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Research article

The GERD dam in the water dispute between Ethiopia, Sudan and Egypt. A scenario analysis in an ecosystem approach between physical and geopolitical geography

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Abstract: This paper examines the transboundary water resources conflict resolution mechanisms. Although different research perspectives, including social planner, water market, game theory, static and dynamic systems engineering model, have already provided conflict resolution mechanisms that could be used to analyze transboundary water conflicts, here an ecosystemic approach based on an analytical model, is proposed. For this aim the case of GERD "Grand Ethiopian Renaissance Dam" on Nile Azzurro, is analyzed. The scenario of the GERD dam, besides being current and interesting in the water dispute between Egypt, Sudan and Ethiopia, is suitable for the application of the proposed analytical model. This model could permit researchers and practitioners to develop more comprehensive mechanisms, complementary to political strategies, with stronger analytical capacity to analyze the different elements of the process of transboundary water dispute resolution.

Keywords: Ethiopia; Egypt; Sudan; GERD; geopolitics; ecosystem; dynamics

1. Introduction

A topic of geographical interest that is always topical, even if in different forms and declinations, is that relating to competition for resources. As will be seen in the following paragraphs, the scientific debate in this sense now presents robust analytical tools that well model conflictual scenarios, configuring them, among other things, in ecosystem dynamics. Particularly, intraspecific competition is a concept of ecosystem dynamics which means competition between individuals of the same species. The resources subject to such competition can be space, water, food, light, or many other factors. The existing models of intraspecific competition show the characteristic of having an optimal threshold value of the shared resource, which allows to reach a balance of the system made up of parts in contention on the resource.

We found this feature very suitable for describing situations in which a negotiated balance is sought in disputes over shared water resources, and therefore we have transposed it to this field.

A real case of particular attention, not only for adherence to such conflict scenarios deriving from access to shared resources, but also and above all for the overlap of the plan relating to physical geography with that of political geography, concerns an African question—which involves at least three states, Ethiopia and Egypt in the main and Sudan in the second order—relating to the water resource of the Nile River. The dispute intensified in recent months, concerns the construction of a dam for energy purposes by Ethiopia.

Water is no longer limited to being a key factor for food security, health concerns and environmental challenges, rather it now plays a significant role in different vital sectors, such as economic and social impact, national security and also has lately obtained distinctive political weight as a source of energy-power.

There are currently several disputes over water, such as violent clashes between local farmers and shepherds in the Sahel region and in the Horn of Africa, or disputes between rural and urban areas over the supply and distribution of water in Brazil, Iraq or Iran. Population growth and improving living standards increase the demand for water and, consequently, the potential for conflict over water-stressed transboundary rivers basins, especially in arid countries that receive the majority of their water from abroad (e.g., Egypt, Syria, Uzbekistan, and Turkmenistan) [1].

Dams in transboundary river basins can be a source of conflict as dams that control river flows in upstream countries can affect water availability in downstream countries. There are 310 transboundary river basins in the world shared by 150 countries and cover approximately 47% of the earth's land surface [2].

The literature regarding transboundary water resources conflicts has proposed different perspectives to approach water resources conflicts. Engineering studies have focused on finding the optimal water allocation among parties sharing water resources [3]. Economic studies have attempted to identify the different economic options for allocating water optimally among conflictive countries [4]. Some of these studies have resorted to conventional economic approaches, such as "social planner" and "water market", to identify optimal water allocation [5]. A more comprehensive economic approach has been provided by game theory in the past two decades [6]. These game theoretic studies have linked the process of transboundary water conflict resolution to its outcome. Political studies have addressed the political constraints that determine the dynamics and the outcome of transboundary water conflicts [7]. Finally, management studies have focused on the facilitation of the process of water conflict resolution. Alternative Dispute Resolution (ADR) is one major approach that has been promoted by negotiations research.

Several conceptualisations of conflict resolution process have been presented in the literature. Some scholars prefer giving a broad meaning to conflict resolution process to include two stages: conflict settlement and conflict transformation. Conflict settlement refers to the achievement of a consensus among parties to settle their political conflict over the issue of conflict [8]. Conflict transformation implies a deep transformation in the deep-rooted sources of conflict to establish a more stable structure of relationships among the conflict parties [9].

With reference to these two stages, the present research is interested in enriching the scientific literature relating to the various analytical models already adopted, proposing a further conceptual model based on ecosystem competition for exploitation that can be used by policy makers and professionals who find in the case of the GERD dam a suitable example of application. As, in fact, already highlighted by Himes [10] a conflict may erupt as a result of competition over various types of scarce resources, such as status, power, position, and natural resources.

The GERD dam currently constitutes an excellent functional case for the application of the proposed model, as there is a direct cause-effect link related to the social stability of Egypt, because its water supply depends almost entirely on the waters of the Nile River.

The Nile River is one of the most important rivers around the world. Eleven nations depend on the Nile water, Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. The conventional water resources in Egypt are limited to the Nile River, ground water in the Delta, Western Desert and Sinai, rainfall and flash floods. More than 96% of Egypt fresh water resources are supplied by the Nile River. Egypt share from the Nile River fresh water is limited by an agreement signed 1959 between Sudan and Egypt. This agreement entitled Egypt and Sudan to 55.5 Billion Cubic Meters (BCM) and 18.5 BCM of Nile River water per year, respectively. Most of the main Nile water comes from the Ethiopian plateau through the Blue Nile and Atbara during the period of flood starting from August to December. Ethiopia's tributaries supply about 86% of the Nile water [11].

In exceptional cases like the GERD where dam design and construction anticipates an agreement on initial reservoir filling and long-term operation, the hydraulic capacity of a dam's outlets, i.e., how much water it can release, could limit the range of potential management options that may be considered in subsequent multi-national negotiations. This condition, therefore, represents very well an intraspecific competition in which the variation over time of the water resource of the Nile is proportionally dependent on the resource itself through an increase rate, which in turn depends on the water resource of the Nile.

In this sense, the proposed eco-system model can model the negotiation phase between the parties in analytical terms, also providing the political stakeholders of the opposite parties with a tool capable of catalyzing the real negotiation through the advantages highlighted by the analytical negotiation. The projection of a possible convergence towards optimal objectives, even multidimensional bound ones, made aware of both sides of the dispute, can in fact facilitate and catalyze the conciliation process. As already demonstrated by Nandalal [12], use of system approach provides a strong analysis platform that can map the interrelationships between the physical systems and social ones. This based system approach has provided, in fact, a powerful tool for analysing water management and conflicts within the national boundaries [13], however, it has lacked a clear conceptualisation of the analytical evolution scenario between parties that are involved in the water dispute.

Several previous studies assessed the impacts of the GERD on Ethiopia, Sudan, and Egypt as a result of changes to water availability for irrigation and hydropower generation [14–29]. However, no study in the published literature analyzed the opportunity to use an ecosystem model to forecast the optimum technical vale of the water resource to catalyze the negotiation phase.

Therefore, the aim of this research rather than providing elements of geopolitical critical analysis, wants to focus on the possibility of using analytical methods for the management of shared resource scenarios between two Parts. For this reason, the research perspective is mainly focused on the role of Ethiopia and Egypt, neglecting Sudan which, although it has great geopolitical importance in the scenario analyzed, is less functional to the application of the model between the two Parts Egypt and Ethiopia. Indeed, the GERD is expected to change the riverine flood hazard in six of Sudan's 18 states. Around 22–80% of the total flood-affected people in Sudan (from both flash and riverine floods) during the period 2012–2020 were located in these six states.

Egypt and Sudan reacted immediately after the Ethiopian announcement was made, protesting and denouncing the Ethiopian decision and declaring their strong opposition to the GERD. Both countries contended that the GERD would decrease considerably the amount of the Nile waters reaching Sudan and flowing thereafter to Egypt. Sudan was also concerned about the safety of the GERD and the extensive harm that Sudan could suffer if the GERD were to crack, fail, or collapse. However, the Sudanese position began to witness some gradual, but steady, changes, and many water experts and politicians started arguing that Sudan will actually benefit from the GERD, with reference to the regulation of the flow of the waters of the river and to the possibility to put an end to the recurrent flooding, and the destruction to property and crops, caused by the seasonal flow of the Blue Nile. Despite the Sudanese position favoring the dam, or perhaps because of that, the Egyptian opposition of the GERD continued to mount.

Therefore, this dynamic allows to consider the water dispute between only the two parts of Egypt and Ethiopia, which is functional for the purposes of applying the proposed ecosystem model.

The river resource represents a necessary condition for survival, economic development and the availability of energy that the physical geography of the place has offered to the various countries bordering the Nile.

To introduce the scenario under analysis, and above all to highlight the urgent need for water as a source of electricity production in Ethiopia, it is necessary to report the framework of African energy phenomena.

The African continent has many contradictions, typical of countries affected by rapidly developing phenomena, as it is increasingly characterized by high economic growth rates, entrepreneurship and a significant demographic increase. The African population is, in fact, among the youngest and fastest growing in the world. According to the estimates of the recent World Energy Outlook report [30], one in two people, among those who will add to the world population by 2040, will become African and the Continent will become the most populous region in the world by 2023, surpassing China and India. A much higher growth than that observed in the urban population in the two decades of China's economic and energy boom.

It seems clear that such dynamism, which is also accompanied by another positive dynamism that can be seen on the Continent such as the entrepreneurial one, can only have repercussions on the energy level in terms of internal demand, export possibilities and above all in terms of actions for sustainability. A route traced in this sense is that of the African Agenda 2063 which dictates a series of goals for the sustainability of the Continent. The way in which Africa meets its growing energy needs is therefore crucial both for the continent's economic and energy future and for global trends.

Antithetical to this scenario of demographic and entrepreneurial dynamism, remains the evidence relating to the persistent lack of access to energy resources still for a very large part of African individuals. Currently about 600 million people do not have access to electricity and the investment plans planned for this are not yet sufficient to fully meet the energy needs of the African population.

In 2030, according to the estimate of the same report, World Energy Outlook 2019, about 530 million people will still not be able to enjoy access to electricity. For example, Figure 1 through only available data, shows the real (from 2000 to 2020) relating to some states, including Ethiopia on which this research is focused. Precisely for this country, Figure 1 clearly shows the strategic value of the necessary actions to upgrade the electricity capacity, which therefore assumes the emblematic value of a real plan for rebirth and a new national identity.

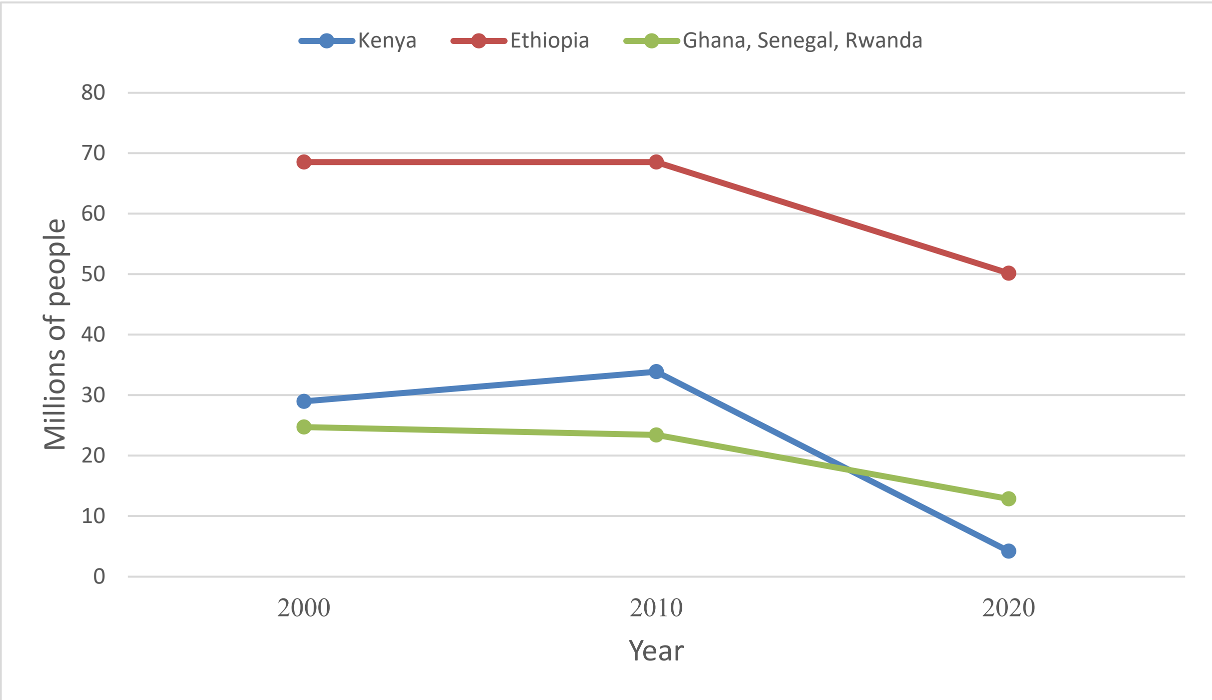

Figure 1. Lack of access to the electricity grid (in millions of people), Ethiopia 2000–2020. Source: authors' elaboration on International Energy Agency data, 2019.

Therefore, with the demand for energy growing at double the world average, Africa has the opportunity to be the first continent to develop its economy using renewable sources.

Hydropower remains the leading renewable resource in Africa with over 37 GW of installed capacity. In states such as the Democratic Republic of Congo, Ethiopia (Figure 2), Lesotho, Malawi, Mozambique and Zambia, the share of hydroelectricity exceeds 75% of production. Ethiopia, particularly, is among the countries with the highest generation capacity based on the exploitation of water resources and has outlined an energy increase roadmap by 2025 of installed power equal to 25 GW, of which 22 GW produced by its own from hydroelectric plants. At the beginning of 2020, the "Ethiopian Electric Power"[1] announced the commissioning of the "Genale Dawa III" project with a total installed capacity of 254.1 MW.

The Nile River in Ethiopia has over 15,000 MW of undeveloped hydropower potential. Exploitation of this potential could improve access to electricity in Ethiopia and other East African

[1] Ethiopian Electric Power is an Ethiopian electrical company configured as a state-owned electricity producer. It is an organization engaged since 1956 in the development, investments, construction, operation and management of power plants, in the production of energy and in the transmission of power.

countries that are connected to the Ethiopian power grid, e.g., Sudan, Kenya, and Djibouti. Currently, only around 45%, 60%, 75%, and 60% of the Ethiopian, Sudanese, Kenyan, and Djiboutian populations, respectively, have access to electricity [31].

In this scenario of energy development, which sees hydroelectricity as the prevailing strategic choice for sustainability, frictions are being generated between some states crossed by the River Nile in relation to the shared management of its waters.

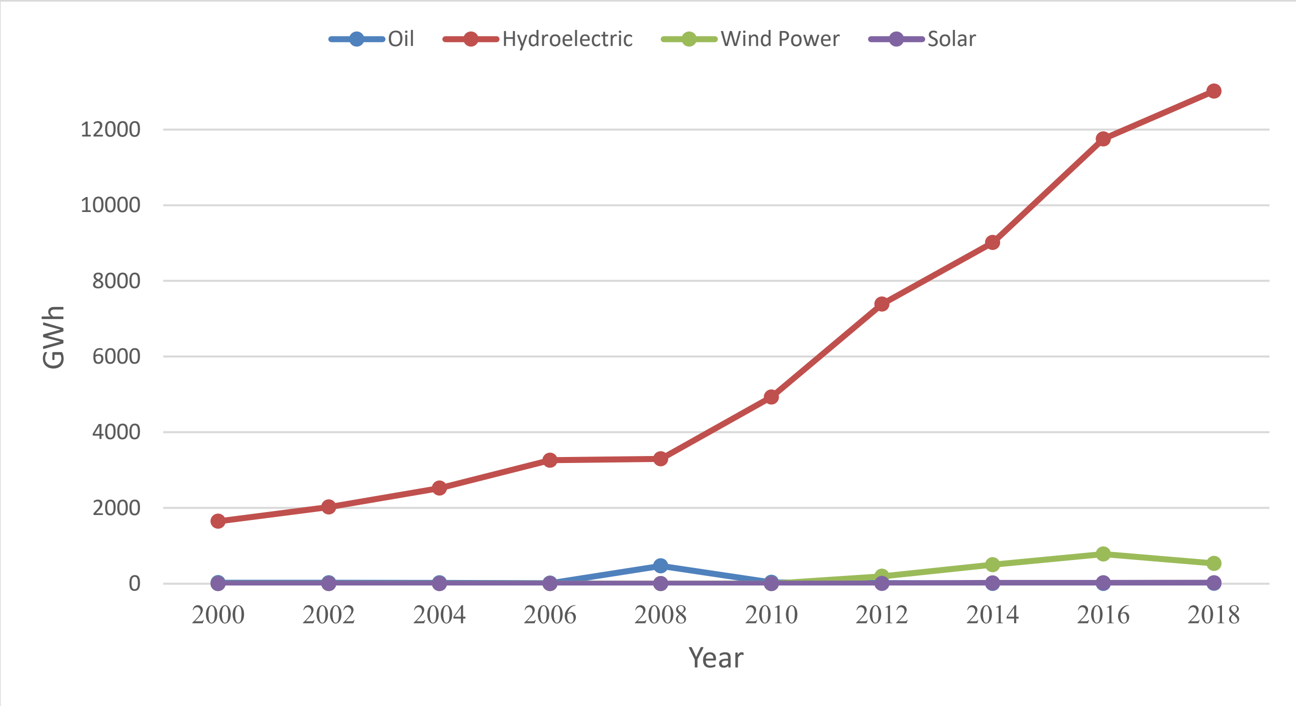

Figure 2. Electricity generation stratified by source, Ethiopia 2000–2018. Source: authors' elaboration on International Energy Agency data, 2019.

In order to have the water necessary for the operation of hydroelectric plants, a dam called GERD—Grand Ethiopian Renaissance Dam is under construction on the branch of the Nile called Blue Nile or Blue Nile in Ethiopia. The Blue Nile originates from the Ethiopian Plateau, near Lake Tana and crosses Ethiopia southwards and then turns north-west through Sudan, where it takes the name of Bahr al Azraq, to finally reach Karthoum joining the White Nile to form the Nile (Figure 3).

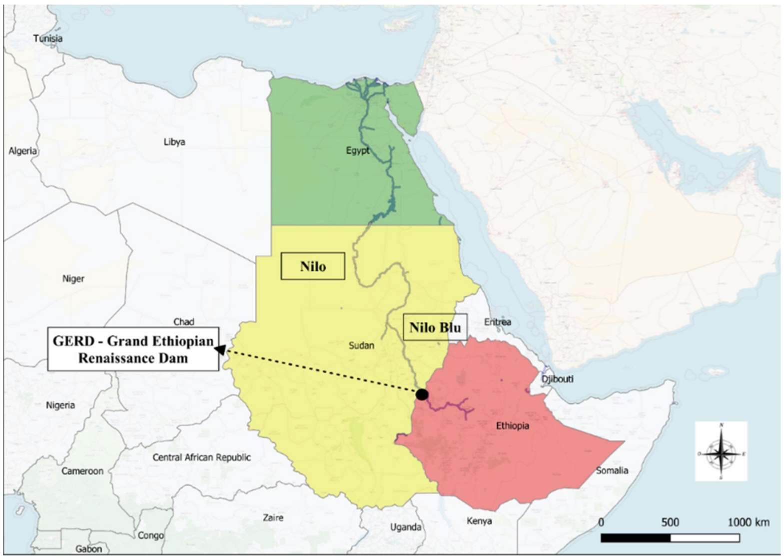

Figure 3. Grand Ethiopian Renaissance Dam. 2018. Source: authors' elaboration.

The construction of this dam, which at the end of the works planned for 2022 will be the largest in Africa, was started in 2011 by the Italian company "Salini Impregilo" and will have a capacity to generate 6600 megawatts of energy, plus double what it does today.

In this scenario, in which positive advantages and corollaries for Ethiopia are outlined, on diametrically opposed positions attributable to claims of a damaged country, Egypt takes place, which draws 90 per cent of its water supply from the Nile, which is already less than needs [32,33].

The bugbear of the reduction in the flow of the river due to a reduced inflow from the Blue Nile, in fact, is arousing active protest actions from the Egyptian to the Ethiopian government. Similar concerns can be seen in Sudan, which over the years and also due to internal political changes has first supported the reasons of Addis Ababa and then moved on to a convergent vision with that of Cairo.

In light of the current described framework, this contribution intends to provide a geographical perspective of the dynamics in progress, highlighting the peculiarity of the case that sees the plans relating to physical geography overlap with those relating to political geography. The eco-systemic proposed approach, which aims to provide an analytical structuring of the case, is based on ecosystem modeling, in which the limiting and development factors that have the greatest impact on the possible evolution of the conflict triggered by competition for water resources are evaluated.

Therefore, after this introduction, the geopolitical context between the countries crossed by the Nile is described, then some detailed elements of the GERD project are provided and finally an ecosystem model of dispute for competition on the shared resource of Nile water is developed. The conclusions close the work by summarizing the terms and results of the described scenario, and also providing a reflective point on the nationalist element that is characterizing the conflictual dynamic.

2. The context geopolitics scenario

The dispute over the sharing of the shared water resource relating to the River Nile has a long-lived history. A first agreement in colonial times dated 1902 between Great Britain and independent Ethiopia under Emperor Menilik II, even if in fact an English protectorate, established very favorable conditions for Egypt as Ethiopia was absolutely forbidden to build any work near the Blue Nile that could have hindered the flow of water [34,35].

These same conditions, not without disputes from Ethiopia which complained of an improper legacy of the past, were re-established in a second treaty in 1929 which effectively restored Egyptian historical rights regarding the decision-making power over the works along the Blue Nile.

Subsequently in 1959 a treaty was stipulated between Egypt and Sudan which excluded Ethiopia, which therefore did not consider it binding. With that agreement of 84 billion cubic meters (MC) of Nile water per year, 55.5 billion were allocated to Egypt, and 18.5 to Sudan, while the remaining 10 MC were left for evaporation from the River. Last, the 1993 post-colonial treaty for general cooperation between the Arab Republic of Egypt and Ethiopia. Article 5 of that agreement stated "each Party will refrain from engaging in any activity relating to the waters of the Nile that could cause appreciable damage to the interests of the other Party" [36].

Cairo continues to support the validity of the latter agreement, arguing that the African countries of the Nile basin (which in addition to Egypt, Sudan and Ethiopia also includes Burundi, the Democratic Republic of Congo, Kenya, Rwanda, South Sudan, Tanzania and Uganda, and Eritrea as an observer) benefit from much more abundant rainfall. This Egyptian position is heavily criticized by other African countries which indeed complain of a harmful irregular flow of the river deriving from the very marked variability of the rains due to global warming.

Beyond the biased positions, the data show the real presence of the growing threat to Egypt of drying up or a drastic decrease in the waters of the Nile [37]. An even more worrying threat when compared to the country's demographic trend: the Egyptian population was 23 million in 1955, which has grown to over 99 million currently and with a forecast of over 150 million by 2050 [38].

When we talk about the Nile river for Egypt we are not talking about something voluptuous but about "life or non-life" [39], as its waters ensure the life of 98% of its population and at least 90 % of the population displaced at a distance of 12 miles from the river [40].

In Egypt, as in few other Parties, there is a continuity with the past and with the habits of life of ancient Egypt, especially as regards life in modern cities and villages along the banks of the river and in its delta, from Cairo up to the Mediterranean [41].

The fear of the drying up of the Nile has its roots in a very distant past that dates back to the early years of the first millennium, when 1066–1072, in fact, Egypt had sent gifts to the king of Ethiopia to restore the river's course after seven years of famine.

The current scenario re-proposes Egypt and Ethiopia opposed in the dispute over the waters of the Nile in a hydro-geopolitical dispute.

The president of Egypt el-Sisi described the issue of the availability of water from the Nile as "a matter of life and death for the country which imposes the obligation to prohibit, even with military force, any action aimed at stealing water. of the river" [42]. Foreign Minister Sameh Shoukry, who warned that Egypt will not give up its water demands, and Badr Abdelatty, the spokesman for the Foreign Ministry, who has described the Nile as "a national security issue on which there can never be compromise" [43].

The media response from Ethiopia was not long in coming and passed through the statements of the Ethiopian military leaders made in an interview during a visit to the GERD shipyard in which they issued a statement, promising to "take revenge on any attacks on the dam" [44,45].

This scenario, therefore, seems to confirm a prediction made in 1995 by the then Vice President of the World Bank, Ismail Seralgedin, who declared that "if the wars of this century had been fought for oil, the wars of the next century would have been fought for the 'water" [46].

Comparing the military power of Egypt and Ethiopia, according to the military ranking compiled by the Global Firepower index[2] there would be a greater strength attributable to Egypt which is ranked 9th in the world, immediately after the United Kingdom, compared to Ethiopia's 60th place [47]. Egypt appears, in fact, to possess the most powerful army in Africa. Additionally, the geopolitical framework appears to be much more extensive, as Egypt certainly can count on the support of several Gulf States, including mainly Saudi Arabia and the United Arab Emirates (UAE) which have made significant financial investments in Ethiopia [48]. On the other hand, Russia could be deployed in support of Ethiopia, but it is not certain. The relationship that binds the two countries dates back to the years of the Cold War, however it is necessary to consider[3], and on the other hand, considering the military power of the force allied with Cairo, official and explicit support with the Addis Ababa government may not be very convenient.

The military route does not, therefore, appear to be the most favorable to Ethiopia which must necessarily navigate the diplomatic route trying to reassure Egypt in every way about the absence of dangers deriving from the construction of the dam in terms of supply of stolen water to the Nile.

Indeed, over the years, Ethiopia made several diplomatic efforts to alleviate the fear of Egypt and Sudan regarding the completion of the GERD dam. Following the agreement on the Declaration of Principles (DoP) relating to the dam—signed on 23 March 2015 in Khartoum by the three countries contending the common river resource Egypt, Ethiopia and Sudan—trilateral negotiations continued, albeit with little progress. In fact, in October 2019 Egypt deemed the trilateral self-regulation strategy ineffective and requested an international mediator, such as the World Bank or the United States, to oversee the next steps of the negotiation [49].

The current scenario shows an escalation between the three countries involved in dispute for water. Particularly in July 2020 the tension between Cairo, Khartoum and Addis Ababa skyrocketed following the announcement launched by Ethiopia in which explicit reference was made to the desire to proceed with filling the GERD dam basin at least until at a height of 145 meters in order to be able to produce the megawatts necessary to optimize the country's economic development.

In that frame, the Egyptian raising of shields was also followed by the Sudanese Minister of Irrigation, Yasser Abbas, who made it known that he had written to the UN Security Council, stressing the need for a preliminary negotiation agreement to fill the basin.

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[2] Global Firepower is a site that reports and updates with a certain frequency a sort of world ranking based on the military power of each country. Of course, this is not a list with an official or absolutely reliable guise. Much more simply, it is a useful database that draws on public and heterogeneous sources such as the "CIA World Factbook" or "Wikipedia", on journalistic contributions and even on estimates when the data are not known.

The information is then processed on the basis of about fifty different freely determined factors (with the exception of nuclear weapons) by extrapolating what the site defines the "Power-index", that is a "power" coefficient, on the basis of which it is drawn up a ranking of 126 countries in descending order of "military power".

[3] In September 2014, for example, both countries reached a trade agreement relating to the supply of weapons worth $ 3.5 billion.

3. The Gerd dam—grand Ethiopian renaissance dam

The Nile is the longest transboundary river in the world which with its drainage basin covers about 3.3 million km^2 and includes 11 countries with a population of about 370 million, of which almost 160 million depend on the river for their livelihoods. The Arabic name of the Nile river is Bahr Al-Nil or Nahr Al-Nil which together with its English name, Nile, have their roots in the Greek word nahal which means river valley.

The length of the Nile is estimated at 6700 km from its sources in Ethiopia and Uganda to its mouth in northern Egypt where it enters the Mediterranean Sea through a large delta.

The flow of the Nile in the periods of maximum vitality is 300 million m^3 of water per day, of which the largest share is received from Egypt, although currently a large part of the available water is used before reaching its delta.

As anticipated in the introduction, the Nile consists of two main waterways. A stream flows into Uganda generated by Lake Victoria, and is called the White Nile and supplies about 20% of the Nile's water. The other stream is called the Blue Nile generated by Lake Tana in Ethiopia and supplies 80% of the Nile's water. Both branches meet near Khartoum, the capital of Sudan.

The GERD dam, whose project was announced in 2011, is located on the Blue Nile on the border with Sudan (Figure 4), and precisely about 750 km north-west of Addis Ababa, in the place called Guba, in the west of Ethiopia, at 45 km from Sudan.

In summary, from a technical point of view, the type of dam is the Roller Compacted Concrete (RCC), i.e. gravity made using rolled and compacted concrete, and is served by two power plants equipped with 10 and 5 Francis-type turbines, respectively. with a total installed generation capacity of 6000 MW. The dam basin is able to cover, at full supply level, an area of 1680 sq km and with a volume of 74 billion cubic meters of water. Normal and minimum operating water levels are 640 and 590 meters above sea level, respectively, and the tank volume at minimum operating level is 12 billion cubic meters of water.

One of the main effects of the GERD dam will be the stabilization of the flow of the Blue Nile (Figure 3) which in the absence of the dam had a minimum and maximum flow rate respectively of 200 m^3/s and 6500 m^3/s measured at the Roseires dam in Sudan [50]. The new water flow, in fact—calculated on the basis of the available information relative to total power equal to 6000 MW, dam height equal to 145 m, number of turbines equal to 15 with a capacity of 350 MW each, and assuming that Ethiopia will use the dam for energy purposes only—it will be used, at full capacity, in a much narrower range (and with the minimum value much higher) between 3600 and 3800 m^3/s throughout the year.

From the point of view of the economic investment, against a total cost estimated at 4.8 billion dollars, in 2015 about 2 billion dollars had already been spent for the dam, of which only a very small part, 16%, was recovered through the sale of bonds of the project, while the remainder went entirely to burden on the economic resources of the country. The International Monetary Fund already in 2014 advised the Ethiopian government to slow down the construction of the GERD dam to avoid an excessive depletion of public resources. According to the IMF [51], the Ethiopian government has unscrupulously resorted to loans, obtained from national banks, of such importance as to undermine the macroeconomic stability of the country.

The real effectiveness of the cost/benefit ratio between the potential of the dam and its real investment cost will only be seen in the next few years.

Actually, the problem of seeking a diplomatic negotiation in the shared water resource management ecosystem remains to be solved first.

Figure 4. GERD Dam, Grand Ethiopian Renaissance Dam. Source: Photograph by the author Stefano De Falco and licensed by the author.

4. An ecosystem approach to the problem

The importance of the water resource for Egypt conflicts with the equally important need for this resource for energy purposes for Ethiopia. It is therefore a question of specific interests peculiar to those places overlooking the banks of the same river. Thus, following this perspective of the place, it appears interesting to employ an ecosystemic approach, in the original meaning of the etymology of the Greek word oikos which means home, a place to live.

In this way, the scenario of the dispute over water can be framed according to two forms of ecosystem competition in series, in the sense that if the first evolves towards a form of instability, it induces the triggering of the second. The first-competition for exploitation—appears to be related to the physical geography as a competition on the natural resource, in this case the water of the river, while the second-competition by interference—concerns political geography in the form of a dispute between competing countries on the banks of the Nile.

The hypotheses underlying the competition model for exploitation of a shared resource provide that:

-countries negatively influence each other by taking away part of the same resource;

-the resource is available in limited quantities (if it were overabundant, the use by one country would not decrease the availability of the other countries bordering the Nile).

Competition for interference concerns the possible critical evolution of the resource contention scenario in the form of a real conflict between countries. This can then be an active conflict of armed confrontation, or passive in the form of defense, again in military terms, of the natural resource threatened by the subtraction of other countries.

The descriptive analytical model of the first type of scenario certainly turns out to be of the time-variant type, in which the quantity relating to the natural water resource of the Nile, A_N, is represented by a time-dependent variable A_N (t). Its trend in relation to the competition of the countries bordering the same river in relative contention, can be described by the classic differential equation (1) of intraspecific competition in which the variation over time of the Nile water resource is proportionally dependent on the resource itself through a growth rate (Ta) which is itself dependent on the Nile water resource.

$$\frac{dA_N(t)}{dt} = T_a\big(A_N(t)\big)A_N(t) \tag{1}$$

The growth rate Ta is a decreasing function of A_N, as the amount of water available to other countries, Egypt and Sudan, decreases as the water taken from a country increases, in this case Ethiopia through the GERD dam. Particularly, when A_N diverges due to the dam effect, the rate becomes negative, while, for small values of A_N, Ta becomes positive and greater than 1. In other words, the model analytically repeats the considerations developed in the geopolitical framework and, therefore, due to limited water withdrawals by the GERD dam, Egypt would not see its availability of water decrease (rate greater than 1).

The condition of physical equilibrium in terms of distribution of the water resource, which should correspond, as seen, to a condition of diplomatic geopolitical equilibrium and not reachable through military force, is particularized in the analytical model in terms of a certain value E of equilibrium that must reach the water resource, $A_N = E$, such that $T_a(A_N) = 0$.

The (1) is particularized in this case as in (2)

$$\frac{dA_N(t)}{dt}\Big|_{A_N=E} = T_a(E)E = 0 \tag{2}$$

Starting from (2) it is possible to evaluate under which conditions the equilibrium reached for a certain value of the water resource shared between the riparian countries on the cross-border river, is an asymptotically stable equilibrium, i.e. it constitutes a condition of a permanent geopolitical scenario that does not require, therefore, further negotiations.

In analytical terms, given the differential function $\frac{dA_N(t)}{dt} = f(A_N)$ with equilibrium in E, this will constitute a stable equilibrium point if $f'(A_N)<0$.

Therefore, being

$$f'(A_N)|_{A_N=E} = [T'_a(A_N)A_N + T_a(A_N)]|_{A_N=E} = T'_a(E)E \tag{3}$$

It turns out that the condition of asymptotic geopolitical stability around the natural resource of water is reached for:

$$T'_a(E) < 0 \tag{4}$$

Basically (4) establishes that the growth rate decreases for water resource values close to those of a fixed equilibrium condition E. The negotiation between Egypt and Ethiopia should therefore involve an agreement on the quantity of water subtracted from the GERD dam in a way that the one available for Egypt is not below a certain threshold, and on the other hand, Egypt should accept that for values close to the chosen threshold it is not possible to further increase the available water flow.

So, which are the strictly geographical factors of influence regarding the condition of equilibrium? To answer this question, it is necessary to particularize the expression (1) always according to an ecosystem model [52–55] which shows a variation of the natural resource as a function proportional to the resource itself through the growth coefficient T_a, and inversely proportional to the square of the resource according to a competition coefficient (C) on the resource itself, in the specific case dictated by energy motivations by Ethiopia, as shown in (5):

$$\frac{dA_N(t)}{dt} = T_a A_N(t) - C A_N(t)^2 \tag{5}$$

Highlighting the growth coefficient T_a we get:

$$\frac{dA_N(t)}{dt} = T_a[1 - \frac{C}{T_a} A_N]A_N = T_a[1 - \frac{A_N}{E}]A_N \tag{5'}$$

where is it $E = \frac{T_a}{C}$ (5') represents the equilibrium condition.

The (5') therefore shows the variation ΔA_N of the shared water resource of the Nile in an interval of exploitation between the absence resource, that is $A_N = 0$, and resource equal to the equilibrium value, that is $A_N = E$.

In both cases the variation of the water resource is zero and therefore in this interval the trend is parabolic with a maximum where the derivative is equal to zero as in (6), that is: $A_N = \frac{E}{2}$ (Figure 5).

$$\frac{d\frac{A_N(t)}{dt}}{dt} = T_a\left[-\frac{A_N}{E} + 1 - \frac{A_N}{E}\right] \tag{6}$$

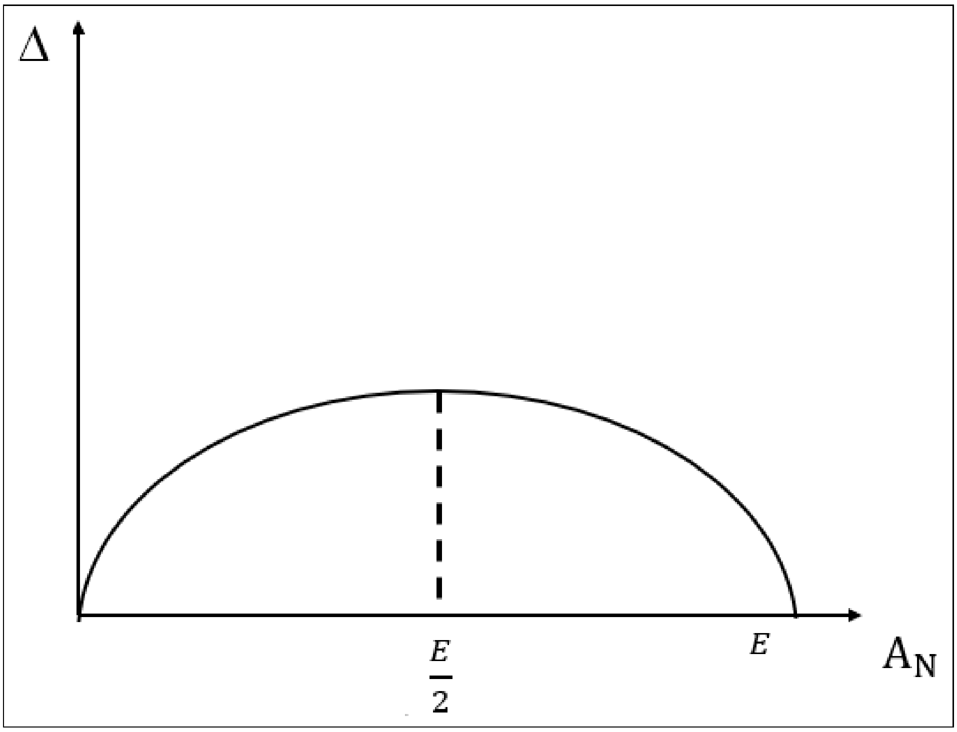

Figure 5. Trend of the variation of the water resource according to the availability of the resource itself. Source: authors' elaboration

From a geographical point of view it is, therefore, necessary to evaluate in (5') the factors of incidence that justify and compensate the increase in the competition coefficient C.

When the construction of the dam started, in fact, the Ethiopian Prime Minister Meles Zenawi, now deceased, during the presentation of the project [56], anticipated a series of externalities and positive corollaries deriving from the limitation of increase of the water of the Nile for Egypt which could be considered compensatory benefits ascribable to factor C of competition on the water resource. On the other hand, as already hypothesized in the initial years of the construction of the GERD dam, the threat to Egypt, in terms of reducing its water growth rate (Ta), is related to a possible and significant (at least 6% according to the IPoE [57]) decrease in the electricity generation capacity of the Aswan dam. The hydroelectric plant associated with this dam consists of 12 generators each capable of delivering a power of 175 MW for an installed power of over 2 GW, more than half of the electricity needed to serve all of Egypt. An emblem of identity and nationalism is that of the Aswan dam as in the 1970s it allowed almost all Egyptians to have an electrical connection for the first time. But not only an energy threat that derives from the reduction of the growth rate of the Nile water on the Egyptian shores, in fact the impacts of competition (coefficient C) would concern the supply of domestic users, irrigation, industry, cultivation (also damaged by an increase in salinity) and even river navigation [58].

From an analysis of the literature (Table 1) relating to the benefits provided in general by a dam, it was possible to select the various possible compensatory factors for external impacts, i.e. not referable only to Ethiopia but to the various coastal countries on the cross-border river, which GERD dam could also induce in the specific case. As can be seen, there are therefore various positive externalities on which diplomatic action by Ethiopia should be strengthened more.

Table 1. River benefits induced by the installation of a dam. Source: authors' elaboration.

Compensating factor coefficient C	Literature analysis
River flow regulation;	[59]
Flood control	[60]
Reduction of sedimentation and silting,	[61]
Reduction of water losses resulting from moving storage to areas with lower evaporation rates	[62]
Environmental benefits deriving from an improvement in the quality and flow of water, capable of ensuring greater protection of biodiversity	[63]
Increase of trade relations, investments and hydroelectric interconnections with other countries of the cross-border river	[64]

Therefore, the convergence between physical geography—which sees the different countries contending on the same resource—and the geopolitics that must lead to a negotiation on consensual distribution, must take place according to precise steps that the proposed model helps to define. First of all, it is necessary to identify a level of water that can be drawn from Ethiopia through the GERD dam for energy purposes (equal to E value provided by the model) and allow a maximum variation equal to half of this value. Secondly, the negotiation must push Ethiopia on the value of the benefits obtainable from the work, as described in Table 1.

Finally, an aspect that emerges from the proposed model regards its importance on the diplomatic communication with particular reference to the dynamics of the administration of water resources.

As mentioned in the introductory paragraph, in July 2020 the announcement of the filling of the dam basin alerted the political and military institutions of Cairo. In these similar informative contexts, the proposed model could allow to highlight (see the appendix where the analytical development of the convergent dynamics is reported) the possible initial conditions relating to the state of the distribution of the water resource. From model emerges an asymptotic tendency to reach equilibrium whether considering the basin empty or in the state of filling.

5. Conclusions

The Grand Ethiopian Renaissance Dam (GERD), begun in 2011, is the largest hydroelectric plant in Africa against an investment never made before in terms of cost and physical invasiveness.
Beyond the grandeur, the work redesigns the hydro-political map of the Nile river giving a geopolitical value to the analyzed scenario. The filling of the dam will be accompanied, in fact, by a corresponding outflow of the Nile near the Aswan dam.

The dam has become a symbol of Ethiopian nationalism and a true "renaissance" (hidase in Amharic) of the country. But to oppose the concept of nationalism in this case it is necessary to keep in mind another concept, that of hydro-solidarity. While, on the one hand, the dam will be vital for energy production and a key factor for food production, economic development and poverty reduction in Ethiopia, on the other hand it is necessary to keep in mind the impacts that derive from it on other coastal countries that use the same water resource as the
cross-border river, in particular Egypt and Sudan.

The case of GERD highlights a number of questions that have great importance beyond the dam itself, such as water sharing in transboundary rivers, collective claim making processes, and global economic development.

Different perspectives, in fact, can be approached to the theme of water sharing in transboundary rivers, from the geopolitical to the cultural one. For example, Rubenson [65] studied in the Nile Basin the historical, nationalistic rivalry between Egypt and Ethiopia on the one hand, and on the other, uniting historical and cultural elements such as the relationships between the Coptic Church and the Orthodox Ethiopian Church.

The perspective followed here, is instead merely linked to the identification of an analytical model for describing the phenomena of water dispute.

To this end, in this paper, after framing in a framework in which we have tried to combine the aspects of physical geography with those of geopolitics, a management model of the shared river water resource based on the dynamics relative to ecosystem competition has been proposed.

Tayia [66] observes that the English language, as well as many other Latin-rooted languages, reflects the historical relation between shared rivers and competition, as it uses the word "rival" to refer to a competitor against others. The word "rival" is derived from the Latin word rīvālis, which refers to an individual using the same river stream as another and originated from the Latin word rivus meaning river stream. Water becomes an element of osmosis but also of contrast, therefore, between physical and political geography. The perspective proposed in this paper hopes to propose an analytical approach for the osmosis of the two paradigms. Particularly, the aim of the research rather than providing elements of geopolitical critical analysis, focused on the possibility of using analytical methods for the management of shared resource scenarios.

The evidence found, arising from the proposed reflection and the analytical modeling developed, highlighted how the diplomatic path, based on the search for a consensual balance in the management

of tensions triggered by conflict, is the only roadmap for the pursuit not only of the good common, but also of the good from the point of view of the national interest of each country involved.
The situation of the GERD is an example from which lessons can be learned for future dam development in politically sensitive river basins. The results show that the ecosystem constraints of the GERD could affect the expected annual river flow to Sudan and Egypt and could have political consequences.

More generally, the design and construction of large dams on transboundary river basins should begin after reaching an agreement between the affected countries and regions on the initial reservoir filling and long-term operation. In this sense, the ecosystem model proposed can provide a forecasting scenario for the negotiation between Parts.

5.1. Appendix. Convergence dynamics in basin filling

The solution of expression (5) is a logistic function that describes an S-shaped curve relative to the growth of the water resource constituted by the water of the Nile. From the point of view of Egypt, at the beginning the growth is very high, and corresponds to the normal hydrodynamic models of the river, subsequently it slows down, becoming almost linear, to reach an asymptotic position where there is no more growth, but a level of equilibrium water flow obtained as a result of the negotiation. This condition takes place due to the water stolen by the Ethiopian GERD DAM, competing on the same resource.

The solution is obtained by separating variables:

$$\frac{dA_N(t)}{dt} = T_a A_N \frac{E-A_N}{E} \tag{7}$$

$$\frac{E-A_N}{A_N(E-A_N)}\, dA_N(t)=\left(\frac{1}{E}-\frac{1}{A_N-E}\right) dA_N(t) = T_a\, dt \tag{8}$$

$$\ln A_N - \ln|A_N - E| = ln\, \frac{A_N}{|A_N-E|} = T_a t + k \tag{9}$$

$$\frac{A_N}{|A_N-E|} = k' e^{T_a t} \tag{10}$$

Where k ϵ R and k' ϵ R + are constant. If the quantity of water of the Nile river is known at the initial moment in which the basin of the GERD dam is empty, then k' can be determined as: $A_N\,(0)$

$$k' = \frac{A_N(0)}{|A_N(0)-E|} \tag{11}$$

And so:

$$\frac{A_N}{|A_N-E|} = \frac{A_N(0)}{|A_N(0)-E|} e^{T_a t} \tag{12}$$

From which it finally derives:

$$A_N(t) = \frac{A_N(0) E e^{T_a t}}{E+ A_N(0)(e^{T_a t}-1)} \tag{13}$$

Therefore, according to this model, once the level of water that can be drawn from the GERD dam corresponding to the E value has been negotiated, whether starting from empty basin conditions ($A_N > E$), whether you are in full basin conditions, ($A_N < E$), the evolution of the dynamics relating to the water resource will converge asymptotically towards the value E (Figure 6).

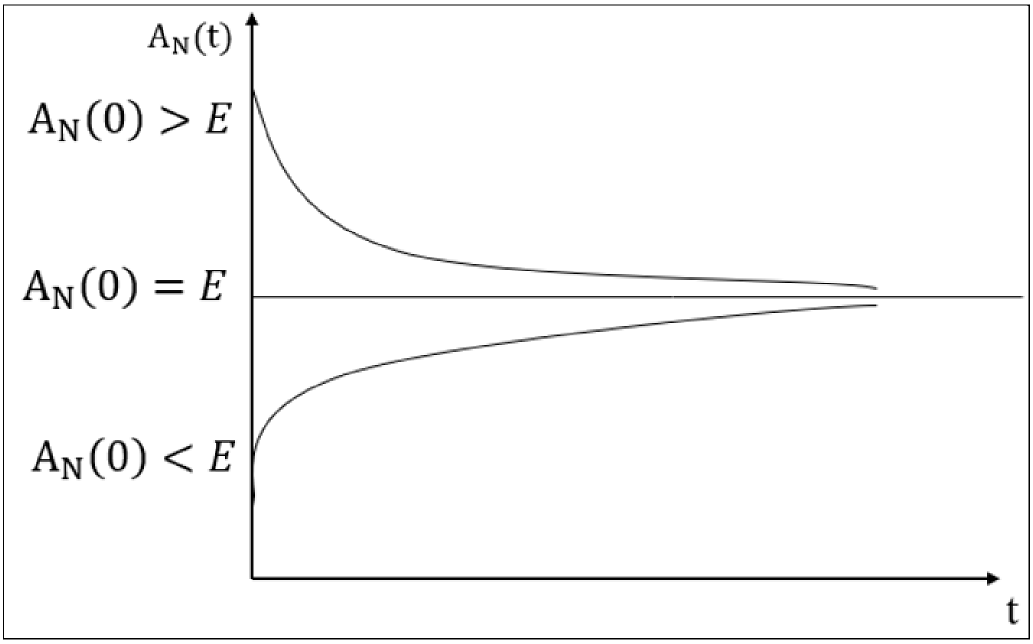

Figure 6. Converging dynamics. Source: authors' elaboration.

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Conflict of Interest

The authors declare to not have any conflict of interest.

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