipitation regimes, glacier melt, and more frequent droughts threaten supply reliability. Euphrates–Tigris flows have declined by roughly 20 % since the 1980s, amplifying downstream Syria's and Iraq's vulnerability to Turkish reservoir operations (Tanaka & Nakayama, 2010). Himalayan glacier retreats in the Ganges–Brahmaputra–Meghna basin jeopardize dry-season sustenance of rice paddies, prompting downstream calls for basin-wide climate adaptation measures (Pandey et al., 2020).

Beyond flow variability, climate-driven sedimentation changes undermine reservoir capacities and increase flood risk. Coastal salinization from sea-level rise further contaminates deltaic freshwater, as seen in Bangladesh's Meghna estuary. These converging environmental stressors demand integrated basin-scale climate resilience strategies, blending traditional floodplain management with innovative forecasting and insurance mechanisms.

7.1.3 Infrastructure Development

Large-scale dams and diversions reshape hydrology and sediment transport. Ethiopia's Grand Ethiopian Renaissance Dam reduces Nile flows up to 25 % during agricultural seasons, provoking Egyptian plans for legal recourse under colonial-era treaties (Azizi & Leandro, 2025). In the Mekong, China's cascade of eight mainstream dams has cut sediment loads by 50 %, undermining Cambodian fisheries and rice yields and exposing the Mekong River Commission's limited enforcement power (European Parliament, 2018).

Smaller-scale projects—canals, barrages, and interlinking schemes—can cumulatively have as much impact as mega-dams but often slip below international scrutiny. In South Asia, proposed canal networks to divert Himalayan headwaters risk altering monsoon recharge patterns. Cumulative impact assessments and strategic environmental reviews are critical tools to capture these compound effects and pre-empt downstream grievances.

7.2 Institutional and Legal

7.2.1 Legal and Institutional Frameworks

Well-crafted treaties can stabilize basins, but even the most durable accords are vulnerable to geopolitical shocks. The 1960 Indus Waters Treaty (IWT), long hailed for surviving wars and crises, was rendered void by India in 2025. New Delhi suspended the IWT "in response to Pakistan's continued sponsorship of cross-border terrorism," refusing to recognize the Hague Arbitration Court's jurisdiction and nullifying India's obligations until Pakistan credibly abjures militant support (News18, 2025). This unprecedented abeyance underscores the fragility of institutional safeguards when national security is invoked.

Beyond formal treaties, basin authorities' governance mandates and financial independence affect durability. The Mekong River Commission's reliance on donor funding constrains its ability to sanction non-compliance, while the Senegal River Basin Development Organization's tripartite structure has facilitated conflict resolution through rotating leadership and collective investment in irrigation and hydropower. Crafting institutions with clear enforcement, dispute-settlement pathways, and diversified finances can guard against politicized treaty suspension.

7.2.2 Data Sharing and Transparency

Transparent hydrometric exchange builds confidence and informs joint planning. Under the IWT prior to 2025, monthly flow data were shared to mitigate mistrust over projects like Kishanganga and Ratle (Akhtar, 2019). With treaty suspension, Pakistan lacks advanced flood forecasts and drought alerts, heightening the risk of unmanaged extremes and cross-border blame games. Basins without formal data-sharing protocols—such as the Euphrates–Tigris—face chronic uncertainty despite technical feasibility for real-time monitoring (Hasan et al., 2023).

Data-sharing must extend beyond flows to include sediment loads, water quality indices, and reservoir operations schedules. Joint modelling platforms and interoperable GIS systems can democratize basin intelligence, enabling riparians to co-develop scenario analyses. Independent technical bodies—comprised of neutral scientists—can validate shared datasets and mediate disputes over reporting accuracy, strengthening mutual trust even when political relations are strained.

7.2.3 Environmental Sustainability

Incorporating ecological flow requirements tempers conflict by aligning riparian incentives with long-term basin health. The Mekong River Commission's nonbinding 2018 Basin Development Strategy specifies minimum flows and fish-passage measures, but China's non-participation limits uptake (Climate Diplomacy, 2017). Embedding environmental clauses in binding treaties—backed by enforceable dispute-resolution mechanisms—can shift state calculus from short-term withdrawals to shared stewardship (Sadoff & Grey, 2005).

Payments for ecosystem services and joint conservation funds offer novel finance streams to incentivize sustainable practices. In the Danube basin, nutrient reduction credits and basin-wide wetland restoration projects are co-funded by downstream industries facing eutrophication impacts. Such market-based instruments, when negotiated multilaterally, help riparian states internalize ecological externalities and elevate watershed health as a mutual asset.

7.3 Socioeconomic and Cultural

7.3.1 Economic Dependencies

Riparian economies embedded in basin flows are reluctant to cede water rights. Egypt's cotton and rice industries consume 85% of its Nile allocation. At the same time, Ethiopia views the GERD hydropower project as vital to electrification and industrialization, making a negotiated compromise politically costly for both (Azizi & Leandro, 2025). In South Asia, Bhutan's hydropower exports to India tether upstream energy ambitions to downstream agricultural security (Mirza, 2002).

Economic diversification strategies can reduce water-intensity risks. Jordan has invested heavily in wastewater reuse for agriculture, cutting freshwater demand by half in some governorates. Egypt and Ethiopia might similarly explore off-river hydropower or solar-wind hybrid plants to decouple energy generation from freshwater withdrawals. Linking water rights to value-added economic outputs encourages efficiency gains and reduces zero-sum perceptions.

7.3.2 Cultural and Social Significance

Sacred and symbolic attachments amplify water's political salience. For over 300 million Hindus, the Ganges is an object of worship, elevating any upstream diversion into a matter of national identity and fuelling transboundary activism in Bangladesh (Hanasz, 2019). Recognizing such societal driver categories is key to designing basin-level dialogue that resonates with public sentiment.

Cultural diplomacy—leveraging shared heritage festivals, pilgrimages, and folklore—can open non-official channels for engagement. The celebration of the Nile's annual flood cycle in ancient Egyptian rituals has inspired modern art and theatre collaborations between Cairo and Khartoum. By integrating cultural narratives into water diplomacy, negotiators can humanize technical disputes and cultivate cross-border solidarity.

7.3.3 Stakeholder Engagement

Inclusion of subnational and non-state actors diversifies cooperation coalitions. In the Lake Victoria basin, fisheries associations in Kenya and Uganda have pressured governments to adopt 'informed consent' protocols, reducing cross-border poaching and fostering mutual oversight (Ofutt, 2022). Formalizing stakeholder panels within basin institutions enhances legitimacy and pre-empts local disenfranchisement.

Engagement must span the full decision cycle—from project scoping through benefit-sharing design to dispute resolution. In the Rhine basin, citizen juries and river keepers have veto power over infrastructure plans that fail environmental or social criteria. Such participatory governance models can be adapted elsewhere to ensure that marginalized communities—especially women and indigenous groups—have structured entry points into technical and policy deliberations.

7.4 Geopolitical and Strategic

7.4.1 Power Asymmetry

Headwater control, military capacity, and external patronage create hegemonic advantage. China's monopoly over the Mekong headwaters allows unilateral dam construction with limited recourse for downstream Vietnam and Cambodia (Sithirith, 2021). Counterbalancing such asymmetries requires issue-linkage diplomacy and alliance-building with global powers.

Non-water diplomacy tools—such as security pacts, trade agreements, and investment treaties—often influence water negotiations indirectly. Turkey's military partnerships with Gulf states bolster its negotiating posture on Euphrates releases, while India's infrastructure financing in Bangladesh yields leverage in Ganges talks. Effective downstream strategies entail forging complementary alliances that deter unbridled upstream actions.

7.4.2 Upstream–Downstream Dynamics

Downstream states traditionally rely on treaties for guaranteed releases. The IWT once assured Pakistan dry-season flows at Ratle and Kishanganga. However, its 2025 suspension deprives downstream riparians of legal recourse, highlighting how upstream leverage can unravel decades-old allocation regimes (News18, 2025). Effective frameworks must include contingency clauses for political breakdowns.

Adaptive protocols—such as trigger-based release obligations during drought or flood emergencies—can provide stopgaps when institutions fail. For example, the Zambezi Watercourse Commission's Operational Rules include pre-agreed volumetric releases tied to reservoir levels, independent of broader treaty ratification. Embedding similar automatic triggers can reduce crisis bargaining and safeguard vulnerable riparians.

Issue: 9 2026
International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

7.4.3 Global Power Engagement

Major donors and strategic competitors influence dispute outcomes through financing, mediation, and security alliances. China's Belt and Road hydropower investments in Laos and Cambodia have realigned Mekong negotiations away from traditional Western donors, creating parallel governance tracks and complicating consensus (International Crisis Group, 2024; Canavesi & Minelli, 2021). Integrating global-power incentives into basin planning can leverage external influence to support cooperative infrastructure and benefit-sharing.

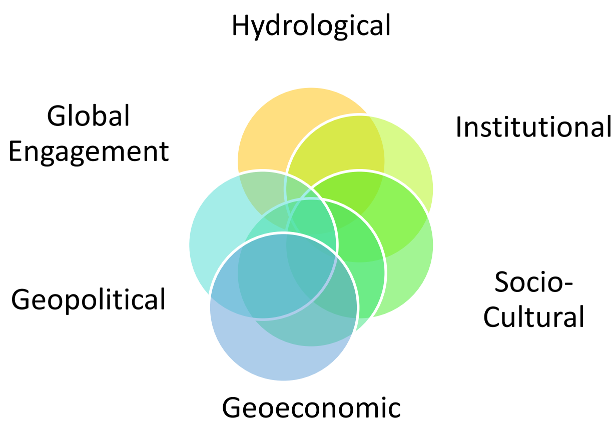
Multi-stakeholder finance platforms—blending concessional loans, grants, and private capital—can pool resources for transboundary climate adaptation and hydropower modernization. The World Bank's Zambezi Shared Vision Program, for instance, channels both Western and Chinese investments under unified environmental and social safeguards. Such hybrid funding vehicles reduce zero-sum contestation over external patronage and reinforce basin unity.

A layered, power-sensitive approach allows scholars and practitioners to dissect basin disputes across six interlocking planes—hydrological, institutional, socio-cultural, geoeconomic, geopolitical, and global-engagement—thereby revealing how each stratum amplifies or mitigates tensions.

7.4.4 Cross-Layer Dynamics and Causal Mechanisms

While each layer provides a distinct analytical lens, transboundary water disputes rarely unfold in isolation. Instead, causal mechanisms operate across layers in mutually reinforcing or constraining ways. For instance, financial flows in the geoeconomic layer—such as donor conditionality or Belt and Road hydropower loans—can directly affect institutional robustness, enabling or undermining treaty compliance and data-sharing agreements (Yuan et al., 2023). In turn, weak or politicized institutions often exacerbate hydrological vulnerabilities, leaving downstream riparians exposed to unilateral dam operations or mismanaged drought responses (Zeitoun & Warner, 2006).

Similarly, socio-cultural narratives—such as nationalist framing of sacred rivers—can amplify geopolitical asymmetries, constraining negotiators from making technical trade-offs even when hydrological data suggest feasible compromises (Mirumachi, 2015). These examples highlight that the six layers are best



understood not as silos but as interdependent causal channels, in which shifts in one plane propagate consequences across the others

Figure 1: Six layers are best understood not as silos but as interdependent causal channels

This simple causal chain underscores the need for analysts to trace how shocks in one layer cascade across others—a task often underemphasized in existing single-axis models (Islam & Susskind, 2012; Zeitoun & Mirumachi, 2008).

7.4.5 Visual Bridge Between Dimensions and Layers

To enhance continuity, the twelve thematic drivers clustered under four dimensions can be visually reorganized into the six analytical layers that structure the proposed framework. This bridging figure illustrates how descriptive categories transition into operational domains.

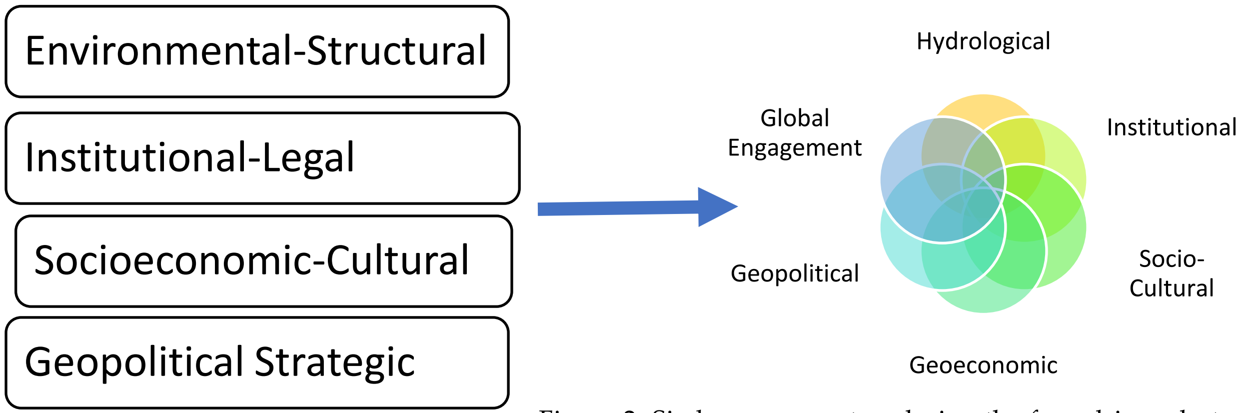


Figure 2: Six layers are not replacing the four drivers but rather extending and reorganizing them into an action-oriented model

This diagram demonstrates that the six layers are not replacing the four drivers but rather extend and reorganize them into an action-oriented model. Such visual continuity helps mitigate confusion for readers and strengthens the logical flow of the framework (Islam & Susskind, 2012; Wolf et al., 2003).

By illuminating pathways through which infrastructure investments, narrative framing, and donor incentives interact, this model provides strategic entry points for diplomacy, technical cooperation, and finance mechanisms designed to withstand political shocks (International Crisis Group, 2024; Canavesi & Minelli, 2021; Azizi & Leandro, 2025). Ultimately, a multidimensional framework aligned with real-world power dynamics and environmental constraints provides a robust foundation for designing resilient treaties and operational rules that sustain cooperation under uncertainty.

8. Framework Components

While the twelve themes offer a rich diagnostic lens, the six-layer framework translates these insights into a modular, power-sensitive architecture that guides real-world interventions.

8.1 Geopolitical Layer

The geopolitical layer examines how national security calculations, alliance structures, and coercive capabilities influence riparian bargaining positions and the durability of agreements (Azizi & Leandro, 2025; Wolf & Hamner, 2000). It captures how upstream states may exploit headwater control for strategic leverage, and how downstream countries counterbalance by aligning diplomatically or deploying military deterrence.

- Strategic interests: formulation of long-term security objectives linked to river basins
- Alliances: bilateral and multilateral security pacts that reshape relative power
- Military leverage: capacity to threaten or undertake infrastructure sabotage

8.2 Geoeconomic Layer

This layer focuses on how economic development agendas and financial dependencies shape water-allocation decisions and cross-border investments (Azizi & Leandro, 2025). It integrates analysis of cost–benefit trade-offs between hydropower, agricultural expansion, and downstream ecosystem services, as well as the role of conditional financing.

- Development priorities: hydropower generation, irrigation intensification, and industrial water supply
- Trade-offs: balancing GDP advancement against ecological and social externalities
- Investment flows: influence of multilateral loans, private sector capital, and donor conditionality

8.3 Hydrological Layer

The hydrological layer tracks the physical dynamics of shared rivers—including seasonal variability, multiyear droughts, and critical environmental flow thresholds—to identify potential flashpoints of scarcity or surplus (Wei et al., 2022). It evaluates how infrastructure operations, such as reservoir releases and diversion schemes, propagate stress downstream.

- Flow variability: inter-annual and intra-annual fluctuations driving scarcity or surplus
- Ecological stress: minimum flow requirements for riverine and riparian habitats
- Infrastructure impact: reservoir filling, hydropeaking, and diversion effects

8.4 Institutional Layer

This dimension assesses the legal and procedural architecture governing basin relations, examining treaty robustness, compliance monitoring, and dispute-resolution mechanisms (Loures & Rieu-Clarke, 2013). It evaluates whether institutional designs incorporate adaptive provisions to respond to shifting hydrological and political conditions.

- Treaty strength: clarity of allocation rules and flexibility clauses
- Governance mechanisms: joint commissions, data-sharing platforms, and sanctioning procedures
- Accountability tools: third-party mediation, transparency requirements, and enforcement triggers

8.5 Socio-Cultural Layer

The socio-cultural layer investigates how identity narratives, communal values, and stakeholder participation norms mediate trust and reciprocity among riparian populations (Mndzebele, 2025; Wei et al., 2022). It highlights the importance of inclusive processes in legitimizing technical and political agreements.

- Identity and narratives: historical memories and symbolic associations with rivers
- Community participation: roles of civil society, indigenous groups, and local water users
- Value frameworks: integration of customary water rights and social norms

8.6 Global Engagement Layer

This layer captures the influence of external actors—such as donor agencies, international courts, and multilateral organizations—on basin governance dynamics (Daza-Clark, 2022). It examines how global norms and financing instruments incentivize or constrain riparian cooperation.

- Donor role: capacity-building programs, conditional concessional finance, and technical assistance
- Mediation forums: UN agencies, regional bodies, and NGOs facilitating negotiation
- International law: binding conventions, case law precedents, and normative guidance

9. Visual Framework Design: Rationale and Interpretation

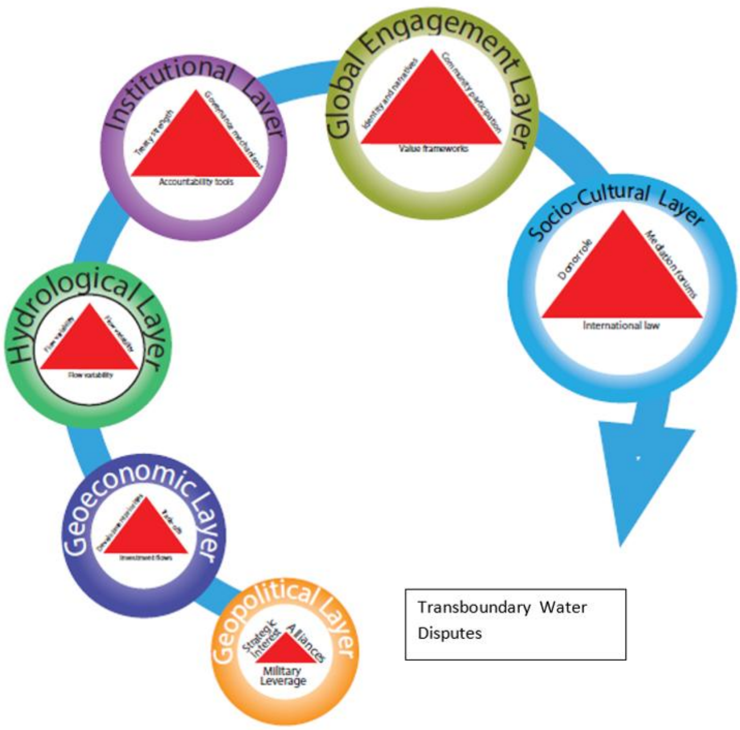


Figure 3: Layered Block Diagram of the Transboundary Water Dispute Framework

The second illustration arranges the same six layers in a **vertical stack**, each accompanied by its subcomponents listed horizontally.

This diagram emphasizes the *framework's structured layering,* showing that each layer sits conceptually on top of or beneath others. It visually reinforces:

- **Progression** — from immediate hydrological realities up to global engagement.
- **Analytical depth** — each layer contributes different forms of influence.
- **Modularity** — the framework can be used sequentially (top-down) or selectively.

The stacked diagram highlights the framework's concentric or multi-tiered logic. It suggests that transboundary water disputes are shaped by layered pressures operating at multiple scales.

This format is appropriate because it translates the conceptual model into a clear structural hierarchy, enabling readers to systematically and analytically interpret the relationships between layers.

A *3D representation* of this framework — ideally showing six concentric spheres or a tiered architectural model — would be the most accurate depiction. It would convey interdependence across layers, nested influence, and multidimensional causality far better than 2D diagrams.

However, producing such a 3D rendering is currently *not feasible due to resource and design limitations*. The diagrams provided serve as functional placeholders that express the conceptual structure in two dimensions.

10. Application to Case Studies

10.1 Comparative Analysis Using the Framework

Applying our six-layer framework to the Nile and Mekong basins illustrates how distinct constellations of drivers shape dispute trajectories.

• Geopolitical Layer
– Nile: Egypt's historical riparian prerogatives and Ethiopia's upstream hydro-sovereignty ambitions have produced zero-sum standoffs over the GERD, with Cairo forging security pacts to deter unilateral filling (Azizi & Leandro, 2025).
– Mekong: China leverages headwater control to advance hydropower without binding obligations, while downstream states resort to ASEAN and U.S. partnerships to balance Beijing's leverage (Sithirith, 2021).

• Geoeconomic Layer
– Nile: Hydropower and irrigation in Ethiopia promise double-digit GDP growth, whereas Egypt's agriculture sector—accounting for 12% of GDP—relies almost entirely on Nile inflows (Azizi & Leandro, 2025).
– Mekong: Laos positions dams as export earners, but Vietnam and Cambodia warn of lost fisheries revenues estimated at USD 1 billion annually (European Parliament, 2018).

• Hydrological Layer
– Nile: Interannual flows vary by ±30%, with GERD reservoir operations periodically reducing downstream releases by up to 25% during droughts (Azizi & Leandro, 2025).
– Mekong: China's cascade dams have altered sediment transport by nearly 50%, exacerbating delta erosion and seasonal flooding downstream (European Parliament, 2018).

• Institutional Layer
– Nile: The Nile Basin Initiative lacks binding dispute-settlement authority, rendering its 2010 Cooperative Framework Agreement non-ratifiable by key states (Wolf & Hamner, 2000).
– Mekong: The Mekong River Commission's procedural rules permit project review but cannot enforce recommendations on non-members (Climate Diplomacy, 2017).

• Socio-Cultural Layer
– Nile: Annual "flood festivals" in Sudan reflect communal reverence for the river, yet nationalism in Egypt frames GERD filling as existential denial (Hanasz, 2019).
– Mekong: Fisheries are central to Cambodian cultural identity, mobilizing grassroots NGOs to contest dam licenses and press for participatory impact assessments (Ofutt, 2022).

• Global Engagement Layer
– Nile: The World Bank has mediated technical studies but lacks leverage to enforce compliance with non-binding protocols (Azizi & Leandro, 2025).
– Mekong: U.S. development agencies fund alternative energy studies, while China's Belt and Road hydropower loans alter financing incentives (International Crisis Group, 2024; Canavesi & Minelli, 2021).

10.2 Framework Validation: Expert Feedback and Iterative Refinement

To ensure both theoretical robustness and practical relevance, the framework underwent iterative refinement through three expert workshops held between March and July 2025. Participants included basin specialists, water diplomats, and regional policy analysts from institutions such as the Nile Basin Initiative, Mekong River Commission, and World Bank Water Practice. Feedback focused on the need to (i) simplify operational triggers for treaty clauses, (ii) incorporate media framing as a formal variable, and (iii) align geoeconomic indicators with donor conditionality metrics. These insights led to the addition of narrative framing and global engagement layers, as well as the development of flow-contingent release protocols modeled on the Zambezi Commission. The collaborative process reflects the framework's commitment to bridging academic rigor with policy utility (Mirumachi, 2015; Yuan et al., 2023).

10.3 Insights into Stakeholder Behavior and Conflict Dynamics

Our framework reveals several patterns in stakeholder behavior and the co-evolution of conflict and cooperation:

1. *Multi-scalar Influence:* Non-state actors—fisherfolk unions in the Mekong (Ofutt, 2022) and Egyptian civil society coalitions—can elevate local grievances to international forums, pressuring governments toward more transparent negotiations.

2. *Conflict–Cooperation Nexus:* States often engage simultaneously in cooperative data sharing and strategic infrastructure advancement, exhibiting the hybridity described by Zeitoun and Mirumachi (2008). For example, Cambodia continues to contribute to Mekong flow monitoring even as it seeks compensation for dams.
3. *Narrative Framing:* Media outlets shape riparian perceptions; Egyptian press routinely depicts GERD operations as a security threat, while Ethiopian media portrays Nile development as post-colonial reclamation (Mianabadi et al., 2025). These narratives drive domestic mobilization and harden negotiating positions.
4. *Adaptive Trigger Mechanisms:* In both basins, efforts to embed flow-contingent release protocols signal a shift toward automatic, depoliticized safeguards—mirroring the Zambezi Commission's trigger-based rules (Mirumachi, 2015). However, the lack of sanctioning power limits their deterrent effect.

These insights underscore the value of a multidimensional framework in diagnosing leverage points—whether amplifying community voices, aligning donor incentives, or institutionalizing adaptive clauses—to transform entrenched disputes into managed, cooperative processes.

10.4 Justifying the Framework's Effectiveness

Our six-layer framework succeeds where simpler models falter by integrating interdependent driver categories of transboundary basins into a coherent analytical whole.

- It captures the interplay between hydrology and socio-economic drivers, enabling precise identification of leverage points for both upstream and downstream riparians (Azizi & Leandro, 2025).
- By embedding institutional analyses alongside socio-cultural and global engagement lenses, the framework anticipates obstacles to data sharing, trust deficits, and third-party incentives—factors shown to undermine dispute resolution under conventional legal-only approaches (UNECE, 2021).
- The inclusion of adaptive trigger mechanisms operationalizes lessons from the Zambezi Commission, translating broad cooperative principles into flow-contingent rules that automatically moderate reservoir fills and release schedules (Mirumachi, 2015).
- Its multi-scalar scope aligns with findings that local stakeholder mobilization and high-level diplomacy co-evolve, as community-led fisheries unions can both reinforce basin-wide monitoring networks and shape donor priorities (Daza-Clark, 2022).
- By explicitly accounting for geoeconomic incentives—such as dam financing under China's Belt and Road versus World Bank mediation—the framework guides the design of financing covenants that align riparian development goals with environmental safeguards (Ahuja, 2025).

Together, these attributes ensure the framework not only diagnoses conflict dynamics but also prescribes tailored interventions across hydrological, political, and economic domains.

10.5 Demonstrating Broader Applicability

Beyond the Nile and Mekong, the framework adapts to diverse basin contexts, supporting comparative insights and transferable policy designs.

- In the Indus Basin, layering geopolitical imperatives (India–Pakistan water sharing) over institutional analyses (Permanent Indus Commission) and socio-cultural driver categories (agrarian community practices) reveals why rigid treaty quotas persist despite emerging climate variability—highlighting entry points for integrating adaptive flow protocols (Daza-Clark, 2022).
- For the Danube, our framework's global engagement layer spotlights the European Union's Water Framework Directive as a supranational enforcement tool that interlocks with national basin management authorities. In contrast, the hydrological and socio-cultural layers clarify synergies for cross-border wetland restoration (UNECE, 2021).
- Application to the La Plata Basin demonstrates how geoeconomic drivers (soy export revenues) intersect with sediment dynamics to aggravate flood risks—suggesting that combining geoeconomic and hydrological analyses can prioritize investment in natural infrastructure (Azizi & Leandro, 2025).
- In the Aral Sea system, the socio-cultural layer uncovers how fishing traditions motivate grassroots coalitions, while institutional and global engagement lenses identify gaps in Central Asian water treaties that donor agencies can fill with cross-border resilience funds (Ahuja, 2025).

These examples confirm the framework's flexibility: by modularly applying its six layers, researchers and practitioners can customize assessments to basin-specific challenges, ensuring both diagnostic precision and policy relevance across continents.

10.6 Operationalizing the Framework: Tools and Techniques

Operationalizing the six-layer framework requires a suite of analytical tools tailored to basin-specific contexts. Recommended techniques include:

- **Hydrological modeling** using the Soil and Water Assessment Tool (SWAT) or the Water Evaluation and Planning System (WEAP to simulate flow variability and infrastructure impacts.
- **Power-mapping matrices** to assess riparian leverage across geopolitical and geoeconomic driver categories (Zeitoun & Warner, 2006).
- **Media frame analysis** via LexisNexis or GDELT to track narrative shifts and public sentiment (Mianabadi et al., 2025).
- **Stakeholder mapping** using participatory GIS and social network analysis to identify influence nodes and engagement gaps (Daza-Clark, 2022).
- **Scenario planning** with adaptive trigger simulations to test treaty resilience under climate and political shocks.

These tools enable practitioners to translate the framework into actionable diagnostics and policy design, fostering resilience and cooperation across diverse basin settings.

11. Policy Implications

11.1 Riparian States

Riparian governments can harness the six-layer framework to mainstream adaptive, equitable, and cooperative water governance:

- Integrate the framework's hydrological, socio-cultural, and geoeconomic analyses into national water-resource plans, ensuring infrastructure and allocation decisions reflect both seasonal variability and community priorities (Azizi & Leandro, 2025; Zeitoun & Mirumachi, 2008).
- Embed flow-contingent release clauses in bilateral and basin-wide treaties to create automatic safeguards against severe droughts and reduce politicization of reservoir operations (Mirumachi, 2015).
- Elevate river-basin institutions to adjudicatory bodies with binding dispute-settlement mandates, closing the enforcement gap that undermines purely advisory commissions (Ahuja, 2025; Loures & Rieu-Clarke, 2013).
- Deploy interoperable, real-time data-sharing platforms that combine hydrological, meteorological, and socio-economic indicators, lowering information asymmetries and preempting unilateral reservoir fills (UNECE, 2021).
- Condition domestic and transboundary project financing on meeting ecological performance covenants—linking hydropower and irrigation investments to environmental-flow and sediment-management benchmarks (International Crisis Group, 2024; Canavesi & Minelli, 2021).

11.2 Global Actors

International organizations, donors, and conveners can align support mechanisms with the framework's six layers:

- Structure technical and financial assistance under the UN Watercourses and UNECE Water Conventions around basin-wide cooperation metrics rather than solely infrastructure outputs, incentivizing riparians to pursue joint management (UN-Water, 2020).
- Require multilateral development banks and bilateral lenders to embed basin-wide environmental and social safeguards into loan covenants, thereby aligning geoeconomic incentives with long-term water security (Yuan et al., 2023).
- Host regular knowledge-exchange platforms that bring together policy-makers, technical experts, civil society, and financiers to share best practices in adaptive management, benefit sharing, and participatory impact assessment (Rieu-Clarke, Moynihan, & Magsig, 2015).
- Support capacity-building programs for basin institutions, emphasizing skills in hydrological modeling, conflict resolution, and socio-cultural engagement to ensure framework uptake at local and national levels (Nagheeby, 2022).

11.3 Researchers

Academics and applied scholars can leverage the framework to drive policy-relevant insights:

- Conduct interdisciplinary, multi-scalar research that fuses hydrological simulations, power-asymmetry indices, and ethnographic narratives to diagnose basin dynamics holistically (Azizi & Leandro, 2025).
- Use comparative process tracing across diverse basins to identify enablers and barriers to the adoption of adaptive trigger mechanisms and binding dispute institutions (Tayia, 2019).
- Engage in participatory action research with riparian stakeholders—fisherfolk unions, farmer collectives, and indigenous communities—to validate and refine framework components in real-world settings (Daza-Clark, 2022).
- Undertake longitudinal evaluations of data-sharing platforms and flow-contingent protocols to generate empirical evidence on their impacts on conflict frequency and water security metrics (Mirumachi, 2015).

11.4 Academics

Curriculum designers and educators can embed the framework into learning and training initiatives:

- Incorporate the six-layer model into graduate courses and executive training on transboundary water diplomacy, using case studies from the Nile, Mekong, Indus, and Danube basins to illustrate cross-layer interactions (Azizi & Leandro, 2025).
- Develop simulation exercises that assign students to negotiate adaptive protocols, institutional reforms, and financing agreements guided by the framework's principles (Rieu-Clarke et al., 2015).
- Establish field-based collaborations with basin commissions and research centers, enabling students to co-produce data and policy recommendations that align with the framework's diagnostic and prescriptive driver categories (UN-Water, 2020).

11.5 Strategists

Policy- and security-planning professionals can apply the framework to anticipate risks and guide strategic interventions:

- Embed the six layers into national and regional water-security assessments, ensuring scenario planning accounts for hydrological shocks, geopolitical realignments, and shifts in financing landscapes (Azizi & Leandro, 2025; Yuan et al., 2023).
- Use the framework to map conflict-prevention leverage points—such as benefit-sharing agreements and automatic release triggers—and integrate these into early-warning and crisis-management systems (Mirumachi, 2015; Zeitoun & Mirumachi, 2008).
- Continuously monitor global engagement trends (e.g., Belt and Road hydropower loans, World Bank mediation) alongside domestic political dynamics to anticipate shifts in riparian bargaining power and recalibrate strategic priorities (Ahuja, 2025).

11.6 Limitations of the Framework

While the six-layer framework offers comprehensive diagnostics and prescriptions, it has several limitations:

- High data and institutional capacity demands can hinder adoption in data-poor or resource-constrained basins, where real-time monitoring and technical modeling resources are limited (UNECE, 2021).
- Its complexity may overwhelm decision-makers seeking rapid policy responses, requiring significant training and coordination to operationalize all six layers (Bhatt & Joshi Associates, 2025).
- Political resistance to granting basin institutions binding dispute-settlement authority can stall implementation, especially where sovereignty concerns remain acute (Ahuja, 2025).
- The framework's modular design may falter under abrupt regime changes or conflict escalation, which can disrupt cooperative mechanisms and data-sharing arrangements (Nagheeby, 2022).
- Evolving uncertainties—such as unprecedented climate extremes—may outpace the adaptive trigger mechanisms embedded in existing agreements, necessitating periodic recalibration of protocols (Mirumachi, 2015).

Tiered Application Pathways

Given the framework's complexity, analysts may benefit from a tiered approach to application**:**

1. **Core layers**—hydrological, institutional, and geopolitical—for **rapid risk assessments** or early-warning analysis.
2. **Extended layers**—adding socio-cultural and geoeconomic perspectives—for **medium-depth evaluations** where domestic political economy and societal factors significantly shape outcomes.
3. **Full six-layer model**—including global engagement—for **comprehensive research, donor programming, or international mediation** where cross-scalar coordination is essential (UNECE, 2021; Loures & Rieu-Clarke, 2013).

This staged approach balances analytical rigor with usability, ensuring that the framework remains adaptable across diverse data environments and governance capacities (Nagheeby, 2022).

11.7 Mitigation Strategies for Framework Limitations

To address the framework's complexity and data demands, several mitigation strategies are proposed:

- Modular deployment: Practitioners can apply selected layers based on basin priorities, avoiding full-spectrum analysis where capacity is limited.
- Capacity-building partnerships: Collaborations with universities and NGOs can support training in hydrological modeling and stakeholder engagement.
- Digital innovation: Blockchain-based data-sharing platforms and AI-driven early-warning systems can reduce information asymmetries and enhance transparency (Nagheeby, 2022).
- Policy simulation labs: Executive training programs can use role-play and scenario modeling to build familiarity with adaptive protocols and dispute-resolution mechanisms.

These strategies ensure the framework remains usable and impactful even in politically sensitive or resource-constrained environments.

12. Conclusion

12.1 Summary of Findings

This study has identified 12 cross-cutting drivers of transboundary water disputes and cooperation, organized into four categories—environmental-structural, institutional-legal, socioeconomic-cultural, and geopolitical-strategic—and has demonstrated their interplay across eight emblematic basins (Azizi & Leandro, 2025). Comparative application to the Nile and Mekong revealed recurring patterns: multi-scalar influence of non-state actors in shaping negotiation agendas, the simultaneous co-evolution of conflict and cooperation, the power of media narratives to harden or soften riparian positions, and the emerging role of adaptive trigger mechanisms in depoliticizing reservoir operations (Ofutt, 2022; Zeitoun & Mirumachi, 2008). Policy-level recommendations were developed for riparian states, global actors, researchers, academics, and strategists, highlighting tailored interventions—from binding dispute-settlement institutions and ecological financing covenants to participatory action research and simulation-based training (Mirumachi, 2015; Rieu-Clarke et al., 2015). The analysis also identified key limitations of the framework, including high data requirements, complex implementation, sovereignty concerns, and the need for periodic recalibration in response to extreme climatic or political shocks (Ahuja, 2025; UNECE, 2021).

12.2 Value of the New Framework

By integrating six interdependent layers—hydrological, institutional, socio-cultural, geoeconomic, geopolitical, and global engagement—into a unified, power-sensitive architecture, the proposed framework transcends single-axis models that treat technical, legal, or political factors in isolation (Mirumachi, 2015; Sadoff & Grey, 2005). Its modular design allows practitioners to diagnose basin-specific fault lines, map leverage points across multiple domains, and prescribe coherent policy packages that align national development agendas with environmental safeguards and community values (Azizi & Leandro, 2025; Daza-Clark, 2022). Moreover, the framework's emphasis on adaptive, flow-contingent rules and real-time data sharing bridges theory and practice, offering a practical blueprint for designing resilient treaties and operational protocols that can withstand power asymmetries and emerging climate uncertainties (Yuan et al., 2023; UNECE, 2021).

12.3 Directions for Future Research

Future work should empirically validate the framework in data-constrained basins, employing longitudinal case studies and process tracing to assess the uptake and effectiveness of adaptive trigger clauses and dispute-settlement reforms (Tayia, 2019). Integrative modeling that couples hydrological simulations with political-economy metrics can refine geoeconomic and ecological indicators, while participatory action research with riparian communities will help to ground the socio-cultural layer in lived experiences and local knowledge (Daza-Clark, 2022). There is also scope to explore digital innovations—such as blockchain-enabled data-sharing platforms and machine-learning early-warning systems—to enhance transparency and resilience during extreme events. Finally, systematic evaluation of media framing trends over time can inform narrative-based confidence-building strategies, ensuring that water diplomacy remains attuned to evolving public sentiments and stakeholder priorities (Mianabadi et al., 2025).

Acknowledgments

This paper required the collection of a wide variety of resources, which was only possible through the efforts of Faizah Shahnewaz. We thank her for her diligence.

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Received: December 22, 2025

Accepted: January 10, 2026

JWMD Issue: 9 2026 International Journal of Water Management and Diplomacy
e-ISSN:2717-8277

Initiating Strategic Micro-watershed Management to Optimize Poverty Mitigation and Biodiversity Restoration in the Philippines

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ABSTRACT

Participatory strategies for engagement of communities are utilized in the assessment of micro-watersheds within local legal frameworks. The objective is to build community-based capacity for consideration of the linkages between food, water, health, biodiversity, and climate change. A generalized water characterization regimen promotes future local community replication of assessments, requiring limited external support. Modified stream visual assessments were conducted considering 17 variables at 39 stations involving one micro-watershed in each of the eight municipalities in the Province of Aurora, Philippines. Additional information was gathered on local and traditional ecological knowledge using Key Informant Interviews (KII) and focal group discussions (FGD). At each station, additional data was collected on water temperatures, PH, Oxygen saturation and total dissolved solids. Strategic consideration was given to facilitating the development of micro-watershed characterization skills that will be of use for future community-based planning on sustainable agroforestry and the targeted poverty issues of maternal and child nutrition. Results and a review of local laws highlight specific areas of planning and management to optimize local watershed ecosystem services. A focus on watershed, riparian and estuarine restoration is suggested as a strategy to both mitigate and adapt to climate change while also supporting coastal small-scale fisherfolk and their ecosystems.

Keywords: socio-ecological; poverty mitigation; micro-watershed characterization; climate change; food; water; health; biodiversity

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1. Introduction

The United Nations Decade of Ecological Restoration 2020-2030 emphasizes the urgent need for actions that help reverse the global erosion of biodiversity. Carbon sequestration through restoration of plant and animal populations mitigates climate change while shoreline considerations can provide adaptation to increased storm frequency/severity and rising sea levels. Although the Philippines is recognized globally for both marine and terrestrial biodiversity, few legal instruments protect that heritage, enforcement is limited and restoration strategies may require specific and applied educational development regarding life below the water surface. The inclusion of economic, social and ecological factors is crtical for integrated watershed management (Zerga 2025), while participatory approaches can support ecohealth development (Watts & Pajaro 2014). Balancing the demand for watershed ecosystem services with the goals of ecological restoration in the Philippines is challenged by extensive rural and coastal poverty, while supported by the high rate of annual primary productivity. Although the concept of *living fence* or boundary species restoration in the tropics is not new (Zahawi 2005), application to riparian and estuarine Philippine habitats could be significant. In the previous decade, it was suggested the national water crisis is a crisis of governance (Rola et al 2012). The establishment of reflexive approaches remains problematic. At the national level, there is an abundance of overlapping legal frameworks governing aspects of the water sector, which can be divided into two categories: legal instruments that potentially consider biodiversity and those that focus exclusively on the provision of water services for drinking, sanitation, and irrigation. Poverty mitigation, inclusive of biodiversity considerations, can perhaps be addressed through a comprehensive merger of these perspectives initiated at the community level, as suggested by Rosen (2016) regarding climate change. In addition, there is a need to consider the ribbon of life that waterflow provides, from ***ridge to reef*** (Alejos et al., 2021) and the linked significance of healthy estuaries for consideration of coastal fisheries. The current efforts are endorsed by the *United Nations Decade of Ocean Science for Sustainable Development 2030*, through the non-government organization (NGO): Daluhay – Daloy ng Buhay's: **ACTION 15.4 Bioregional Resilience: Professional Coastal-zone Resource Management Planning**. In the Philippines, this OCEAN Decade action is through the CRM-*Siningbayan* program (Coastal-zone Resource Management using Siningbayan social artistry approach) (Ayala et al., 2016), regularly applied across Aurora Province.

Although Philippine development programs and funding regarding water provision are generally focused on urban settings, poverty rates of rural farmers and coastal fisherfolk are two to three times that of cities and developed areas. Many coastal fisherfolk are also small-scale farmers who suffer from a lack of upstream management of watersheds, while also having the highest national rates of mother and child malnutrition (Alejos et al., 2021). Recognizing that the poor are the most vulnerable to limited water access (Rola et al., 2015), programs can best be community-based (Rosen, 2016; Talampas et al., 2025) with the inclusion of local and traditional ecological knowledge (TEK) (Maliao et al., 2023) as part of the institutionalization of participatory approaches in environmental governance (Gera 2016). These strategies can optimally be initiated in upland areas where, in the Philippines, biodiversity is often still present to a larger extent and where small-scale communities are dependent on specific micro-watershed areas for their ecosystem services. This requires the harmonization of environmental mandates, a programmatic strategy previously initiated across the current study area of Aurora Province (Raquino et al., 2023).

There are generally three levels of water management in the Philippines that have inadvertently resulted in a contradiction-laden, overlapping, and fragmented national watershed management approach. National legal instruments include those recognized by the National Water Regulatory Board, such as the Clean Water Act (RA 9275), the National Water Crisis Act (RA 8041), the Indigenous Peoples Rights Act (RA 8371) the National Integrated Protected Area System (RA 7585), and several Presidential Decrees, most notably the Philippine Water Code (PD No. 1067). These laws result in management regimens such as water districts, local government run facilities, homeowner associations, urban Barangay (smallest level of elected officials) associations, and a wide range of private approaches. While large-scale watershed characterizations provide significant tools for higher levels of government management (Boothroyd et al., 2022), these are generally not of use for small more isolated communities. A second level of management is through the Local Government Units (LGUs) that are tasked to provide water services to the communities. As part of decentralization under the Local Government Code (RA 7160), the LGU is mandated to provide a wide range of services and facilities, including Barangay waterworks, fee collection, pumps, cisterns, reservoirs, water quality, canals, aqueducts, pumping stations excavations for water extraction, spring development, flood control, development and maintenance of waterworks, sewars and in partnership with the Department of Health and other agencies, sewage treatment. Although some Philippine settings, particularly those in rice growing areas, may have water control systems through the National Irrigation Administration, rural settings rarely involve the aforementioned LGU programs. The third level of watershed management is in the more rural and isolated communities and involves customary, informal and unregulated extraction and use. Water property rights are complicated from the lack of integration in these three approaches. In their review of Philippine water property rights, Lizada et al., (2019) identified that both rights and responsibilities to water usage need to be clarified and further coordinated. Working within both actual and perceived or informal rights (Hall et al., 2015) may be critical in linking Philippine forest and watershed restoration strategies. Landscape Forest Restoration (LFR) is of great significance in the Asia Pacific Region (Appanah et al., 2016). However, participatory small-scale and socio-ecological approaches may be best suited for agroforestry settings in the rural Philippines. One way to develop a common legal language for planning of shared futures across entire watersheds is through the use of maps as legal documents.

A recent review considering the linkage between Philippine watersheds and forests (Rodriquez et al., 2023) highlighted the need for effectivity in strategies involving land use planning and an integration of policies/actions involving forests, soil conservation, water supply sustainability and research on understudied areas. Arguably, global focus on conservation in general can only provide witness to further biodiversity erosion and there is a critical need for wholistic restoration paradigm applications. This is a perspective also supported through the *United Nations Decade of Ecological Restoration 2030*. One understudied Philippine area for prioritization is the community-based facilitation of watershed management and restoration strategies in concert with rural poverty mitigation. Somewhat critically in the complex Philippine setting, there is a need to establish attainable change goals. The authors suggest this can be accomplished through progressive and iterative Action Research cycles (Watts & Pajaro 2014). Progressive results can perhaps best be attained through annual Action Research cycles that parallel government funding cycles to facilitate long term engagement with jurisdictional mandates and budgets. The current Action Research cycle reports a focus on the engagement of rural communities in watershed characterization that is aimed at preparing residents for both management and potentially, restoration planning. To fully activate provincial aspects of the Local Government Code (RA 7160), the current initiative is duplicated in each of the eight municipalities of the Province of Aurora, thus potentially stimulating the provincial role in training and coordination.

Long term studies in the Yantze River Delta of China (Cai & Shu 2024) have led to the conclusion that system-based approaches are necessary for balancing desired development of urban settings and the restoration of ecosystem services. Considering large ecosystem, Cai & Shu (2024) further conclude that there is a need for the application of scientific mechanisms to identify priority plots that support planning for ecological restoration. In the current work, the focus is on the engagement of pilot communities and specific micro-watersheds of interest to those communities, with the goal of initiating a full LGU process for the development of watershed restoration. Similarly, there have been calls for system-based approaches to Philippine watersheds (Herbohn et al., 2017) where participatory and diplomatic strategies may be more critical to restoration success, particularly involving rural communities and informal water use designs. The identified need for small scale "stepping-stone" approaches to watershed restoration in China (Xu et al., 2024) also fits with the current approach to Philippine small communities and micro-watersheds. Establishing specific and realistic socio-ecological restoration priorities (Glassic et al., 2025) such as those described by Li et al., (2022) may be central to ecosystem service provision (Vandershot & Vandershot 2023), critically requiring participatory engagement in rural Philippines as well as consideration of food security and livelihoods (Gregario et al., 2015).

In many Philippine settings, the short distance between mountain ridges and the coast suggest watershed restoration goals might best be directly linked to forest and agricultural activities as well as urban ecology and small-scale coastal fisheries (Alejos et al., 2021). In the Philippine Province of Aurora Province, the many rural Barangays (smallest LGU unit of elected officials) have a coastal area as well upland agricultural and forest habitats (Figure 1). Community residents often have livelihood strategies that involve all of the aforementioned habitats, while all Filipinos are significantly dependent upon marine small-scale fisheries for protein. The current work builds upon the concept of ridge-to-reef socio-ecological connectivity (Alejos et al., 2021) and the cultural focus of Philippine coastal communities on the development of collaborative environmental management and education strategies (Watts et al., 2022). Sustainable development in these settings require a ridge to reef consideration of biodiversity, livelihoods, human health (water and food security) as well climate change mitigation and adaptation.

Effectively, the current work is applying the IPBES paradigm (Wiegleb & Burns 2023) at the local level. A global review of the linkage between watersheds and coastal fisheries can best be addressed through an integrated approach (Broadley et al., 2022) as freshwater conditions significantly effect marine fisheries (Gillson, 2011; Hansen et al., 2023). Marine fisheries in the Philippines are in decline as a result of coastal degradation (Altamirano et al., 2014); requiring consumer engagement for fisheries recovery (Anticamara & Go, 2016). Forest considerations need to prioritize aspects of riverscape and riparian habitats (Boongaling et al., 2018; Glassic et al., 2025) to focus on streamflow quality (Herbohn et al., 2017;) linked to effective social-forestry programs that have been demonstrated to enhance watershed ecosystems services (Orias & Bande, 2018). The Philippine Water Code (PD 1067) does have a riparian habitat related provision for protecting all shorelines from private building establishment and habitat destruction; 3m in urban setting, 20m in agricultural settings and 40m in forested areas.

Enhancing the socio-ecological productivity of these areas could perhaps best be considered through collaborative government/society efforts to restore aquatic, riparian and living fence species (Zahawi 2005). This approach could also be expanded to consider the connectivity of estuaries, both upstream and in terms of coastal ecology and fisheries. The current work focuses on an initial micro-watershed focus where eight communities (Figure 1) are currently being facilitated to consider watershed management, restoration and collaboration to encompass larger socio-ecological scales to optimize, Barangay, municipal and provincial ecosystem services.

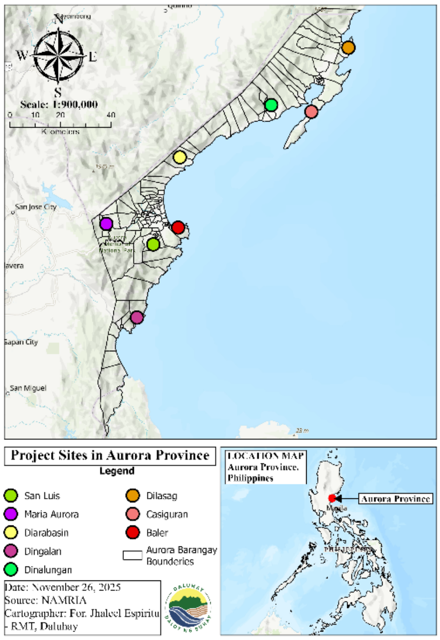

Figure 1. Municipal locations of micro watershed assessments in the Philippine Province of Aurora with Barangay boundary delineations

2. Methods

The current work prioritized participatory engagement at the community level where local residents were trained as citizen scientists and became connected to their specific micro-watershed regarding biodiversity, water provision, health and food access. These skills will be part of an educational approach to Philippine technical and vocational education and training on coastal resource management through the Technical Education and Skills Development Authority (TESDA), (Pajaro et al., 2022). Related certification of residents supports the local economy as they are then eligible for hire to conduct monitoring, which is important for integrated watershed management (Zerga 2025). One community was selected from each of the eight municipalities of Aurora Province based upon local interest in their sub-watershed and a willingness to contribute their time to a larger project aimed at linking watershed management with sustainable farming approaches and the development of reflexive actions to mitigate maternal and child malnutrition. The work has been supported in part through funding from the Canadian New Frontiers in Research Fund and the United Nations Development Program – Small Grants Program 7.

The eight communities selected for the program involve 200-400 individuals in each location. Participatory strategies in part focused upon mainstreaming the involvement of both the women and youth sectors. Community leaders assisted in the identification of the micro-watershed area through training provided on GPS data logging. This information was then converted to formal maps using Arc GIS (Figure 1, 2). The area of the individual micro watersheds is between 15-275 Hectares. In each of these rural locations, watershed ecosystems services have previously been determined by more customary, informal and unregulated extraction and use, rather than through more programmatic approaches. The first step in the program was to conduct an initial Action Research cycle that would engage representatives of the community regarding their ecological knowledge and in characterizing the ecology of their micro watershed to provide a foundation for further community-based planning and management.

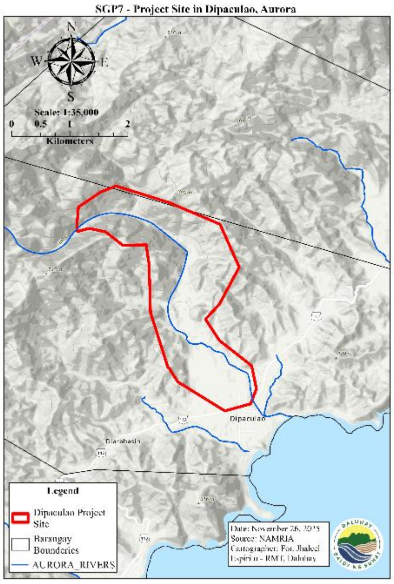

Figure 2. Micro watershed delineation for assessment in the Barangay of Diarabasin, Municipality of Dipaculao in Aurora Province, Philippines

Indigenous Ancestral Domains cover 75% of the province of Aurora and although water rights are considered under the Indigenous Peoples Rights Act (RA 8371), biodiversity, spatial considerations and integrated sharing across complete watersheds are not considered. In addition, there are several protected landscapes and watersheds in the province where water use is somewhat regulated by permits, while aspects of the Clean Water Act and other national laws are not considered on a regular basis. As part of the current work, the existence of LGU regulatory articles for water were explored for the province. The Province of Aurora has a generalized Environmental Code with limited focus on specific regulations for water usage. One initial challenge is that few of the municipalities have digitized records and cannot easily access documents on water or other specific topics. In addition, there are two levels of local legal documents, ordinances and resolutions. Ordinances are directly linked to government fund allotment and have the potential of being connected to enforceable approaches, for example, there is an ordinance for the protection of a local water conservation area in the Municipality of Maria Aurora, while resolutions are more of a statement about the philosophy of governance. Some municipalities only have resolutions regarding water, while for others, interested researchers may have to go through the files to determine if there are any legal documents associated with water use and watershed management. Effectively, the current work initiates a new standard of legal documentation through the development of formal maps as per national and international standards (Figure 2).

Characterization of the watershed (and subsequent management planning) was based upon a review of historic conditions in the micro watersheds using key informant interviews (KII) and focus group discussions (FGD). Water chemistry quality was measured through determinations of PH, total dissolved solids and Oxygen saturation. Although several national laws consider biodiversity, these are usually focused on preventing logging. No laws or regulatory bodies currently focus on stream biodiversity, which continues to be in decline nationally. Further characterization of the micro watersheds did not involve detailed taxonomic reports, such as those in Tingson et al. (2022). Instead, watershed characterization focused on fully transferable data collection skills at the community level that can be more easily duplicated through local initiative. Current efforts employed an approach developed through Philippine-Canada collaboration and the use of a Modified Visual Stream Visual Assessment Protocol Field Guide (Magbanua et al., 2013) based upon the foundational Philippine biodiversity assessment led by Dr. Perry Ong (Ong et al., 2002). Local residents were trained and facilitated to assess 17 parameters at 4-6 stations selected within each micro watershed. These parameters include, for example, assessments of the watershed canopy, riparian habitat, flow rate of water, water pool characteristics, sediment characteristics underneath the water flow, *etc* (Table 1). Each survey began by hiking to the highest elevation of the micro watershed while accessing areas of commonality, each as an individual stream 'reach'. The site for each station location was based upon a central location within a stream reach where the length of the assessment reach was six times or more the active channel width and representative of the stream over that length of flow. The seventeen characteristics (Table 1) determined at each of the stations were evaluated based upon the field guide scale of 1-5 (poor), 6-10 (marginal), 11-15 (sub-optimal), and 16-20 (optimal). The categories of both the optimal and poor ratings were reduced to a single number to fit with the limited experience of the local citizen scientists. Results where then summarized for ecological quality as High (11+), Medium (6-10) or Low (<5); with medium and low rankings as an initial focus on possible aspects for stream restoration. Across the eight study sites, a total of 39 stations were sampled, each for 17 visual characteristics.

3. Results and Conclusions

Focus group discussions and KIIs indicated a historic decline in stream biodiversity across the 8 study sites. In all cases, the use of the micro watersheds as a food source has been reduced by illegal harvest of freshwater shrimp and, in some cases, fish, through the use of chemical poisoning and electro-fishing, which tend to kill a wide range of stream biodiversity. These activities are often carried out by individuals travelling to the area from other communities. The results of the PH, temperature and total dissolved solids were all within optimal range for stream biodiversity, except in a low-lying area of the most urban setting of the eight. That setting will require a specialized approach to restoration requiring a different complexity of social and governance approaches regarding sewage. Sewage treatment in the Philippines is non-existent in the majority of community settings. Parallel government/NGO/society efforts to develop local solutions to sewage in more urban settings of Aurora are under discussion and will be reported separately. The current work is focused on the 17 visual characteristics in preparation for the next Action Research cycle where participatory community-based watershed management plans and any restoration strategies will be developed. The collective results indicate that the lowest quality of stream biodiversity aspects concerns canopy cover, where 28 of the 39 or 75% of the stations had either medium or low levels of forest canopy cover (Table 1). Streams are historically used for transportation associated with both illegal and legal logging and tend to be the first place where forest harvest occurs.

Table 1. Modified Visual Stream Assessment Variables (Magbanua et al., 2013) involving 39 stations in eight micro watersheds of Aurora Province.

	ASPECT OF STREAM QUALITY ASSESSMENT*	MEDIUM OR LOW	LOW
I	Channel flow	19	
II	Channel alteration	7	3
III	Velocity/depth regimen	13	4
IV	Pool variability	17	4
V	Bank stability	9	
VI	Bank vegetative protection	5	
VII	Riparian vegetative zone width	12	
VIII	Canopy cover	28	
IX	Water appearance	22	
X	Nutrient enrichment	14	
XI	Sediment deposition	16	
XII	Riffle embeddedness	14	
XIII	Pool substrate characterization	19	
XIV	Barriers to aquatic species movement	10	4
XV	Fish habitat complexity	20	
XVI	Aquatic macroinvertebrate habitat	17	
XVII	Aquatic macroinvertebrate community	18	2

e-ISSN:2717-8277

*Results summarize the assessments in 39 water stations

The initial results are of assistance in outlining a possible facilitation focus on small-scale riparian forest restoration across the selected micro-watersheds of the province. Half of the stations had medium or low-quality habitats for fish and macro invertebrates. Channel alteration, the velocity/depth regimen, pool variability, barriers to aquatic species movement and macro invertebrate communities were recorded as being of low quality in 5-10% of the stations. Slowing down the flow in many places through the diversification of pools could help to optimize the substrate conditions for biodiversity that can help support both local food and water security. For the purposes of the participatory management plan development, visual characteristics for each of the community-based participatory processes will be used separately. Considering the example of Barangay Diarabasin, in the Municipality of Dipaculao (Figure 2) the results indicate a high level of stream quality (Figure 3) with the majority of assessments high quality (15+) with only 10% of lower quality. The slope of this micro-watershed is approximately 10% with sections at higher elevations where the slope is two-three times that average. The extension of restoration approaches from this reported micro watershed to the estuarine coastal area (Figure 2) would involve collaboration with another community and could be a further development, specifically focused upon support for small-scale coastal fisherfolk and their ecological settings.

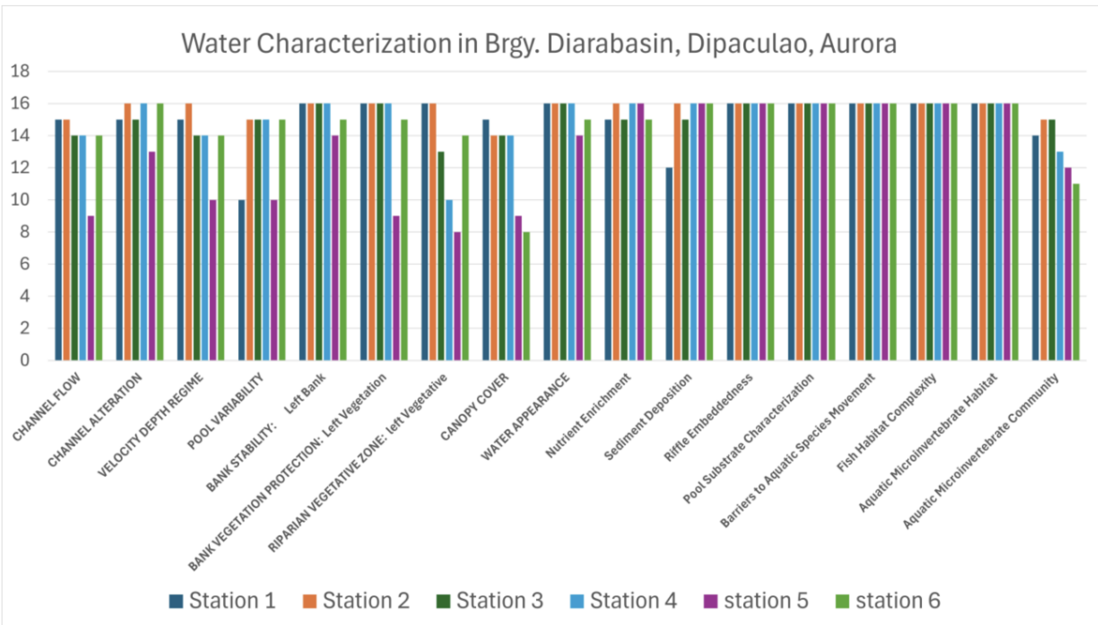

Figure 3. Modified Visual Stream Assessment (Magbanua et al., 2013) for a micro watershed in Diarabasin, Dipaculao, Aurora, Philippines

The use of a citizen science approach has a bias towards local perceptions and as a result may not be consistent with similar assessments in other locations. However, the results do provide a basis for the development of participatory micro-watershed planning and management and will be reported back to the community both by station and through consideration of results across the 8 individual micro watersheds. Further consideration for the development of more detailed citizen science skills concerning the assessment of canopy cover may involve the use of light meters. In some micro watersheds, slowing down the flow could be done within a reasonable cost as a response to low levels of quality in channel flow, pool variability and depth (Table 1).

Critically, if there is to be restoration of the harvestable vertebrates and invertebrates, there will need to be some form of culturally-based enforcement system put into place to limit illegal activities such as timber poaching and the use of poisons to capture fish, as well as electro-fishing. Considering, one project micro watershed in the Municipality of Dipaculao (Figure 2) legal water documents are only in the form of resolutions, thus generally not useful in terms of enforcement. However, the local cultural approach to enforcement for the management plan development has been considered through a separate community-based training initiative as a precursor to the participatory watershed management planning for that Indigenous community. One of the significant outputs of the current project is to provide rural community residents with an overriding legal consideration of the micro-watershed through the use of formal maps as legal documents (Figure 1,2). These illustrative tools can help communities in addressing how the watershed security of the community can be integrated with national laws, local ordinances and resolutions as well as the interests of neighbouring communities. The lack of clarification of rights and responsibilities for water parameters (Lizada et al., 2019) reduces management and restoration to a complex diplomatic dialogue between national agencies, local government and communities sharing watershed resources. Local watershed management regimens based upon formal maps/training provide a foundation for economic, social and ecological integrated watershed management (Zerga 2025) through monitoring and the identification of emerging challenges. The systematic consideration of micro-watershed characterization can be used to maintain water security, mitigating poverty increase; while targeted restoration can reduce poverty through enhanced food and water security, as well as future employment for local residents monitoring.

The utilization of maps as legal documents will facilitate collaboration between micro-watersheds on management and restoration and can potentially lead to increased and ecosystem service synergies. When adjacent communities within a complete watershed collaborate, estuarine connectivity can be targeted as critical habitat for coastal fisheries ecology, supporting the national dependence upon marine-based protein provision. Optimizing the size of scalar management and restoration strategies would also represent an increased contribution to climate change mitigation which is also a spatial consideration. Customary land use boundaries are often defined by waterways, with agriculture extending to the stream. One agroforestry aspect for possible prioritization is the restoration of riparian habitats to provide better canopy, and consideration of extended buffer zones. The overlapping of agricultural activities and riparian habitat protection can best be considered through further local diplomacy and the establishment of common goals for a shared future. Considering the significance of a pluralistic bioregional approach for climate mitigation (Pajaro et al., 2024) the use of both social artistry and participatory approaches for an adaptive management process may have application in other cultural settings.

Micro-watershed restoration, scaled up to consider estuarine and ridge-to-reef connectivity, could also be significant for production in coastal fisheries. This approach could be further supported by an amendment to the Philippine Water Code (PD 1067) to indicate that, it is the responsibility of the national and local governments in partnership with the land owners to work together, towards watershed ecological restoration including aquatic species, optimal shoreline (riparian) vegetation in support of biodiversity and ecological conservation of these areas previously protected from building and habitat destruction; 3m in urban areas, 20m in agricultural settings and 40m in forested areas. Recognizing that the decline in Philippine small-scale marine fisheries is a result of coastal degradation (Altamirano et al., 2014), estuarine and boundary or living fence species restoration could form a consequential Philippine program contributing to enhanced biodiversity and coastal fisheries (Hansen et al., 2023) as well as climate change adaptation and mitigation. The map-facilitated development of biodiversity-friendly intracommunity relationships could also lead to improved livelihoods. Results from the current municipality-based actions will be used to build collaborative educational program approaches (Pajaro et al., 2022) for the training and coordination role of the province under the Philippine Local Government Code (RA 7160). *Acknowledgements:* The authors greatly appreciate the support provided by local government officials, the efforts of residents in their role as citizen scientists and the initial development of Daluhay's Aurora Province water-health considerations by S.F. Alejos.

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Received: December 18, 2025

Accepted: January 10, 2026

JWMD
Issue: 9 2026
e-ISSN:2717-8277
International Journal of Water Management and Diplomacy

HPA