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Assessment of Grand Ethiopian Renaissance Dam impacts using Decision Support System

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Abstract: *Ethiopian government undertakes plans to develop massive hydropower potential with the construction of a large scale Grand Ethiopian Renaissance Dam (GERD) upstream of the Ethiopian-Sudan border in an effort to utilize the water resources potential, improve the water and energy security in order to reduce poverty, create an atmosphere for social change and bring economic growth to the country.The Analytic Hierarchy Process (AHP) is one of the most widely used multi-criteria decision analysis in water resources management and energy planning.AHP was used to study the trade-offs of reservoir capacity design plansin order to promote a sustainable strategy for water resources management in the Eastern Nile countries that includes Egypt, Ethiopia and the Sudan, without dangerous impacts on the environment and riparian countries. Several environmental, economic and social criteria were considered when choosing the best alternative for sustainable water resources management in the Eastern Nile countries to mitigate the adverse impactsresulting from the construction of GERD to downstream countries. The results of this study showed that the "Do-nothing" is the most appropriate option with regard to the environmentalimpact on the Eastern Nile countriescompared to the original plan and the new applied one (running now).*

Keywords: *Analytic Hierarchy Process; dam impacts; decision support systems; environmental impacts; GERD; Nile River; water management*

I. Introduction

The Nile Basin is considered one of the most complex and unique river basinsdue to its size and varying climate, hydrology, topography and demography (Sileet*et al.* 2013). This variation poses many challenges to the management of transboundary water resources of the basin, under the growing pressure from increasing population, poverty, famine, climate change, shrinking water levels of dams and related power shortages, dams' construction and agricultural development plans within the basin(Batisha 2013). These challenges could trigger social, political and economic conflicts that would threaten the stability of communities and nations among riparian states. Transboundary water resources offer a great opportunity for developing and sharing the water resources of the region for personal and household needs, hydropower generation, agriculture, navigation and several other social needs. The full potential of these shared water resources has not been fully realized due to the lacking of investment funding requirements. Shared water resources represent a source of cooperation and negotiation that need to be greatly enhanced at all political levels and the institutional support for the management and the sustainable use of these water resources (Nile Basin Initiative 2012).

The Nile constitutes of two important water supply sources. The Eastern Nile Basin (Blue Nile) has about 85% of the flow of the Nile that is originated from Ethiopia whereas Eastern Equatorial Nile (White Nile) has the remaining of the flow that is about 15% of the flow. The Blue Nile has about 60% of the total flow at Aswan and is still considered an important river basin to the Eastern Nile countries that includes Egypt, Ethiopia and the Sudan (Mulat and Moges 2014). The major water uses are irrigation and hydropower. Both Egypt, and to a less extent Sudan, are dependent significantly on water that come from the Nile for use in irrigation in both countries (Waterbury 2002). On the other hand, Ethiopia contributes with less than 5% of the irrigable land in the basin and less than 3% of the hydropower potential (Block *et al.* 2007). Ethiopia has a plenty of water resources and abundant hydropower potential that is estimated to be about 30 000 MW with a total potential of 159 TWh/year (World Energy Council 2007). Currently, 94% of Ethiopia's population still depends on fuel wood for cooking and heating and 83% has no access to electricity (Thomson 2006).

The Nile riparian countries have substantial potential energy resources that include hydropower, natural gas, oil, coal, peat, biomass, geothermal, solar, and wind energy. Hydropower remains the preferred renewable energy source in which the power is producedas the result of moving the energy of water from higher to lower elevations. It takes the dominant and central role among the various energy options for several reasons. One of the key reasons is the low price-competitive technology that makes electricity affordable to urban and rural areas. It is reliable power supply and pollution free. It also provides abundant employment opportunities during construction and operation with additional benefits for flood control and river flow regulation, irrigation, transport and navigation, aqua farming, recreation, industrial and domestic supply. Moreover, it allows the construction of infrastructure projects as for roads, electrification, telecommunication, schools, health centers, government services, commercial and industrial use and thus, delivers additional benefits to rural communities (Nile Basin Initiative 2012).

1.1. Hydroelectric plans of GERD

The hydroelectric potential in the Nile Basin is massive that is estimated at 150,000 MW of hydropower potential. Despite the region's endowment with enormous hydropower potential, a small fraction has been utilized by the downstream countries except for Egypt, whose hydropower potential is fully utilized. There are also restrictions and challenges that impede the full utilization of the region's hydropower potential that demand an implementation of mitigation measures for the negative impacts from hydropower planning projects in the region. Hydropower potential has also limited ability to meet the energy needs in the region in the long term. The projections indicated that the total demand and the total hydropower potential will be equated in the region by 2030. Thus it becomes urgent to explore alternative scenarios to optimize power supply that requires regional cooperation and power integration, thereby making the region more exposure to investments in the power sector (Nile Basin Initiative 2012).

Therefore,the Ethiopian government has ambitious plans and programs to develop hydropower in an effort to utilize the water resources potential, improve the water and energy security and thus reduce poverty, develop an atmosphere for social change and thus bring economic growth to the country (Whittington *et al.* 2005).A Large scale hydropower dam known as Grand Ethiopian Renaissance Dam (GERD) is under construction on the Blue Nile River in the upstream of the Ethiopian-Sudan border in Ethiopia. The GERD will create a reservoir with storage capacity of 74 billion m3 and is expected to produce 6000 MW of hydropower energy. By this, Ethiopia will have a massive upgrade over the existing hydroelectric power. At the same time, this will have a significant impact on the Nile flow for countries downstream of the GERD (Mulat and Moges 2014). The larger the project, the greater the impacts on the natural and social environment is to be expected. Large-scale development demands integrated planning for an entire river basin before initial implementation of individual project(s). As the Nile river basin isan international river shared by eleven riparian countries, such planning fosters further international cooperation.

1.2. Impact of GERD project on Downstream Countries

The international panel of experts submitted its final report in May 31, 2013 submitted a report with the impact of GERD to Egypt and Sudan and the main gaps on GERD project studies. The report concludes that the main dangerous impact in Egypt will be a reduction in power generated at Aswan High Dam when the water levels of Lake Nasser is decreased, salinization of Egypt's agricultural lands in the Nile Delta due to the increased upstream withdrawals resulting from GERD operation and large scale loss of flood recession agriculture in Sudan during GERD impounding and operation (IPoE 2013).

A Group of professional from Egypt published a recommendation report for their government on the effects of Ethiopian Grand Renaissance Dam Project (GERDP) on Egypt in June, 2013 of social, economic, and political impact as consequences of Ethiopian dams. The report concludes that the impact will be a reduction in the water share of Egypt resulted in securing the future supply of water to Egypt for drinking, agriculture and industry, production of electricity from the High Dam and the Aswan Dam during the impound and operation of GERD especially during the drought period, abandoning agricultural lands, and water pollution, navigation, tourism, fish farms, and catastrophic consequences in both Sudan and Egypt due to GERD rupture where the water released by GERD's saddle dam failure would flow that includes drowning of major towns and villages exposing millions to the dangers of death and relocation (GNB 2013).

1.3. Environmental impact of GERD project

The environmental impact of the implementation of the Grand Ethiopian Renaissance Dam include direct and indirect impacts on the biological, physical and chemical features of the river and the environment where it is located (International Rivers, n.d.-b). Due to the transformation of the riverine ecosystem upstream of the dam into an artificial lake, the river's natural plant and animal species are undermined. Riverine plants and animals are often not adapted to live in a lake environment (Federal Democratic Republic of Ethiopia Ministry Of Water Resources, 2002a; International Rivers, n.d.-b; Than, 2011).The changes in water temperature, dissolved oxygen, chemical composition, salinity and the physical properties of the impoundment generally happen too fast for the species to adapt themselves (International Rivers, n.d.-b; Than, 2011). In addition, the survival of natural animals and plants could be further undermined by the presence of non-native and invasive species. A second undermining factor could be the separation of animals' spawning habitats and rearing habitats due to the dam (Federal Democratic Republic of Ethiopia Ministry Of Water Resources, 2002a; International Rivers, n.d.-b). Also, the distribution of wild life and vegetation in the river catchment is affected. The inundation of the forests and riverbanks will force animals and plants to migrate uphill (Ahram online, 2013; International Rivers, 2012b). Quick habitat changes could threaten animals and plants with extinction, which endangers the catchment's biodiversity (International Rivers, 2012b).

The (involuntary) resettlement of inhabitants living in the project region is one of the most challenging and controversial outcomes of large dam projects (LererandScudder, 1999; Tilt *et al*., 2009). The Consulate General of Ethiopia in Los Angeles (2012), states that the project is located in an area without significant human settlements or economic activity and will, therefore, involve minimal social and environmental costs. On the opposite, a field survey conducted by International Rivers (2012b) states that the dam construction will induce the resettlement of at least 5110 inhabitants that are now living in the reservoir area and downstream of the dam. Additionally, an approximately 7380 inhabitants living in villages near the future dam impoundment will be relocated. A survey for resettlement purposes was conducted in the communities threatened with resettlement, which are almost all areas inhabited by indigenous people (International Rivers, 2012b). It is important to anticipate on the emergence of conflicts about resource division and utilization between resettled residents (International Rivers, 2012b). The construction of the Grand Ethiopian Renaissance Dam project on the Blue Nile can be considered as a perfect example of a top-down process. They state that the involvement and opinion of local residents was completely neglected during the preparation phase of the project (Bosshard, 2011; ImhofandLanza, 2010; International Rivers, 2012b). According to Bosshard (2011), the Ethiopian government currently does not even shy the suppression of everyone who adopts a critical attitude towards the construction wave of large hydropower projects. However, at least the inhabitants threatened with resettlement should be involved in the planning of their future (Imhof andLanza, 2010; International Rivers, 2012b).

1.4. Purpose of Study

In this study, the Analytic Hierarchy Process (AHP), a technique in Multicriteria Decision Analysis (MCDA), was used to assess the trade-offs of reservoir capacity design plans relating to its social, environmental, and economic indicators in the Eastern Nile Basin in order to secure the regional electricity market without adverse impacts on the environment and riparian countries, and thus promote a sustainable strategy for water resources management in the Blue Nile Basin. It also fosters the cooperative management of shared water resources between riparian countries, thus allowing a sustainable and equitable way to ensure prosperity and security for all its communities, reducing poverty and promoting economic integration under conservative environmental prospect.The aim of this study is to assess the potential impact of the GERD Dam on the downstream riparian countries in the Eastern Nile Basin with the use of the decision support system, mainly the Analytical Hierarchy Process (AHP), a multi-criteria decision technique based on social, environmental, and economic indicators.

II. Positive and Negative impacts of Dam

This section summarizes the positive and negative impacts of Dam on the environment:

- **Employment opportunities:** The power project is expected to generate employment opportunities during both construction and operation associated with the construction of transmission lines, and an additional people will probably get direct and indirect jobs during operation(ADBG 2010).Improving access to electricity in the rural areas will encourage the development of rural industries and services and thus open up many opportunities for young people at minimum cost to national economies (NBI 2012).
- **Gender Issues:** Women will have equal employment opportunities as well as men that will be created during construction within the project skills requirements; and from convenient and safe access road facility. Women can obtain further income generating activities for women such as food catering/restaurants for workers on the construction sites and the selling of local products to construction camp workers and thus maximizing the purchase of local products and services(ADBG 2010).
- **Physical displacement and resettlement:**Dam construction brings considerable disadvantages to local communities. Due to the newly created reservoir,some people may lose their land and assets whilst the need to be resettled. People, who remain in the construction area, may find their livelihoods affected by changes in river flow (NBI 2012). Local communities do not share the same benefits of the hydropower project, while they carry most of the burden due to the construction of the dam. The agricultural lands and the resettlementof millions of families will be also affected due to the reduction in the water share of downstream countries.
- **Public Health:**Newly created water bodies can produce water related diseases such as malaria and bilharzia that affect public health. Some infectious diseases can spread around hydroelectric reservoirs, in specific in

warm climates and densely populated areas (NBI 2012).The possible health impacts caused by theimplementation of large dam projects for inhabitantsclose to the dam site, but also upstream, downstream and eventually even nationally or internationally are presented in Table 1 (Lerer and Scudder, 1999).

Table 1 Potential Health Impacts of Large Dam Projects (Lerer and Scudder, 1999)

Impact Area	Effect of the Dam	Health Impact
Upstreamcatchment and river	Loss of biodiversity, increased agriculture, sedimentation and flooding, changes in river flow regime	Changes in flood security, water related diseases, difficulties with transport and access to health facilities
Reservoir area	Inundation of land, presence of large man- made reservoir, pollution, changes in mineral content, decaying organic material	Involuntary resettlement, social disruption, vector- borne diseases, water- related diseases, reservoir-induced seismicity
Downstreamriver	Lower water levels, poor water quality, lack of seasonal variation, loss of biodiversity	Food security affected on flood plains and estuaries (farming & fishing), water-related diseases, dam failure and flooding
Irrigation areas	Increased water availability and agriculture, water weeds, changes in flow and mineral content, pollution	Changes in food security, vector-borne and water- related diseases
Construction activities	Migration, informal settlement, sex work, road traffic increase, hazardous construction	Water- related diseases, sexually transmitted diseases, HIV/AIDS, accidents and occupational Injuries
Resettlement areas	Social disruption, pollution, pressure onnaturalresources	Communicable diseases, violence and injury, water- related diseases, loss of food security
Country/ regional/ Global	Reduced fuel imports, improved exports, loss of biodiversity, reallocation of funding, sustainability	Macro- economic impacts on health, inequitable allocation of revenue, health impacts of climate change

- **Water Supply:** Dams create reservoirs that supply water for many uses, including domestic, industrial and agricultural. The seasonal and annual changing in stream flow may cause water rarity problems to people in the riparian countries. It is expected that the livelihoods of farmers and other rural people in downstream countries would be substantially impacted.
- **Safety and Security:** Dam safety concerns are related to faulty design or wearing out of materials used for construction. FEMA ("Why Dams Fail", 2015) outlined several reasons to why dams can fail, including (a) overtopping caused by floods that exceed dam capacity; (b) Structural failure of materials used in dam construction; (c) movement and/or failure of the foundation supporting the dam; (d) settlement and cracking of concrete or embankment dams; (e) piping and internal erosion of soil in embankment dams; and (f) improper sufficiency of maintenance and upkeep.
- **Improve Investments:** A country is characterized by reliable power supply is definitely an attractive to investors leading to supporting expansion, of the industrial and service sectors, creating employment and improving living standards. An effort is required to speed up the implementation of the transboundary transmission interconnector to move energy from countries with surplus to countries with deficit, and thus embracing peak power swapping in an aim to boost the economy with the volume of investments required (NBI 2012).
- **Fisheries:** Hydroelectric projects often have major effects on fish and other aquatic life. Reservoirs positively affect certain fish species (and fisheries) by increasing the area of available aquatic habitat. However, the net impacts are often negative because (a) the dam blocks upriver fish migrations, while downriver passage through turbines or over spillways is often unsuccessful; (b) many river-adapted fish and other aquatic species cannot survive in artificial lakes; (c) changes in downriver flow patterns adversely affect many species, and (d) water quality deterioration in or below reservoirs (usually low oxygen levels; sometimes gas super-saturation) kills fish and damages aquatic habitats. Freshwater organisms are even more sensitive to these changes than most fish species, due to their limited mobility (Ledec and Quintero, 2003).
- **Irrigation:**It is expected that the increase in the water surface area will lead to evaporation losses from water reservoir.As the result, water shortagewill impact the water efficiency reached in the agriculture by means of irrigation that has substantial economic impact.Also diversion of water through irrigation further reduces the water supply for downstream.
- **Cultural assets:** Cultural property that includes archaeological, historical, paleontological, and religious sites and objects, can be inundated by reservoirs or destroyed by associated quarries, borrow pits, roads, or other works (Ledec and Quintero, 2003).

- **Downstream Flow regime:**Major downriver hydrological changes can damage riparian ecosystems that depend on periodic natural flooding, water pollution degradation during low flow periods, and increase of saltwater intrusion near river estuaries.
  Agriculture and human water supplies can be damaged due to (a) reducing sediment and nutrient loads in the downriver of dams leading to an increase in the river-edge and coastal erosion and damage the biological and economic productivity of rivers and estuaries, and (b) diversion of water to another portion of the river, or to a different river kills fish and fauna and flora dependent on the river (Ledec and Quintero, 2003).
- **Water quality:**Serious water quality declination will occur due to the reduced oxygenation and dilution of pollutants by relatively stationary reservoirs, flooding of biomass and resulting underwater decay, and/or reservoir stratification where deeper lake waters lack oxygen (Ledec and Quintero, 2003).
- **Greenhouse gas emission:**In northern regions, Greenhouse gases (carbon dioxide and methane) emission from hydroelectricity are significantly smaller than corresponding from thermal power plants alternatives varying from < 2% to 8% of any kind of conventional thermal generation alternative whereas in tropical region, these emissions cover a much wider range of values, varying from less than 1% to more than 200% of the emission factors reported for thermal power plant generation (Tremblay *et al.* 2002)
- **Floating aquatic weeds:**Floating aquatic vegetation can rapidly increase in eutrophic reservoirs, causing problems such as (a) degraded habitat for most species of fish and other aquatic life, (b) improved breeding grounds for mosquitoes and other nuisance species and disease vectors, (c) impeded navigation and swimming, (d) blocking of electro-mechanical equipment at dams, and (e) increased water loss from some reservoirs.
- **Climatic variability and change:**Large areas in the basin are vulnerable to drought because of high variability in rainfall and high evapotranspiration rates. Seasonal shortages in water associated with natural climate variability make it difficult to maintain peak generation capacity throughout the year, and may reduce the long term economic feasibility of candidate hydropower projects. The negative impacts of climate on the power sector are expected to greatly increase with global climate change (NBI 2012).
- **Tourism:** It provides additional income for local populations throughout recreational facilities and water sports. Accommodation areas offer an income-generation option for the local residents. When the dam site attracts tourism, it creates an incentive for maintaining environmental sustainability in the area.
- **Navigation:**Dams create barriers for upstream-downstream navigation and movements of fish and other creatures. Dams can also substantially change the flow of water and transport of sediment, nutrients, and food materials that supply downstream aquatic ecosystems and estuaries, with impacts commonly extending for hundreds of kilometres downstream (Krchnak*et al.* 2009). Lower water levels have an adverse impact on tourism and boating used for movement and trades downstream the river. With increased sediment transport, serious changes are occurred to navigation channels and harbours.
- **Industrial growth:**Electricity plays a significant role in poverty alleviation and in promoting the economic productivity. The production of hydropower would allow the expansion of power-requiring industries and factories in the surrounding urban areas and thus creating more permanent job opportunities for local community.

III. Materials and Methods

Multi-Criteria Decision Analysis (MCDA) is an approach that provides a systematic way for decision makers to reach same consensus by identifying, assessing and scoring options against a set of decision criteria. It helps solve complex problems by creating structured framework that allows the decision maker to select the optimal alternative scenario, according to the identified set of criteria.

3.1. Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is one of Multi Criteria decision making methodsoriginally proposed by Saaty (1980). It is a theory of measurement through pairwise comparisons that relies on the judgments of experts to derive priority scales.It represents a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, and alternatives. The priority scales are derived by using a set of pairwise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria. It provides a mechanism for improving consistency if the comparisons and judgments are inconsistent. Thus, it helps the decision makers to achieve better judgments based on hierarchy, pairwise comparisons, judgment scales, allocation of criteria weights, and selection of the best alternative from a finite set of alternatives.

The methodology of AHP involves four main steps that can be explained in brief as follows:

1. Decompose the complex problem into a hierarchical structure with decision elements descending from an overall goal to the objectivesfrom a broad perspective, the criteria in the intermediate levels, and then the alternatives in the lowest level. The multilevel decision hierarchyprovides an overview of the relationships inherent in the context for practical problem solving. It helps to decompose the complex decision problems into more comprehensive ones that can be easily evaluated independently. Figure 1 illustrates the hierarchy structure corresponding to the example.
2. Construct a set of pairwise comparison matrices of various criteria and all decision alternatives under each criterion, based on Saatyqualitative preference rating scale as per Table 2. Each elementin an upper level is used to compare the elements in the level immediately below with respect to it.The diagonal elements of the matrix is 1 indicates the comparison of the criterion to itself.The criterion i is more important than criterion j if the value of the element (i, j) is greater than 1. The criterion i is less important than criterion j if the value of the element (i, j) is less than 1.
3. Develop the relative weights for the criteriato produce the priority vector of a pairwise comparison matrix. The relative weights are computed by using the geometric mean of each row. That is, the elements in each row are multiplied with each other and then the nth root is taken (where n is the number of elements in the row). Next the numbers are normalized by dividing them with their sum.
4. Check the consistency of the judgments used to develop the pairwise comparison matrix that can be measured using the consistency ratio (CR). The pairwise comparisons in a judgment matrix are considered to be consistent if the corresponding consistency ratio (CR) is 10% or lower (Saaty, 1994). The judgments are considered random if the consistency ratio (CR) exceeds 10%. The judgments should revise the pairwise comparison matrix and the pairwise comparison matrix should be recomputed.
5. Aggregate the relative weights of the criteria to perform the overall evaluation of the alternatives. Each alternative can be evaluated in terms of the relative importance (or weight) of each criterion.

Table 2 The pairwise comparison scale

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate importance between adjacent scale values	Compromise is needed between two judgment

Source: Saaty (1977)

3.1.1. Compute the criteria weights

1. Construct the pairwise comparison matrix A. The matrix is n×n where n represents the number of criteria to be evaluated. Each element aijis derived quantitatively based on Saaty qualitative preference rating scale as per Table 1. The rating scale is used measure the relative importance of criterion i in comparison to criterion j for each criteria pair (i, j). The pairwise comparison matrix can be represented in the following form:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \vdots & a_{22} & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}$$

2. Calculate the geometric mean of the i^{th} row by estimating the n^{th} root of the product of the pairwise comparison values in each row.

$$GM_i = \left\{ \prod_{j=1}^{n} a_{ij} \right\}^{1/n}$$

3. Derive the relative weight of each criterion by normalizing the aforementioned n^{th} root of criteria

$$w_i = GM_i \Big/ \sum_{i=1}^{n} GM_i$$

4. Produce a matrix of priority vector representing the relative weights of the criteria as follows

$$W = [w_1 \quad w_2 \quad \dots \quad w_n]^T$$

3.1.2. Calculate the consistency ratio (CR)

1. Compute the eigenvalue by the sum of the jth column and then multiplying it to normalized principal eigenvector or the relative weight of respective criterion.

$$\lambda_j = \sum_{i=1}^{n} a_{ij} w_i$$

2. Calculate the maximum eigenvalue(λmax)of the priority vector by summing them as principal eigenvalue. It can be used to estimate consistency in a matrix, as reflected in the proportionality of preferences (Saaty 1995, 1980).

$$\lambda_{max} = \sum_{j=1}^{n} \lambda_j$$

The closer λmax is to the number of elements n in the matrix A, the more consistent the matrix will be.

$$\lambda_{max} \cong n$$

3. Calculating the Consistency Index (CI) to measure the inconsistency and deviations from the consistency is expressed by the following equation (Albayrak*et al.* 2004; Lee *et al.* 2002; Saaty1995). The smaller the value of CI, the smaller is the deviation from the consistency.

$$CI = (\lambda_{max} - n)/(n-1)$$

4. Derive the Random Index (RI) from Table 3 on the basis of the size of matrix (or n), where n = the number of the elements in the matrix.
5. Calculating Consistency Ratio (CR) by dividing Consistency Index (CI) by Random Index (RI). If the CI is less than 0.10, the consistency of the decision-maker is considered satisfactory. But if CI exceeds 0.10, some revisions of judgment may be required (Lee *et al.* 2002).

$$CR = CI/RI$$

Table 3 Random Index (RI) for size of matrix

Size of matrix(n)	1	2	3	4	5	6	7	8	9
Random Consistency Index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3.2. AHP Hierarchy Tree

In this study, a hierarchical decision making approach based on multi-criteria decision making approach according to the criteria such as social, environmental, and economic, was presented in order to prioritize the alternatives for reservoir capacity planning for power generation. The hierarchy tree is composed of 3 main criteria, 18 sub-criteria, and 3 alternatives.

Figure 1 The hierarchical structure for the selection of the reservoir capacity planning

3.3. Indicators

The comparative evaluation of proposed alternatives was based on criteria and indicators that are of fundamental importance for the assessment of GERD construction according to the categories identified, including Social, Environmental, and Economic. The following table (Table 4) summarizes the indicators that are used to measure the impacts of alternatives.

Table 4 Criteria used for the alternatives evaluation

Criteria (Level 2)	Sub-Criteria (Level 3)	Symbol
Social	Physical displacement and resettlement	SO1
	Gender equality and women empowerment	SO2
	Water Supply	SO3
	Public Health	SO4
	Safety and Security	SO5
Environmental	Fisheries	EN1
	Downstream Flow regime	EN2
	Cultural Assets	EN3
	Water quality	EN4
	Greenhouse gas emission	EN5
	Floating aquatic weeds	EN6
	Climatic variability and change	EN7
Economic	Employment opportunities	EC1
	Navigation	EC2
	Energy production	EC3
	Irrigation	EC4
	Industrial growth	EC5
	Tourism	EC6

3.4. Alternatives

This section identifies the alternatives to the hydropower GERD dam construction in Ethiopia:

1. **Alternative 1: “Do-Nothing”:** With the “Do-nothing” alternative, the quality of life would remain at a low level for local community. It indicates that no increase in economic activity would occur. The existing conditions of the socio-economic and biophysical environment would remain unchanged.
2. **Alternative 2: “Dam-planned”:**The proposed capacity of GERD was 1200 MW with a reservoir of 14 BCM water volume.On the other hand, Ahmed and Elsanabary (2015) proved that the best accepted scenario for constructing the dam is by charging a reservoir with 10 BCM/year or less in 3.8 years. This amount of water will be sufficient for power generation and less impacts on the upstream counties.
3. **Alternative 3: “Dam-reality:** The GERD is projected to have 6,000 MW with a reservoir of 74 BCM water volume when it is completed in 2017 that will constitute a significant threat to downstream countries.

IV. Results and Discussion

The relative weights of main criteria and sub-criteria that were considered in the reservoir capacity planning for power generation, is shown in Figure 2. According to these weights, the environmental criteria seemed to be the most important criteria in the selection of the best alternative with regard to the construction of GERD dam. The criterion with the least significance seems to be the economic criteria.

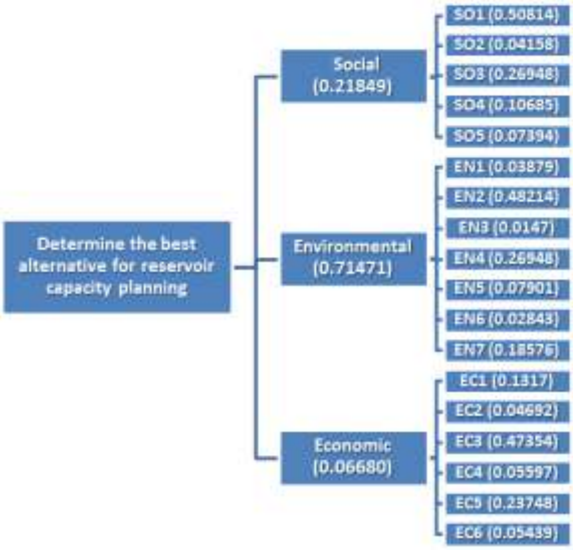

Figure 2 Relative weights with respect to main and sub-criteria

Following is to determine the importance values for alternatives, this study showed that the "Dam-reality" alternative was ranked last (0.115) behind the "Dam-planned" (0.297) and "Do-nothing" (0.587) as shown in Figure 3.

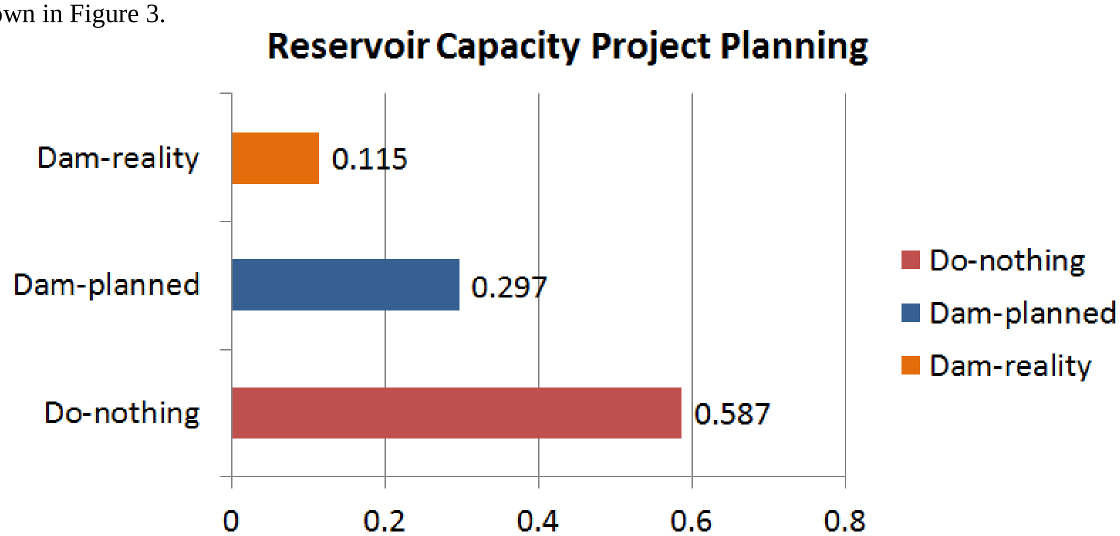

Figure 3 Ranking of alternatives

If the GERD Dam was a multipurpose project for water storage, irrigation, or flood regulation as well as for hydroelectricity, then the "Dam-planned" would be a considerable reasonable. However, the Ethiopian government has stated that the dam will be used solely for electricity generation. This means that, in theory, if the decision makers give marginal attention to the environmental and social aspects, then the decision was not made to build the dam.

V. Conclusion

This study investigated the impacts of constructing such a dam from social, environmental, and economic aspects using decision support system. The approach of AHP is relatively new in the field of water resources, even having its high usefulness in the public sector decision making and resolving controversies and conflicts. Thus AHP proved to be one of suitable methods in accordance to the problem nature on the scale of hydropower development in the eastern Nile Basin from application point of view as many criteria are involved in the decision making.

Poor project design can lead to soil erosion, water quality deterioration, and eutrophication during the construction and operation of hydropower facilities. The very high sediment loads in the headwater areas (especially in the eastern Nile region) will affect the economic feasibility of possible hydropower projects by reducing the storage capacity and water volume available for generating electricity. Trapping the sediment load in the new reservoir has the effect of altering downstream scour and deposition patterns, ultimately producing changes in river morphology (NBI 2012).The Ethiopian government has planned to postpone the filling of the reservoir until after the river's sediment peak to reduce the sedimentation in the basin of the Grand Ethiopian Renaissance Dam (International Rivers, 2012b). According to International Rivers (2012b), the population in the study area knows about the implementation of a development project on the Blue Nile in their area but they were not properly informed about the project.Therefore, they did not have the chance to understand the impact the Grand Ethiopian Renaissance Dam could possibly have on their lives (International Rivers, 2012b).

According to Michaela Schoeters (2013), the benefits of the GERD- project are rather limited. So to maximize the dam's benefits, the project should be implemented as part of an integrated water management plan, in which the impact of this project is described while bearing all the river-based developments planned and build in the entire river basin in mind.

Transboundary watercourses traversing different states present a challenge in terms of management as each country has differing interests as per their national and local needs. It sets a stage to potential disagreements pointing to the need for cooperation between countries and even lower levels (UNEP 2013).Water resources management affects everybody and should be undertaken with the participation of relevant stakeholders to promotecooperation and joint action between three co-basin countries of the Blue Nile through win-win solutions without severe environmental degradation.

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References

[1]. Ahmed, A. T. and Elsanabary, M. H. (2015), Hydrological and environmental impacts of grand Ethiopian renaissance dam on the Nile river, Eighteenth International Water Technology Conference, IWTC18, SharmElSheikh, pp. 12-14.

[2]. Ahram online (2013). Egypt presidency issues summary of tripartite report on Ethiopia dam. *Ahram online*, p. 2. Retrieved fromhttp://english.ahram.org.eg/NewsContentPrint/1/0/73064/Egypt/0/Egypt-presidency-issuessummary-of-tripartite-repo.aspx

[3]. African Development Bank Group (ADBG) (2010), Environmental and Social Impact Assessment Summary, Electricity Transmission System Improvement project, P-ET-FAO-008, Ethiopia.

[4]. Albayrak, M. (2004), 'Using Analytic Hierarchy Process to Improve Human Performance: An Application of Multiple Criteria Decision Making Problem', Journal of Intelligent Manufacturing, Vol. 15, No. 4, pp. 491-503.

[5]. Batisha, A. F. (2013), "Sustainable Water Cooperation in the Nile River Basin: Problems and Prospects", International Journal of Sustainability, Vol. 2, No. 1, pp. 39-53.

[6]. Block, P., Strzepek, K. and Rajagopalan, B. (2007), Integrated Management of the Blue Nile Basin in Ethiopia: Hydropower and Irrigation Modeling. IFPRI Discussion Paper No. 700, International Food Policy Research Institute, Washington DC.

[7]. Bosshard, P. (2011). Sustainable Hydropower – Ethiopian Style.

[8]. Consulate General of Ethiopia (CGE), (2013).Grand Ethiopian renaissance dam. Retrieved from: http://www.ethiopianconsla.org/Documents/BONDINFORMATION.pdf

[9]. Federal Democratic Republic Of Ethiopia Ministry Of Water Resources. (2002a). WATER SECTOR DEVELOPMENT PROGRAM MAIN REPORT VOLUME II.

[10]. Federal Emergency Management Agency (FEMA) (2015), Why dams fail. Retrieved September 11, 2015, from http://www.fema.gov/why-dams-fail

[11]. Group of Nile Basin (GNB) (2013), Cairo University's report on Ethiopia's Great Renaissance Dam, Cairo University, Egypt.

[12]. Imhof, A., and Lanza, G. R. (2010).Greenwashing hydropower.*World watch*, *23*(1), 8–14.

[13]. International Rivers (n.d.-b).Environmental Impacts of Dams.

[14]. International Rivers. (2012b). *FIELD VISIT REPORT GERD PROJECT* (p. 61).

[15]. IPoE (2013), International Panel of Experts on Grand Ethiopian Renaissance Dam Project (GERDP).

[16]. Kiker, G. A., Bridges, T. S., Varghese, A., Seager, T. P. and Linkov, I. (2005), "Application of Multicriteria Decision Analysis in Environmental Decision Making," Integrated Environmental Assessment and Management, Vol. 1, No. 2, pp. 95-108. doi:10.1897/IEAM_2004a-015.1.

[17]. Krchnak, K., Richter, B., and Thomas, G. (2009), "Integrating Environmental Flows into Hydropower Dam Planning, Design, and Operations", Water Working Notes, Note No. 22.

[18]. Ledec, G. and Quintero, J. D. (2003), Good Dams and Bad Dams: Environmental Criteria for Site Selection of Hydroelectric Projects, Sustainable Development Working Paper No. 16.

[19]. Lee, T. N., Fawcett, S. E. and Briscoe, J. (2002), 'Benchmarking the Challenge to Quality Program Implementation, Benchmarking', An International Journal, Vol. 9, No. 4, pp. 374-387.

[20]. Lerer, L. B., and Scudder, T. (1999). "Health impacts of large dams." *Environmental Impact Assessment Review*, *19* (2), 113–123. doi:10.1016/S0195-9255(98)00041-9.

[21]. Mulat, A. G., Moges, S. A. (2014), Assessment of the Impact of the Grand Ethiopian Renaissance Dam on the Performance of the High Aswan Dam, Journal of Water Resource and Protection Vol.6 No.6, pp. 583-598.

[22]. NBI (2012), Chapter 6: Hydropower Potential and the Region's Rising Energy Demand, State of the River Nile Basin, pp 163-186.

[23]. Nile Basin Initiative (2012), State of the River Nile Basin, Online: http://nileis.nilebasin.org/content/state-river-nile-basin-report (Retrieved in 2nd of May 2015).

[24]. Saaty, T. L. (1977), A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, 15(3), 234–281

[25]. Saaty, T.L. (1980), The Analytic Hierarchy Process, New York: McGraw Hill. International, Translated to Russian, Portuguese, and Chinese, Revised editions, Paperback (1996, 2000), Pittsburgh: RWS Publications.

[26]. Saaty, T.L. (1994), How to make a decision: the analytic hierarchy process', Interfaces, Vol. 24, No. 6, pp.19–43.

[27]. Saaty, T. L. (1995) Decision Making for Leaders, RWS Publications, USA.

[28]. Saaty, T.L. (2008), 'Decision making with the analytic hierarchy process', Int. J. Services Sciences, Vol. 1, No. 1, pp.83–98.

[29]. Schoeters, M. (2013), "An analysis of a big dam project: The Grand Ethiopian Renaissance Dam, Ethiopia." Gent University.

[30]. Sileet, T. M., El Shamy, M., Abdel Aty, M, Sharak, A. M. (2013), “The Development of the Baro-Akobo-Sobat sub basin and its Impact on Downstream Nile Basin Countries”, Nile Water Science & Engineering Journal, Vol. 6, Issue 2.

[31]. Stockholm International Water Institute (SIWI) (2012). Large-Scale water storage in the water, energy and food nexus Perspectives on benefits, risks and best Practices. Retrieved from http://www.siwi.org/documents/Resources/Papers/Water_Storage_Paper_21.pdf

[32]. Than, K. (2011). “Ethiopia Moves Forward with Massive Nile Dam Project.”*National Geographic News*, 8–11.

[33]. Thomson, G. (2006) Encyclopedia of the Nations-Africa. Thomson Corporation, Farmington Hills.

[34]. Tilt, B., Braun, Y., and He, D. (2009). “Social impacts of large dam projects: a comparison of international case studies and implications for best practice.” *Journal of environmental management, 90* (Supplement 3), S249–57. doi:10.1016/j.jenvman.2008.07.030

[35]. Tremblay, A., Varfalvy, L., Roehm, C., and Garneau, M. (2002). “The Issue of Greenhouse Gases from Hydroelectric Reservoirs: From Boreal to Tropical Regions.” Table 1, p. 3.

[36]. UNEP (2013). “Adaptation to Climate-change Induced Water Stress in the Nile Basin: A Vulnerability Assessment Report”. Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya.

[37]. Waterbury, J. (2002) The Nile Basin: National Determinants of Collective Action. Yale University Press, New Haven.

[38]. Whittington, D., Wu, X. and Sadoff, C. (2005), Water Resources Management in the Nile Basin: The Economic Value of Cooperation. Water Policy, 7, 227-252.

[39]. World Energy Council (2007), 2007 Survey of Energy Resources. World Energy Council, London, p. 586.