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Master thesis in Sustainable Development 2019/56
Examensarbete i Hållbar utveckling

The impact of the Grand Ethiopian Renaissances Dam on the Water-Energy-Food security nexus in Sudan

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DEPARTMENT OF
EARTH SCIENCES
INSTITUTIONEN FÖR
GEOVETENSKAPER

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Published at Department of Earth Sciences, Uppsala University (www.geo.uu.se), Uppsala, 2019

Contents

Table of Figures

The impact of the Grand Ethiopian Renaissances Dam on the Water-Energy-Food security nexus in Sudan

MUGAHID ELNOUR

Elnour, M., 2019: The impact of the Grand Ethiopian Renaissances Dam on the Water-Energy-Food security nexus in Sudan. *Master thesis in Sustainable Development at Uppsala University*, No. 2019/56, 36 pp, 30 ECTS/hp.

Abstract: Controversy in transboundary rivers usually arises due to lack of inclusive agreement and cooperation between the basin countries. Originating from Ethiopia, the Blue Nile River contributes most of the Nile River water making it vital for water, energy, and food security at downstream Sudan and Egypt. In 2011, the Ethiopian government announced the construction of the Grand Ethiopian Renaissance Dam (GERD) along the Blue Nile 40 km away from the Sudanese borders. The dam will be the biggest in Africa and seventh-largest in the world producing 6,000 Megawatts of electricity with a reservoir volume of 74 billion cubic meters. Great concerns were raised on the impact of this megaproject for downstream countries due to the expected changes in water quantity and quality. Different studies were published regarding the potential impacts of this dam on the Eastern Nile countries. However, these studies have usually focused on one aspect of the impact (e.g. hydropower, agricultural projects, water use) despite the connection that exists between these sectors. This research aims to investigate the impact the GERD operation will have on Sudan in terms of WEF security and sustainability. The study uses the WEF security nexus framework that addresses the interconnectedness between these sectors instead of treating them in silos. A sustainability assessment is also carried out to analyze the impact of the dam operation on the environmental, social and economic areas in Sudan. The study first looked into the current state of Sudan's WEF security nexus and highlighted the vulnerabilities that exists within these sectors. Then analysis of the GERD operation was carried out and the results showed that water regulation and sediment reduction will reflect positively on Sudan as it will enable for expansion in agricultural projects, increase hydropower production, and provide flood control. Some negative impacts, however, are to be expected especially during the impounding phase from water level reduction and change in river characteristic which will greatly affect the environment and society downstream. The safety of the dam was found to be the biggest threat to Sudan's security, as the case of dam failure will have catastrophic consequences for the country. The study concluded that increase in cooperation between the Eastern Nile countries will decrease the downstream negative impacts of the GERD and increase its overall benefits ultimately leading to sustainability, peace, and welfare for these countries. Sudan also needs to take measures in accommodating for the new flowing conditions including reoperation of the Sudanese dams and mitigation strategies for the potential negative impacts.

Keywords: Sustainability, WEF-Nexus, GERD, Sudan, Ethiopia,

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Summary: Ethiopia is constructing and soon planning to start the operation of the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile River near the Sudanese borders. The aim of this research is to see how the operation of this dam will impact Sudan's water, energy, and food security. The environmental, social and economic consequences are also investigated to explore the effects of the dam on Sudan's sustainability. The results show that some benefits are to be expected from the regulation of water flow and reduction in sediment transported as this will allow for expansion in agricultural production and enhances hydropower production. There are, however, some negative consequences that will take place more severely during the filling phase compared to the full operation of the GERD. The most negative impact is going to be on the environmental side, as changes in the river characteristics will greatly alter ecosystems downstream. Cooperation between the Eastern Nile countries is necessary to increase the benefits and reduce the downstream negative consequences. Adaptation and mitigation measures are also needed in Sudan to accommodate for the new flowing conditions.

Keywords: Sustainability, WEF-Nexus, GERD, Sudan, Ethiopia,

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List of Abbreviation

GERD	Grand Ethiopian Renaissance Dam
WEF	Water, Energy, and Food
MW	Megawatts
bcm	billion cubic meters
IPoE	International Panel of Experts
ESIA	Environmental and Social Impact Assessment
ITEIA	Transboundary Environmental Impact Assessment
ktoe	kiloton of oil equivalent
kV	kilovolt
IEA	International Energy Agency
USD	United States Dollar
SDGs	Sustainable Development Goals

1 Introduction

1.1 Introduction

Transboundary waters are a critical resource for peaceful cooperation and Sustainable Development. There are more than 263 transboundary lakes and river basins covering nearly half of the planet's surface (Yihdego et al., 2017). Transboundary aquifers provide about 60% of freshwater supply that nearly 40% of the world population depend on them for their livelihood (UN Water, 2013). Providing clean and accessible water for everyone is one of the major challenges of the twenty-first century. The increase in world population, agriculture, and manufacturing puts more stress on the limited available clean water resources around the world. By 2050, global water demand is expected to increase by 55% and people living in severe water stress areas to increase by more than 40% (Unesco, 2014).

More than 60% of large river systems were affected by dam construction across the world as of 2008. Large dams are often criticized for exaggerated economic benefits while ignoring their negative socio-cultural and environmental consequences (Karami & Karami, 2019). A great amount of environmental and social impacts is widely documented as a result of large dam construction across the world. Some of these impacts include drying of lakes and wetland and alteration of water quality and aquatic system. Change in sediments transported downstream can reduce nutrient supply in the river and greatly affect the ecosystems in these areas. Displacement of local people is one of the most common sociocultural problems that led to the extinction of indigenous cultures, destruction of historical sites, and breaking of the social fabric in local communities (Karami & Karami, 2019).

The Nile River is vital for the livelihood in the north-east African region that is used for water and energy security and agricultural production. The Nile River is considered one of the hotspots for water conflict in the world due to the increase in water stress and absence of inclusive legal framework between the Nile countries (Yihdego et al., 2017:p.4) More than 96% of the water in Sudan is used by the agricultural sector, and hydropower is one of the main sources of energy accounting for 55.8% of the total electricity supply (Nexus Dialogue Programme, 2018). With the increase in population, urbanization and the effect of climate change, Sudan is expected to suffer from water deficiency of 3 billion cubic meters (bcm) between 2012-2027 (Shay, 2018).

Transboundary rivers connect national and international scales, as actions taken by upstream countries can lead to an increase in water stress and insecurity in downstream ones. The Blue Nile river is one of the two main branches of the Nile River that originates in Ethiopia and contributes by about 85% of the total Nile water (Yihdego et al., 2017:p.4). The Ethiopian government announced in 2011 the construction of the Grand Ethiopian Renaissance Dam (GERD) in the Blue Nile 40 km away from the Sudanese borders. The dam is considered the biggest dams in Africa and will provide Ethiopia with 6,000 MegaWatts (MW) of electricity (Yihdego et al., 2017). The GERD operation will alter the Blue Nile flow leading to different impacts downstream including change in the water level and sediment transportation. Given the magnitude of the GERD, it is expected that it will greatly influence the socio-economic and hydrological position of downstream countries.

The water, energy, and food sectors are inextricably linked and an action taken on one of them usually have a direct impact on one or all of the others (UNECE, 2019). In this study, the impact of the operation of the GERD on Sudan will be investigated in term of water, energy, and food (WEF) security nexus. The nexus approach provides a clear framework to navigate the interconnectedness between the water, energy, and food sectors instead of treating them separately. A sustainability analysis will also be carried out to analyze the impact of the dam operation on the environmental, social and economic aspects in Sudan.

1.2 The Nile River

The Nile River is considered the longest river in the world with the Nile basin covering an area of 3.18 million Km^2 over eleven countries in East and North Africa. The river has two main tributaries called the White Nile and the Blue Nile that unite at the Sudanese capital, Khartoum, to form the main Nile as shown in figure (1). The White Nile originates from the Great Lakes in Central Africa while the Blue Nile begins at Lake Tana in Ethiopia and accounts for most of the Nile waters (Wheeler *et al.*, 2016; Yihdego et al., 2017). The average annual runoff of the Nile River is approximately 85 Km^3 with the Blue Nile contributing about 57% to 80% depending on the season, and 29% and 14% coming from the White Nile and Atabara river respectively (Mordos, 2016).

The eleven Nile basin countries have a total population of more than 400 million people with an expected increase to about 600 million by 2025 (Oestigaard, 2012:p.32). Due to the hot and dry climate in the region, the Nile River has been of high significance since ancient times especially for the Sudanese and Egyptian civilizations. The majority of the historic and cultural sites in these two countries are found near the river and most of the population and cities are located along the riverbanks. Most of the Nile water is used by Sudan and Egypt for agricultural, energy, and freshwater security making the river the life-artery in these countries.

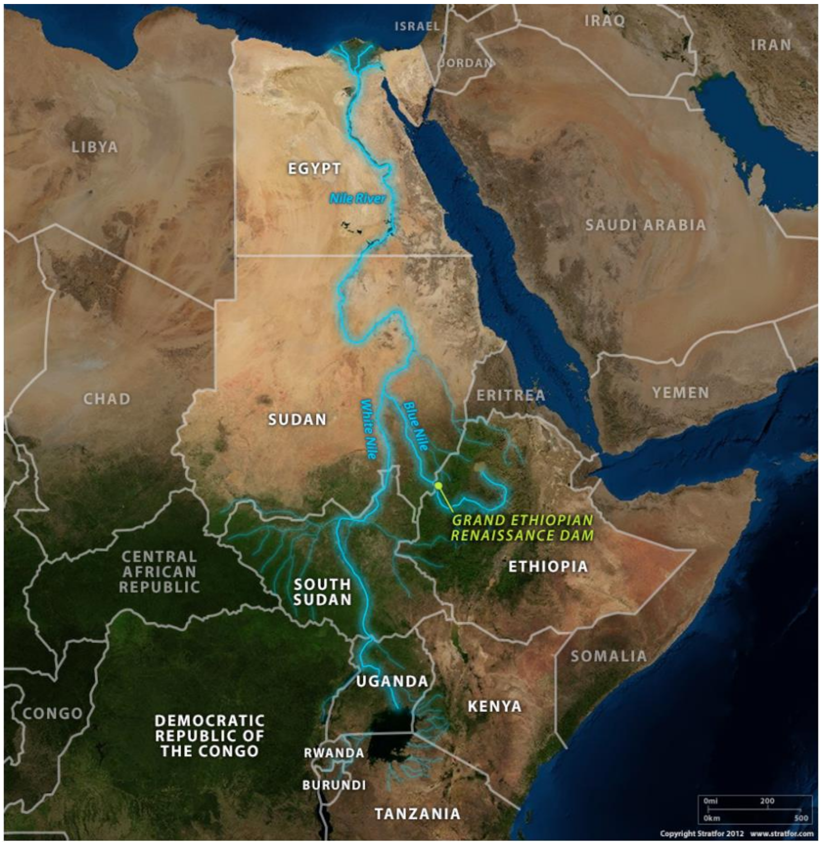

Fig. 1. The Nile River and its tributaries (Mahgoub, 2014:p.23).

When rivers cross political borders the issue of water allocation becomes of great focus to all involved parties (Munia et al., 2016). Figure (2) shows a timeline of the different agreements and cooperation attempts between the Eastern Nile countries (i.e. Sudan, Ethiopia, and Egypt). In 1959, an agreement was made between Sudan and Egypt that gives each country a share of 18.5 and 55.5 billion cubic meters (bcm) respectively from the average annual Nile flow. According to the agreement, Sudan takes a share of 22% of the total Nile water even though 60% of the Nile basin lies within its borders (El-Dukheri et al., 2011:p.17). This agreement replaced the one made in 1929 by colonial Britain and gave Egypt the veto rights against any major irrigation or power project to be constructed in the Nile River and its branches. Ethiopia never acknowledged the two previous agreements and considered them as non-binding to their use of the Nile water as it was not colonized by Britain or any other nation (Oestigaard, 2012). The Nile Basin Initiative (NBI), established in 1991, was launched between the Nile riparian countries for peaceful cooperation in socio-economic development and as a legal framework for the regulation and management of their shared resource (Oestigaard, 2012; World Bank Group, 2010:pp.91–92).

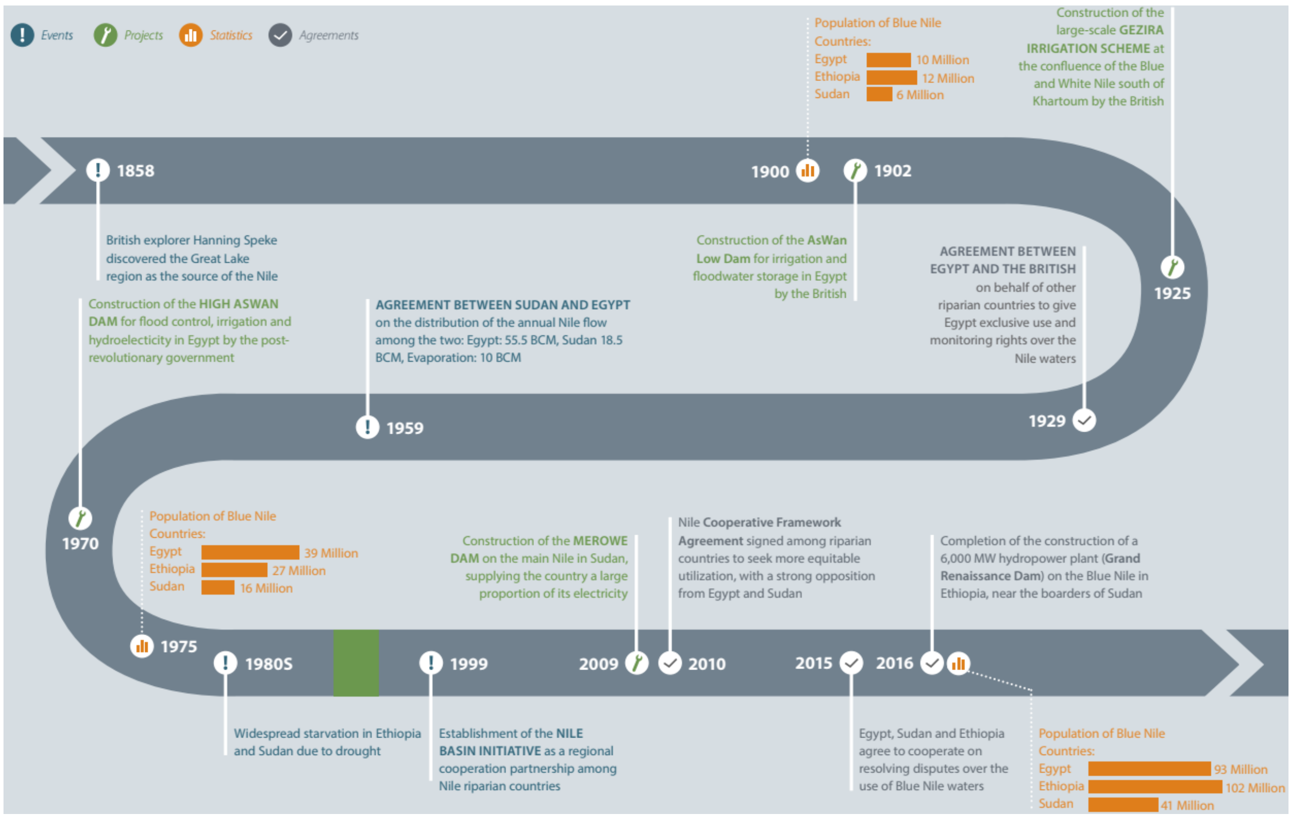

Fig. 2. Timeline showing development plans and agreements of the Blue Nile River (Al-Saidi & Ribbe, 2017:p.50).

1.3 The Grand Ethiopian Renaissance Dam

The GERD is a major hydroelectricity dam that is being constructed in Ethiopia along the Blue Nile River. The dam is considered as the biggest dams in Africa and the seventh largest in the world providing Ethiopia with 6,000 MW of electricity which will be used by domestic consumers and sold to neighboring countries. The Ethiopian government identifies the dam as a huge step in its process of achieving energy security and economic development (Yihdego et al., 2017). The dam was initially planned to be constructed within 5 years and start the impounding phase by 2017 as shown in figure (2) (Getachew, 2018). However, challenges in the construction process and changes in the design have led to great delay in the dam construction. As of April 2019, the Ethiopian ministry of Water, Irrigation, and Energy

(MoWIE) announced the completion of 65% of the dam while the remaining percentage could be completed as the dam is generating electricity (AWNY, 2017; Astatike, 2019). The ministry also stated that impounding will start in 2020 and the generation capacity will reach 750 MW from 2 turbines out of 16 by December of that year (Astatike, 2019).

The site of the dam was identified and recommended in a study done by the US Bureau of Reclamation in a survey done on the Blue Nile between 1956 and 1964. The Bureau planned for the dam to generate 1,400 MW with a reservoir of 11 bcm (Ahmed & Elsanabary, 2015). Two site surveys were also carried out in 2009 and 2010 before the dam design was submitted in November 2010 with a change in reservoir capacity to 74 bcm. On April 2011, the Ethiopian government laid the foundation for the dam at the Benishangul-Gumuz region of Ethiopia 40 Km away from the eastern Sudanese borders as shown in figure (1) (Ahmed & Elsanabary, 2015). The main dam is planned to be 175 meters high while the saddle dam will have a height of 45 meters (Figure 3). The reservoir will cover an area of 1,874 km^2 with a storage volume equivalent to 1.3 times the annual Blue Nile discharge (Yihdego et al., 2017).

In November 2011, the ministers of water affairs of Sudan, Egypt and Ethiopia met and agreed on a procedure for dam review through an International Panel of Experts (IPoE) that consisted of two experts from each country and four international experts in the field of dam construction and analysis (Shay, 2018). In 2012, the Ethiopian government published two reports for the dam environmental impact the first one was an Environmental and Social Impact Assessment (ESIA) while the second one was an Initial Transboundary Environmental Impact Assessment (ITEIA). In 2013, the IPoE published a report containing their assessment from reviewing the dam documents and visiting the dam site (Anon, 2014). The report raised concerns regarding the possible downstream damage the GERD can have and recommendation for changes in the dam design. Negotiation between the three countries have been fluctuating regarding the dam operation and first filling with no clear agreement reached yet. Egypt expressed great concerns and opposition against the dam and considered it as a threat to its national security. In Sudan, there was initial skepticism but the government acknowledges the benefits the dam will provide for Sudan (Shay, 2018).

Fig. 3. Main Dam and Saddle dam of GERD (Poindexter, 2017).

1.4 Study area

Sudan is a northeastern African country with an area of 1,879,400 km^2 and a population of more than 40 million people mostly living in rural areas (about 65%) (Nexus Dialogue Programme, 2018). Sudan has an abundance of natural resources that constitute the country's main source of wealth ranging from fertile lands, fresh waters, livestock, and minerals. Agriculture represents the backbone for the economy providing 30% of the GDP and about two-third of the population is dependent on it for their livelihood (Nexus Dialogue Programme, 2018). Different climates exist within the country that extends from north to south as desert, semi-desert, and poor savannah.

The Nile River and its tributaries are considered the main source for water in the country with the Blue Nile contributing the majority of the Nile water. The construction of the GERD on the Blue Nile is expected to greatly change the quantity and quality of the river flow downstream. In this research, these expected changes will be studied in term of impact on the main hydropower and agricultural projects located along the Blue Nile and the main Nile Rivers from the Ethiopian to the Egyptian borders. The study will focus on three main operational dams and one irrigation project that will be directly affected by the GERD operation namely Roseires, Sennar, and Merowe dams as well as Gezira irrigation scheme as shown in figure (4).

The Sennar dam was constructed in 1925 under the British rule near Sennar town about 300 km south from Khartoum. The dam is 3,025 m long and about 40 m high with an initial purpose to irrigate the Gazira scheme (Rabah et al., 2016; A. Zeidan, 2013). In 1962 the dam was expanded to provide hydroelectricity production with 15 MW installed capacity. In 1966, the building of the Roseires dam was completed under the 1959 agreement with the purpose of controlling flood water coming from Ethiopia. The dam is located approximately 110 km from the Ethiopian borders and is about 1 km wide and 68 m high (A. Zeidan, 2013). The dam was also not initially intended for hydropower production but a power generation plant was added in 1971 with an installed capacity of 280 MW. Heightening of the dam with an extra 10 m was carried out between 2010 and 2012 that increased the reservoir capacity from 3 bcm to 7.4 bcm and added 50% increase in its power generation (Alrajoula et al., 2016; A. Zeidan, 2013). Inaugurated in 2009, Merowe dam located along the Nile River, some 350 km north of Khartoum, is 9 km in length and 67 m in height. It is considered the largest hydroelectricity dam in Sudan with an installed capacity of 1,250 MW and a 12.5 km^3 in reservoir storage (20% of the annual flow of the Nile) (A. Zeidan, 2013).

The Gezira scheme started in 1925 after the construction of the Sennar dam and is considered the largest irrigation project in the country and one of the largest in the world covering (with the Managil extension) an area of around 880,000 ha (about half the country's irrigated lands) (Oestigaard, 2012:p.51; Nexus Dialogue Programme, 2018). The project is a gravity irrigation system from the Blue Nile that uses about 35% of Sudan's water share according to the 1959 agreement (30.5 X 106 m3/day). About 120,000 farmers are associated with the project cultivating cotton, groundnut, wheat and sorghum (Al Zayed et al., 2015; Oestigaard, 2012). Cotton production was the focal crop at the beginning of the project but in the recent years sorghum became the main crop taking about 35% of the cultivated area, while wheat, cotton, and groundnut cultivation area account for 25-30%, below 24%, and around 20% respectively (Al Zayed et al., 2015).

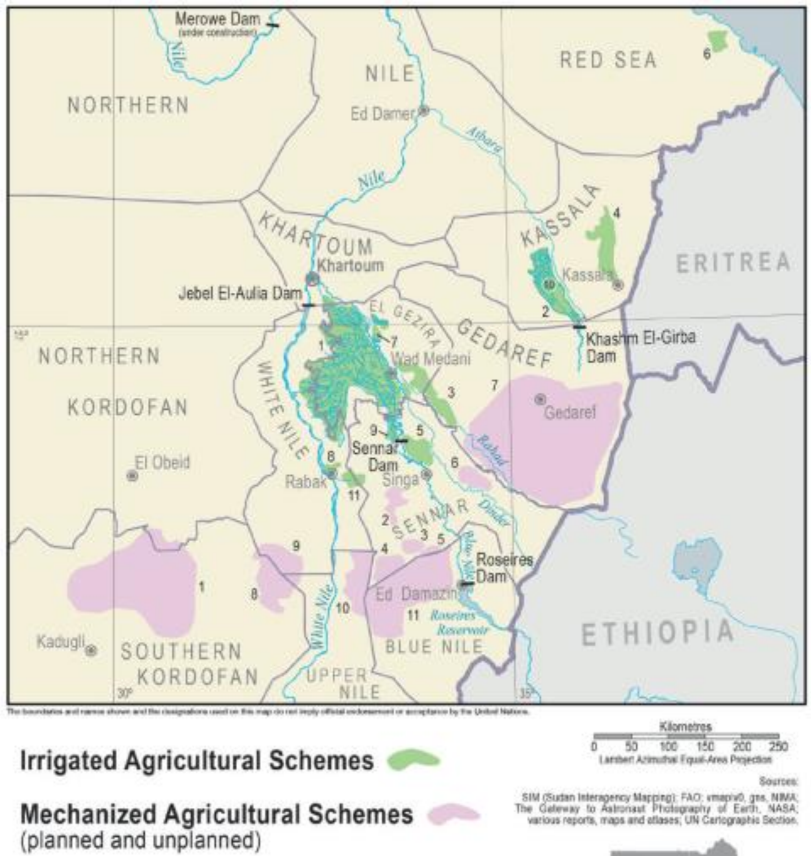

Fig. 4. Major agricultural schemes and dams in Sudan (Nexus Dialogue Programme, 2018).

1.5 Aim of the research

The purpose of this study is to assess and analyze the impact of the GERD first filling and operation on the WEF security nexus in Sudan. The study uses the nexus perspective which increases the understanding of the interdependencies between these sectors instead of treating them in silos (UNECE, 2019). The study also aims to carry out a sustainability assessment on the impact of the dam on the environmental, social, and economic aspects in Sudan. The study further aims to explore strategies to utilize the dam operation to increase resource efficiency and ways to mitigate the trade-offs and negative impacts on Sudan.

1.6 Research questions

The main question in this thesis will be:

- How will Sudan’s WEF nexus be affected by the operation of the GERD?

In addition, some sub-questions the thesis will look into are:

- What is the current situation of Sudan’s water, energy, and food security?
- How sustainable will the impact of the GERD operation be on Sudan?
- What measures could be taken to utilize and mitigate the GERD impact on Sudan?

2 Methodology

2.1 Research method

This will be a study of the impacts of the GERD on Sudan's water, energy, and food security nexus based on secondary literature and available data. The research will be a qualitative desk study that incorporate literature from various disciplinary perspectives. Different literature will be collected and analyzed ranging from scientific peer-reviewed articles, academic materials, and official documents and data from international organizations and local ministries. Qualitative studies have the advantage of being more holistic and having a systematic perspective with flexibility in the design approach (Batisha, 2015:p.36). The lack of adequate data and limited time availability are some of the reasons that necessitate the use of qualitative approaches, which is the case in this study. The method for assessing security will be based on the effect of the GERD operation on the major agricultural and hydroelectricity project in Sudan including water availability and ecosystem services.

Two theoretical frameworks will be used to guide the study while answering the research questions. The main theory to be used is the WEF nexus which offers a framework to treat and navigate the interconnectedness between the three sectors instead of treating them in silos. The sustainability theory will also be employed which seeks to balance the social, economic and environmental dimensions to produce a frame for development that operates within the boundaries of our planet. Two scenarios will also be analyzed for their impact on Sudan's security and resource use which are the case of the GERD failure and the benefits of cooperation between the Eastern Nile countries.

2.2 Research limitations

- Restrictions on data access and availability from official institutions in Sudan and Ethiopia.
- Lack of adequate and reliable research and statistics on the impact of the GERD on some of the major sectors and projects in Sudan.

2.3 Theoretical framework:

2.3.1 WEF nexus

The WEF nexus got great attention and acceptance after the International Conference on Water, Energy and Food Security Nexus: Solutions for Green Economy in Bonn 2011. It is a multi-centric approach that provides a map of the interdependences between the water, energy, and food as well as other areas including biodiversity and climate change, unlike the Integrated Water Resource Management (IWRM) approach and many others that have one sector as a focal point. Different national and international organizations including FAO and Further Earth are currently operating upon this concept (Liu et al., 2017). The nexus perspective is an important method to minimize trade-offs and increase synergy between the water, energy, and food sectors that can lead to improved cross-sectoral coordination and cooperation. It also helps in identifying and assessing interventions and responses that will assist decision-makers in their effort to develop natural resources (UNECE, 2015. Hoff, 2011).

The 2015 report of the World Economic Forum classified the WEF nexus as a major risk to the economic stability of the world (World Economic Forum, 2015). More progress has been done in studying the relationship between sectors like water-food or water-energy compared to the relatively new WEF framework. The new challenges the world is currently facing in feeding the increasing population and the shortage of available water and energy resources necessitate a quick development and adoption of the WEF nexus framework. An increase of the world population of more than 2 billion people is expected by the year 2050, which will increase the global demand for energy by more than 80% and for food by more than 60% (Liu et al., 2017).

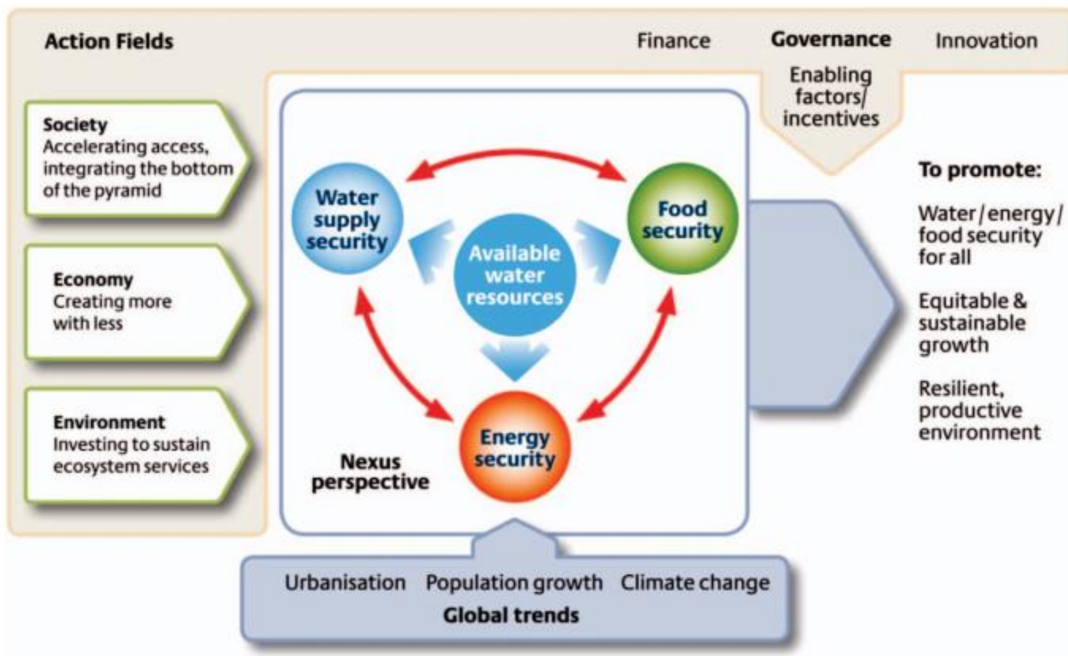

Fig. 5. Hoff's WEF security nexus framework (Hoff, 2011).

Depending on the purpose of the nexus assessment, several nexus frameworks were developed since Bonn that had different scopes and geopolitical scales (McGrane et al., 2018:p.2; UNECE, 2015). There is a lack of unified definition and common conceptual framework for the WEF nexus which was described in some publications as problematic (Wichelns, 2017). For the purpose of this study, the definition of WEF security nexus framework devised by Hoff (2011) is used (Figure 5). Water is identified as a central piece in this framework that plays the role of both the state and control variable for change. It identifies urbanization, population growth, and climate change as main drivers for pressure on resources which calls for integrated nexus approach (Hoff, 2011).

The term security is currently used in a much broader sense than its classical use to mean conflict and military risk. Broadening the definition of national security was proposed by Mathew (1989) "to include resource, environmental and demographic issues" (Mathews, 1989:p.162). Human security now encompasses a wide range of sectors including personal, health, food, environment, political, energy and water securities (Bigas, 2013).

Water security is defined by Grey & Sadoff, (2007) as "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks". Despite the current availability of water to meet the growing population, more regions around the world are starting to suffer from a temporal or permanent shortage of water including parts of China, India, and the Middle East. Water security is highly important for energy security with around 8% of water withdraws worldwide used for energy production (up to 45% in industrial countries) (Hoff, 2011). Water is used for the production and processing of all types of energy source including fossil fuel, biofuel, and renewable energies. Worldwide, hydropower production accounts for 86% of renewable energy generation and 16% of electricity generation. Several regions, however, still behind in using their available potential of this energy with Africa only utilizing 5% of its true hydropower potential (Hoff, 2011). Water quality is also affected by the energy sector including oil spills and change in river characteristics by the construction of dams. Water for energy accounts for most of the water used around the world with one liter of water, on average, is required to produce one calorie of food energy (Hoff, 2011).

The Food and Agricultural Organization (FAO) defines Food Security as "the availability and access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life" (FAO, 1996). Most of the world blue water (80-90%) is used for food production as well as a large share of green water (Hoff, 2011). The agricultural sector is the backbone for livelihood in rural areas especially in developing countries where it contributes greatly to their GDP. The decrease in water availability is expected to greatly impact agricultural productivity leading to an increase in poverty levels in the developing world (Karami & Karami, 2019).

There is no common unified definition for energy security. The International Energy Agency (IEA) defines it as “the uninterrupted availability of energy sources at an affordable price” (IEA, n.d.). Lack of energy security can intensify water demand as energy is used for water treatment, extraction, transportation, and distribution. The term “bottled electricity” is coined for desalinated water due to the great amount of energy used (2.6–4.36 kWh) compared to surface water processing (0.37 kWh) (Hoff, 2011). The use of energy for food production greatly increased the yield due to the mechanization of the process. It also, however, increased energy intensity use in agriculture, resulting in dependency between the profit from high input agriculture and energy prices (Hoff, 2011).

2.3.2 The sustainability theory

The publication of the 1987 report Our Common Future by the UN’s World Commission defined the most cited and widely used definition of the term Sustainable Development as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). The definition highlights the future dimension of sustainability and emphasizes the importance of equity across generations. This definition was criticized for being too broad and ambiguous which limited its overall effectiveness and impact. The Brundtland report, however, helped Sustainability to evolve from a mere concept to a movement, with more international debate and actions taken since then.

Signed by all nations around the world, the 17 Sustainable Development Goals (SDGs) were adopted by the United Nations in 2015 as a successor to the eight Millennium Development Goals (MDGs) that were formulated in the year 2000. The aim of these SDGs is to improve the prosperity and wellbeing of all nations around the world while conserving the environment. They are criticized, however, for different reasons including their prioritization, focus, and legality. Out of the 17 goals, the environmental ones are placed at the end of the list (goal 13, 14, and 15) while the economic and social goals are placed ahead. Failure to meet the climate goals poses a threat to the achievement of all the other goals and targets making them extremely important (Howard, 2018). Another issue raised is the contradiction exist in some of the goals more particularly goal 8 that aims to achieve decent work and economic growth. The call for indefinite growth that targets a 7% annual economic increase in developing countries is a recipe for environmental degradation and neglect the ideas of planet boundaries and resource limitation

(Montemayor, 2019). Finally, each country sets its own targets which are legally not binding with no repercussions if they failed to deliver which gives an excuse for these countries to continue with business as usual.

Sustainability seeks to achieve equal harmony and balance in the economic, environmental, and social dimensions (pillars). The system could be regarded as unsustainable if anyone of these dimensions is weak. The environmental dimension focuses on living within the finite resources available and to ensure ecosystem wellbeing to maintain its diversity, quality and ability to sustain all life (Michael et al., 2014:p.492). The economic dimension refers to growth and productivity, where resources are exploited in a sustainable and efficient way that ensures their availability in the long term (Wanamaker, 2018). The focus in human wellbeing is part of the social dimension, which aims to increase equal distribution of opportunities for everyone in the society (Michael et al., 2014:p.493).

Performing sustainability assessments depends largely on the expert's view and conceptualization of sustainability and its related issues. Within environmental science, the understanding of sustainability is categorized into four main types (Al-Saidi & Ribbe, 2017). The first type is *Intervention Sustainability*, which seeks to assess the impact of a particular set of actions (like new environmental project or policy) in order to see the benefit or harm of their implementation after the life span of the intervention. It is characterized by dealing with a specific set of issues and for having a small time-frame. The second type is *Resource Sustainability* that explores the impact of using a certain resource (e.g. water or land) with regard to different issues including resources protection, equity of access, etc. (Al-Saidi & Ribbe, 2017). Assessing the environmental issues at a large scale is referred to as *Environmental Sustainability* which looks into issues like society's footprint or climate change impact on the environment. The final type of sustainability and the more inclusive term is *Sustainable Development* as it combines sustainability with the social model of development. It thus has *Environmental Sustainability* as one of its pillars, as well as the economic and social elements of development (Al-Saidi & Ribbe, 2017).

Based on the perspective in question, Sustainability assessment of the WEF nexus can be related to one or both of *Resource* and *Environmental* sustainability. The assessment could be taken from one sector while considering the others (e.g. energy sustainability considering water and food) or an integrated assessment of all three sectors, which could then be extended to consider other environmental aspects as well including eco-systems and climate (*Environmental* Sustainability) (Al-Saidi & Ribbe, 2017).

The Nexus and sustainability theory go hand in hand, as the achievement of the United Nation's SDGs calls for an integrated nexus implementation. The three sustainability pillars (environment, society, and economy) are identified as action areas in Hoff's WEF security nexus to promote water, energy, and food security for all (Hoff, 2011). According to the UNECE, the nexus approch is directly linked to three main SDGs. It is also, however, relatively connected to the other goals as an action taken on one of the 17 goals can have a direct impact on the rest (UNECE, 2019:p.9). The three goals are:

- SDG 2: *Zero hunger* with the aim of providing food security for all.
- SDG 6: *Water and sanitation* to provide clean water and sustainably manage the resource.
- SDG 7: A*ffordable and clean energy for all*.

3 Results

This section starts by looking into the current states of the WEF security nexus in Sudan. Then an analysis of the expected impact from the GERD operation according to research done in the areas of water, energy, and food will be described. The section further looks into the impact in the case of dam failure, transboundary cooperation, and sustainability assessment of the dam impact.

3.1 Sudan's current WEF nexus

Sudan's overall resources security is characterized by increasing demand, shrinkage of availability, and vulnerability to external influences. Sudan remains low in term of human development with an index of 167 out of 188 countries as of 2015 (WFP, n.d.). In the following, the country's current status and challenges in each of the sectors will be described.

3.1.1 Water Security

Sudan's water security is vulnerable to high risk of extreme droughts and floods, due to a mostly desert climate and very high reliance on water originated as precipitation from outside the country(96%) (Nexus Dialogue Programme, 2018). There are four main water resources in Sudan which are rainwater, the Nile River, seasonal streams, and groundwater. (Sudan uses 13.8 bcm which is less than its share)

In term of rainfall, there are three diverse climate zones in Sudan that goes from north to south as a desert belt with an average annual rainfall of less than 75 mm, semi-desert belt with an average between 75-300 mm, and poor savanna belt with rainfall between 300-500 mm (Idris, 2016). There is a relatively short rainy season that extends from July to September with estimated annual rainwater falls of 1,000 milliard Cubic Meters (Mcm). A decrease in rainfall and an increase in drought spills was observed in recent years which is attributed to climate change (Idris, 2016).

The main source for water in Sudan is considered the Nile River as 70% of the country lies within the river basin (Nexus Dialogue Programme, 2018). Several seasonal streams, locally called Wadis, flow across the country during the rainy season and drain the major basins. The average annual yield is approximately 5-7 Mcm with the possible occurrence of harsh floods from large streams like the Gash river (200-800 Mcm) (Idris, 2016). This water provides a valuable source for irrigating small nearby areas, recharging groundwater, or to be collected by harvesting structures. Four major groundwater aquifers are distributed throughout the country that covers half of its surface area. Some of the challenges posed for groundwater is its limited annual recharge of 4.5 Mcm for an estimated total groundwater basin storage of 12,000 Mcm, as well as the high cost required to exploit the resource resulting in a small sum of abstraction at only 2.9 Mcm (Idris, 2016). Furthermore, the unplanned manner of groundwater extraction poses a risk to water quality and yield reliability due to overproduction (Nexus Dialogue Programme, 2018).

The majority of water use comes from surface water, which is mainly utilized for agricultural production that consumes more than 96% of extracted water. Groundwater is used mostly for municipality water supply accounting for 3.5% of the total water use, and 0.3% is used by industries (Nexus Dialogue Programme, 2018).

3.1.2 Food Security

The majority of water in Sudan is used for agricultural production (97%) with an increase in the amount of water required to meet the demands of a growing population. (Mahgoub, 2014:p.32). The Sudanese government estimated that 32 bcm of water will be required by 2025 to achieve food security and meet other needs (Oestigaard, 2012:p.28).

During the time of Sudan's independence in1956, Sudan was said to be a potential breadbasket for Africa and the Middle East due to its extensive arable land that is suitable for agricultural production through rainfed or irrigation farming (El-Dukheri et al., 2011:p.29). The country, however, often failed to feed its own population during the past few decades. More than 80% of the Sudanese people are estimated to lack affordability for healthy daily food and about 38% of the population suffering from chronic malnutrition. Food insecurity has been quickly raising in recent years with an estimated 5.5 million people considered food insecure in early 2018 compared to 3.8 million in 2017. (WFP, n.d.). Sudan was among the worst eight countries that experienced food insecurity in 2018 and is expected to remain in the same ranking in 2019 (FSIN, 2019). Food expenses are the main spending in Sudanese households accounting for 61% of the income. The continual increase in food prices due to economic challenges in recent years further impacts the food security in Sudan (Nexus Dialogue Programme, 2018). In addition, the influx of 1.1 million South Sudanese refugees in the recent years increased food insecurity with only 2% of the Internally Displaced People (IDP) in Darfur and 1% of the refugee population capable of affording to buy their food (WFP, n.d.).

Despite that third of Sudan's area is arable land covering 84 million hectares, only 21% of this area is utilized for agricultural production. Forest and pasture further account for approximately 40% of the total land. More than 80% of the population in rural areas are dependent on farming and herding for their livelihood (El-Dukheri et al., 2011). Sudan has the largest irrigated area in sub-Saharan Africa with about 80% of these irrigated structures being originated in the 1960s. Sudan's agricultural sector has different agricultural zones irrigated through rainfall or river irrigation making it suitable for a variety of crops (Mahgoub, 2014:p.33). The country's major agricultural projects are the Gezira, New Halfa and Al-Rahad schemes producing cotton, wheat, sorghum and vegetables. Irrigation covers about 7% of cultivated area but accounts for over 50% of crop yields. Most of the irrigation projects use gravity, water pumps, and basin from the Blue or White Nile (Mahgoub, 2014).

Fishing and aquaculture harvest are important food resource in Sudan due to its diverse marine and freshwater resources. The total fish production from inland water is estimated at 45,000 metric tons (MT)/year while the potential yield is estimated at 110,000 MT/year (El-Dukheri et al., 2011:p.27). Rangelands are another important resource that covers about 117 million hectares mostly in semi-desert and low rainfall savannah areas. It provides feed for around 80% of the national herd requirement, habitat for wildlife, protection for soil and water, and conservation for biodiversity. An estimated decline in the rangelands area by 19.6% was observed due to lack of policies and legislation to protect these areas (El-Dukheri et al., 2011:p.33).

Agriculture accounts for about 12% of the total GDP, while animal resource and forestry add another 18% and 1% respectively. Sudan has higher imports to export in food and agriculture essentials with 750 million USD on agricultural exports and 1,776 million USD of food-related imports (Nexus Dialogue Programme, 2018; El-Dukheri et al., 2011:p.18).

3.1.3 Energy Security

The Sudanese energy security is vulnerable due to high reliance on hydroelectricity for energy generation, which could be affected by droughts, climate change, or upstream countries' activities. There are four main energy sources in Sudan namely hydroelectricity, petrol, biomass, and renewable energy.

Electricity production is highly dependent on the Nile River with 55.8% of electricity generation coming from hydropower followed by thermal production at approximately 44%. Despite the huge potential for renewable energy like solar and wind; their share is still extremely low at less than 1% (Nexus Dialogue Programme, 2018). Electricity coverage in the country is also low, only 45% of the population had access to electricity in 2014 with about 70% of people living in urban areas having access compared to rural areas where only 22% of people are covered (EIA, 2018; Nexus Dialogue Programme, 2018). Another issue is the shortage of reliable electricity supply at peak hours especially during the summer season of late April to July where the demand is very high. As of 2016, the total electricity generation was about 14,431 GWh with extra 440 GWh imported from nearby Ethiopia. Biomass or diesel generators are used to generate electricity at off-grid locations. (Nexus Dialogue Programme, 2018).

The installed capacity from hydropower was 1,585 MW in 2014, which accounts for about 38% of the installed and potential hydroelectric power (Rabah et al., 2016). There are seven hydroelectricity dams in Sudan namely Roseires, Sinnar, Jebel Aulia, Khashm el-Girba, Merowe, Rumela and Burdana. Along with the Sennar, Roseires, and Merowe dams that have a cumulative capacity of 1,545 MW, Rumela and Burdana dams, which were constructed at the upper Atabara and Setti rivers, started operation in 2017 and added an extra 320 MW and 15 MW to the total electricity supply respectively (EIA, 2018). Some of the other planned hydroelectricity dams are Kajbar, Dal, and El-Shireig. The construction of the Kajbar dam in the northern part of the Nile valley has halted because of strong opposition from the local community due to its potential environmental impact (EIA, 2018).

As of 2016, thermal power contribution in electricity production was at 1,400 MW from 8 power plants, with another 405 MW and 600 MW from stations under construction and planned power stations respectively. Moreover, all utility services including medical, government, and higher education facilities are usually equipped with an off-grid standby power generation (Nexus Dialogue Programme, 2018; Rabah et al., 2016). The Sudanese government is working to diversify the electricity generation sources with several conventional thermal plants. The majority of these planned project, however, are mainly financed by Saudi Arabia. The decrease in oil prices in recent years resulted in substantial cuts in their budget which makes the future of these projects questionable (EIA, 2018:p.11). Another diversity issue that is affecting energy security is the use of gasoline in steam turbines. The gasoline dependency for thermal generation is undesirable due to its competitive nature as it is being used by both the agricultural and transport sectors, in addition to its relatively higher cost compared to heavy fuel and coke (Rabah et al., 2016).

The secession of the country´s southern part in 2011 had a huge impact on oil production and the country's economy, as 75% of the oil producing fields were located there (EIA, 2018). The current total oil supply is 7,594 kilo tonne of oil equivalent (ktoe) coming from crude oil, associated gas, and imported oil. The majority of the total oil mix is used to meet the demand of mainly the transportation sector at 79% as well as the industrial and residential sectors at 11% and 8% respectively (Rabah et al., 2016). The increase in industrialization and car acquisition increased the number of imported oil products to meet the increasing demand. In 2015, 40% of the total consumption was from diesel and fuel oil to generate electricity, and 17% in the form of gasoline for the transportation sector. China is a leading importer of Sudanese crude oil with almost 99% of the total crude exported going there (EIA, 2018). The total import of fuel oil is at 1427 ktoe and 40 ktoe in electricity from Ethiopia accounting for 7% of the energy the mix (Rabah et al., 2016:p.9).

Biomass contributes to about 56% of the total energy generation. This high percentage is due to the fact that most of the population in Sudan are located in rural areas (70%). The lack of access to grid electricity, fuel gas, and kerosene resulted in high dependency on biomass to meet the daily demands (Rabah et al., 2016). Directly burning of wood and crop residue is inefficient and very harmful to the environment and health. The annual consumption of dedicated biomass fuels is 13 X 10^6 m^3 with reforestation programme of 1.05 X 10^6 m^3 hectares initiated by the government (El Zein, 2017:p.8). Sudan has a high potential for solar, wind and geothermal energy due to favorable operation condition, however, there is a poor contribution of these sectors to the total energy generation. Despite having average daylight of 9 hours and an average wind speed of 4.5 meters/second across almost half of the country; renewable accounts for less than 1% of the total power generation. The telecommunication industry has about half of the 2 MW installed capacity of solar in Sudan (El Zein, 2017).

Biomass has the highest consumptive use accounting for 56% of the total primary energy use, followed by oil and hydroelectricity at 39% and 5% respectively. The residential sector is the highest energy-demanding sector at 40% (3,911 ktoe) of the total energy share followed by the transport and services sectors at 31.4% and 16.1% respectively (El Zein, 2017). The total electricity consumption in the country is at 11,796 GWh, with more than half of the energy being used at the household level, with industrial, agricultural and governmental consumption next at 15.2%, 6.1%, and 9.5% respectively (Nexus Dialogue Programme, 2018).

3.1.4 Nexus security assessment

Pardee RAND Food-Energy-Water (FEW) Security Index is presented in this section to show how much Sudan scores in term of resource security and the most insecure resources. This index uses indicators of *Availability* and *Accessibility* for each nexus aspect as well as *Adaptive Capacity* for water security. The FEW index consists of three sub-indices for each sector (water, energy, and food), which are derived from combining 20 different measures including food prices, electrification rates, and access to improved drinking water. The FEW index and the sub-indices have assigned values between 0 and 1, with 0 representing minimum values and 1 for values that are sufficient to meet the basic demand (Willis et al., 2016).

Willis et al. (2016) see *Availability* as a determinant link between resources and human development “and whether the population is provided with adequate resources to support needs for dietary requirements, sanitation, and productivity”, while *Accessibility* as the “distribution of those resources across society”. *Adaptive capacity*, on the other hand, reflects “a nation’s capabilities to provide water resources over time and in response to disruptions” (Willis et al., 2016).

Sudan’s FEW security nexus is presented in Figure (6). The Figure shows that water security is the lowest among other resources with water adaptive capacity scoring the least in all indicators. Food, on the other hand, scored the highest among sub-indices with food availability having the highest scores among the indicators. The overall integrated FEW security index for Sudan is 0.39, which is the geometric unweighted average of all the sub-indices.

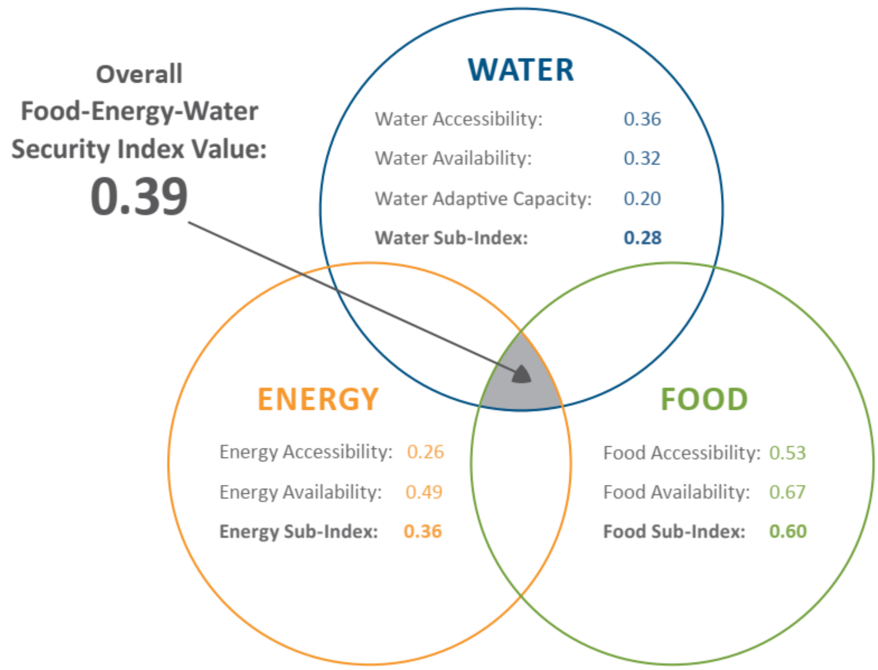

Fig. 6: Sudan's FEW security index (Nexus Dialogue Programme, 2018)

3.2 The impact of the GERD on Sudan's WEF nexus

Dams are constructed as means to achieve national development plans, yet they have a considerable impact on the socio-economic and environmental aspects. Changes in ecosystems, resettlement of locals alter in river characteristics are among the possible negative impacts that need to be managed and mitigated (Jalilov, 2010). There seems to be a lack of agreement in literature for whether the GERD will have a positive or negative impact on the riparian countries (Liersch et al., 2017). This section looks into the published research regarding the impact that the GERD will have on different sectors and projects in Sudan.

3.2.1 Water security

The amount of water reduction from the GERD filling is still unknown as there is no published public plan by the Ethiopian government nor is there an agreement with the riparian countries regarding the dam filling and operation. Different scenarios were proposed regarding the impound phase to fill the 74 bcm reservoir volume (1.5 times the annual Blue Nile discharge of 48.85 bcm) (Mohamed, 2018:p.455). The selected filling scenario will lead to implication on the amount of time required to fill the reservoir, power generation and reduction in discharge flow. Ethiopia is likely to favor a quicker scenario as it will result in commencing hydropower generation earlier. On the other hand, slow filling scenarios would limit the impact of water reduction on Sudan and Egypt livelihood and economic sector.

A study by Zhang et al. (2015) looked into the impact of different filling rates (including 5%, 10%, and 25% impound) on Gezira scheme and lake Nasir in Egypt while considering evaporation losses and potential climate change effect. The results showed that there is more reduction in annual water flow that enters the Gezira scheme compare to lake Nasir. This is attributed to the fact that the Blue Nile is the main tributary for the Gezira scheme whereby the White Nile and Atabara river join the streamflow for lake Nasir. The study found that the 25% impound resulted in a quicker filling for the GERD reservoir but fluctuating flow for downstream countries (Zhang et al., 2015). Drier future will increase the time required to fill the reservoir and significantly reduce the streamflow for the Gezira scheme that could extend to water scarcity with an average flow reduction of up to -27.8% in the first 5 years. Over long filling stage (15 years), the average reduction at the Gezira scheme will range between -9% to -11.5% from the different filling scenarios under no precipitation trend. Climate variability and net evaporation will be the main factors for streamflow reduction after the full supply level is achieved at the GERD (Zhang et al., 2015).

Tesfa (2013) looked into the benefits of water regulation from the GERD on downstream countries. The Blue Nile River has a minimum flow of 200 m^3/s and a maximum of 6,500 m^3/s at the Roseires Dam. After the filling of the GERD, Tesfa estimated that water discharge level will be maintained between 3,600 – 3,800 m^3/s throughout the year as shown in figure (7) (Tesfa, 2013). This regulation of water flow will have a positive effect on the food sector in Sudan, as it will allow for expansion of agricultural production and improve efficiency and productivity in irrigated projects by maintaining sufficient water supply even during the dry season. It will also improve the energy sector by increasing the efficiency of downstream dams due to sediment reduction and regular water flow throughout the year (Tesfa, 2013).

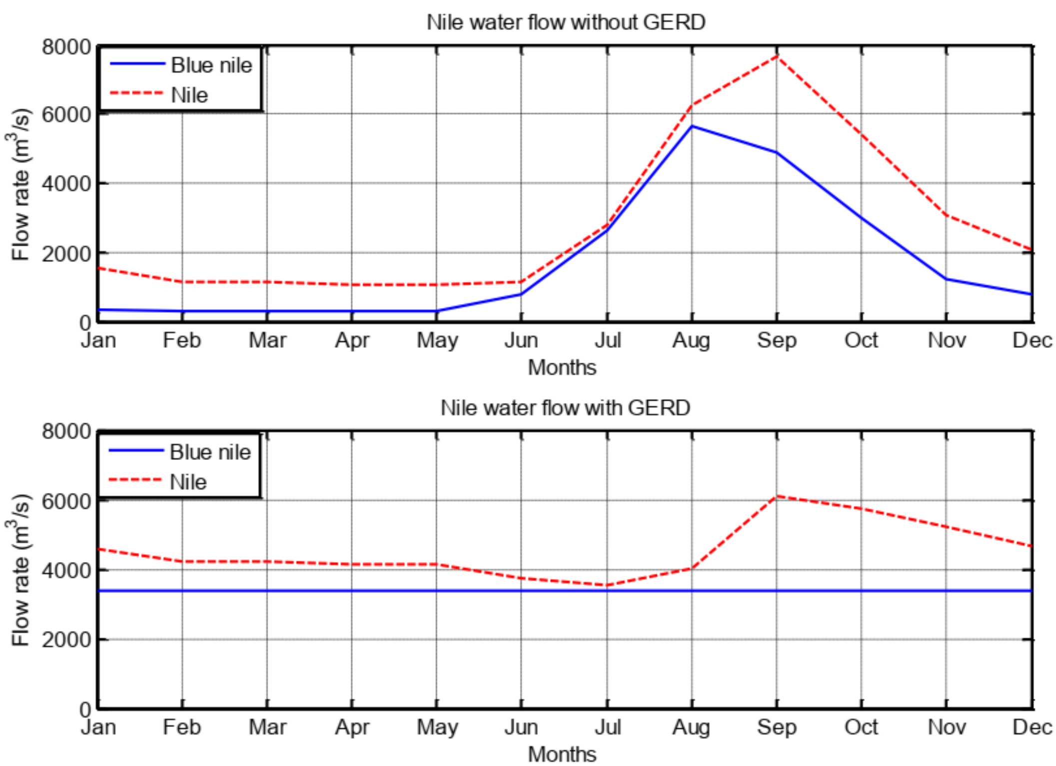

Fig. 7. Water flow from Blue Nile and Nile River before and after the GERD (Tesfa, 2013).

The research also argues that evaporation losses will be reduced by the GERD operation as the Blue Nile water will be stored at Ethiopia's highlands at a height of 570 – 650 m. The annual water evaporation losses from the dams located in Sudan or the High Aswan dam are estimated at 4.7 bcm and 14.3 bcm respectively (Tesfa, 2013). In comparison, the evaporation losses from the fully developed GERD's reservoir was estimated at a maxim value of 0.4 bcm. This is attributed to the topography and climatology of the GERD location, as the reservoir will be in a deep gorge in the Blue Nile River resulting in a minimum surface exposure to direct sunlight. Moreover, the water evaporated from the GERD reservoir will form clouds and result in less exposure to sunlight compared to downstream reservoirs where water evaporated will disperse into the desert (Tesfa, 2013).

Another study by Elkrail & Omer investigated the effect of the GERD operation on Gezira state, where the Blue Nile river is the main source of groundwater recharge (58% of the inflow). The groundwater is crucial for the Gezira scheme as well as for household water use accounting for around 85% of the total water supply. The state is covered by two aquifers namely the Nubian aquifer that has water suitable for all purposes, and the overlying Gezira aquifer where water is mostly suitable for irrigation purposes (Elkrail & Omer, 2015). The study concluded that the GERD regulation of water level keeping it high all over the year will increase recharge and aquifer seepage. Water infiltration will also increase from agricultural expansion at the Gezira scheme that will continue all the year. The study also concluded that the increase in agricultural activities over the years did not have any risk to the water quality of the Nubian aquifer. This is attributed to the presence of a thick clay layer on top of the Gezira formation that prevented pollutants from reaching the aquifer system (Elkrail & Omer, 2015).

3.2.2 Food security

Despite the importance of the agricultural sector to Sudan's economy and livelihood, there is little research done on the impact of the GERD on the food sector. Some studies suggested that the GERD operation will allow for expansion in agricultural projects in Sudan due to the regulation of water supply around the year. The expansion of agricultural activities in Sudan is not constrained by land availability (only 22% of the arable land is used) but rather water supply (El-Dukheri et al., 2011:p.18). Basheer et al. (2018) pointed out that under the absence of the GERD, Sudan showed a risk of a daily water supply shortage of about 0.03%. This small risk comes from the deficiency of water supply during the annual filling of the Sennar reservoir as well as the Roseires reservoir with its additional reservoir capacity attributed to the new heightening of the dam. Despite this minimal percentage risk of daily water supply shortage, it indicates that the expansion of agricultural activity in Sudan is only possible under the GERD operation (Basheer et al., 2018).

Silt and sediment transported along the Blue Nile will be removed by up to 86% under the GERD full operation (Figure 8), which will have both positive and negative impacts on downstream agriculture and hydroelectricity projects (Tesfa, 2013). Sediment can deposit in the dam reservoir leading to a huge decrease in their storage capacity. The Sennar dam lost 71% of its original capacity in the span of 61 years and the Roseires dam lost 36% over 28 years. Silt and sediment reduction by the GERD will improve reservoir storage and increase dam life cycle and electricity generation capacity (Zhang et al., 2015:p.6; Tesfa, 2013). There is a high cost associated with sediment deposit including costs for dredging and clogging, infrastructure maintenance, and reduction in hydropower efficiency. An estimated 50 million USD/year will be saved in Sudan from the cost of canal dredging alone (Tesfa, 2013). On the other hand, silt transporter downstream is the reason behind the great number of fertile lands in Sudan. This reduction in sediment transportation will greatly decrease land fertility for agricultural projects along the Blue Nile and necessitate the use of fertilizers by Sudanese farmers (Tayie, 2018).

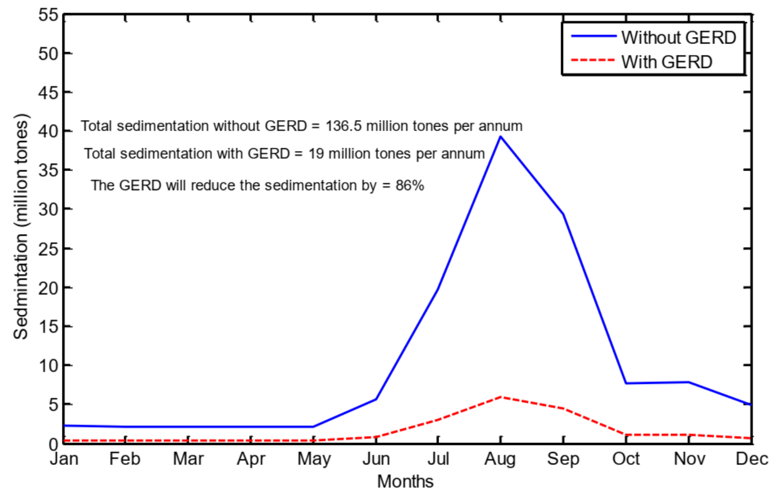

Fig. 8. Sediment transportation downstream with and without the GERD operation (Tesfa, 2013).

A study was done by Basheer et al. (2018) that looked into suitable cropping patterns that would allow for agricultural development with a minimum daily water shortage in the Blue Nile basin. The study investigated three cropping patterns for seven crops (cotton, sesame, wheat, sunflower, sorghum, sugarcane, and groundnut) under 9 planned irrigation schemes in Kenana, Roseires, Dinder, and Rahad areas. It was concluded that two cropping patterns allowed for the implementation of the planned schemes with no risk of a daily water supply shortage. The first pattern is by distributing the same percentage (14.29%) of cultivated area to all the crops, while the second pattern is to give 20% of the area to cotton, sesame, and sugarcane, as they have the highest annual gross margin, and each of the other crops to be given 10% of the cultivated area (Basheer et al., 2018). The results obtained are consistent regardless of the cooperation level between Ethiopia and Sudan, however, higher cooperation would likely to increase the economic benefit to all countries.

3.2.3 Energy security

Different studies and publications were carried out to investigate the potential effect of the Ethiopian dam on the energy sector in Sudan. One study by Mordos (2016) looked into the impact on Merowe dam's electricity generation during the first filling and long-term operation. During the first impounding of the reservoir, the study analyzed five different water retain scenarios that ranged from 10 – 50% with a 10% step for an impound period of 6 years. The average annual generation from Merowe dam before the GERD is 6,465 GWH. This amount will be reduced to an annual average that ranges between 6,333 – 5,668 GWH with a mean monthly generation between 539 – 474 GWH based on the scenario (Mordos, 2016). On average, it was found that there will be a decrease of 2-12% in electricity generation from the baseline with a lower deficit of 5% during summer seasons (January - June), and higher deficit of 2-22% in July, and 33% in October as shown in figure (9) (Mordos, 2016).

After the dam full operation, the average annual generation in Merowe is expected to increase to 7,891 GWH with a mean monthly generation of 658 GWH. This will amount to an average increase of 33% from the monthly baseline discharge. This increase, however, varies along the year, with a 60% rise during summer months and reduction of 46% and 20% below baseline during July and September respectively as shown in figure (10). This decrease is mainly because of the lower energy generation, and the annual impound of the GERD during July. Recover of generation capacity above baseline level will be experienced from October (Mordos, 2016).

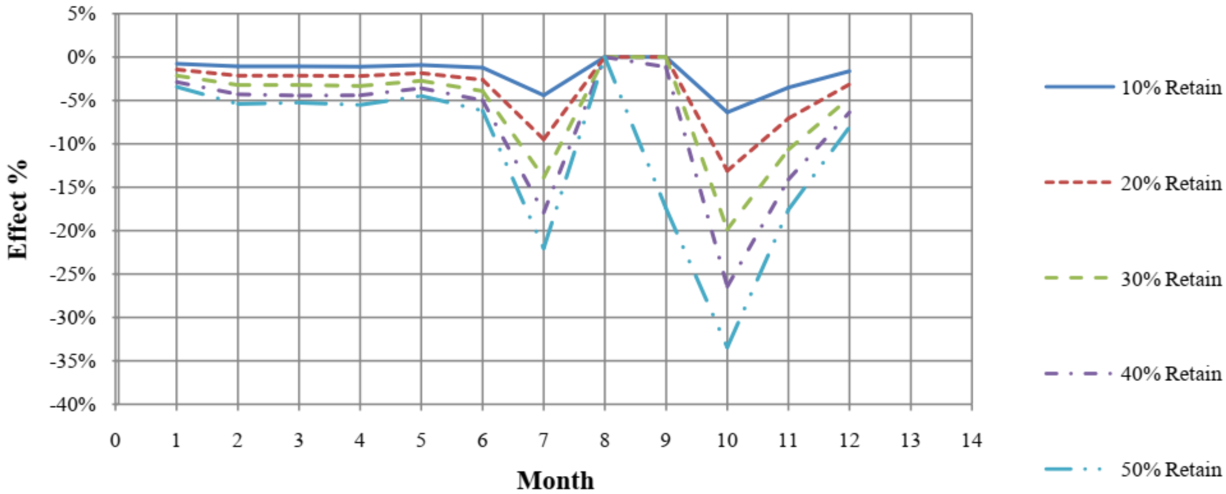

Fig. 9. The effect of the GERD first impound on the average monthly energy output from Merowe dam compared to average (Mordos, 2016).

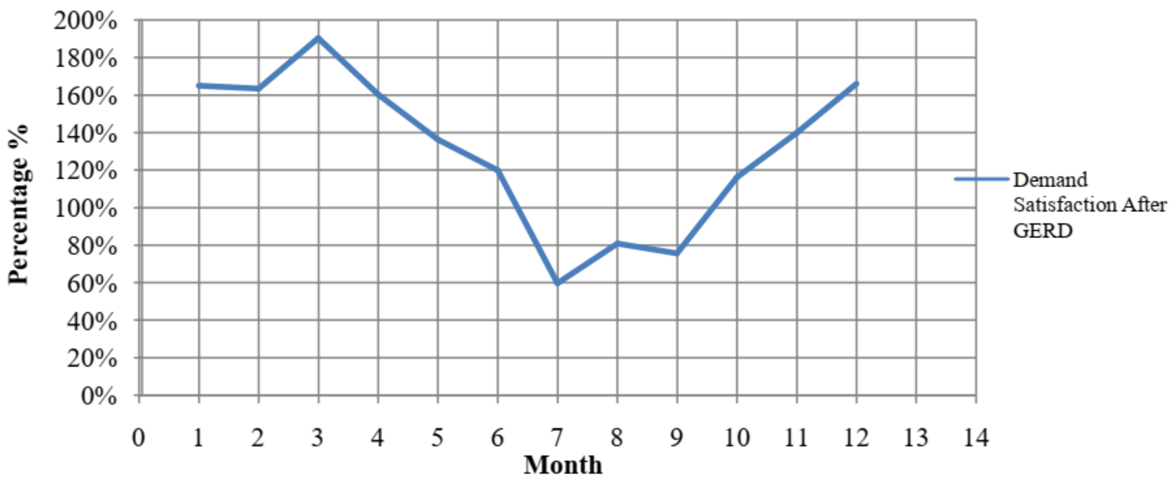

Fig. 10. The effect of the GERD long-term operation on demand satisfaction from Merowe dam compared to average (Mordos, 2016).

Mohammed et al. focused on analyzing sediment transportation downstream of the GERD on the Merowe reservoir. The operation of the GERD will change downstream water discharge and reduce sediment transported by up to 86% (Tesfa, 2013). The sediment starved water, however, will result in high scouring of downstream channels and possible bank failure and collapse (Mohammed et al., 2018). For the Merowe dam, an increase in reservoir sedimentation of 1.17% was estimated under the current operating conditions of the dam according to Mohammed et al. This will lead to an increase in the average loss of reservoir storage from 13.8% before the GERD to 15% during the first 8 years of operation (Mohammed et al., 2018). The study concluded the need for optimization of the Merowe operation rules to reduce the amount of deposited sediment in the reservoir.

Another study assessed the hydro-economic impact of the GERD on hydropower generation in Sudan (Mordos et al., 2018). The study showed that after the GERD operation, the optimal water level at the Merowe and Roseires dams during the flood season will be 471 m and 291 m respectively. This level is the most economical option for both reservoir sustainability and energy generation capacity and will lead to significant passing of sediment in the long term (30 years). The increase in hydropower generation will account for 2,000 GWh/Year, which is an increase of about a quarter of the average generation before the GERD. Economically this will amount to about 23 million USD annually of clean hydropower generation (Mordos et al., 2018).

In term of electricity import from Ethiopia, the first transmission line to Sudan was established in 2011 with a total capacity of 200 MW. Two planned transmission lines of 500 kilovolt (kV) connecting the GERD to Sudan are to be completed by 2021(Khadam et al., 2016). The increase in electricity import will enhance Sudan's power system stability and security. Compared to the thermal generation, this will also reduce air, water, and waste pollution and improve climate change resilience. An annual estimated gain of 400 – 500 million USD is to be achieved through energy trade between Sudan and Ethiopia (Jeuland et al., 2017:p.136). It is expected, however, that with the projected expansion of Ethiopia's electricity consumption, less energy reserve will be available in the long term to be exported to neighboring countries (Khadam, et al., 2016).

3.3 The case of dam failure

An accurate assessment of failure is necessary to estimate the number of people under the risk of such a case. Dams are considered to have failed if there is an uncontrolled discharge of the reservoir or in case of collapse in some or all of its physical structure (Elsanabary & Ahmed, 2018). The International Panel of Experts highlighted in their 2013 report that there is an absence of a dam failure scenario at the Initial Transboundary Impact Assessment report published by the Ethiopian government. Different studies pointed out that there is a high probability for the GERD failure as a result of the geological and meteorological nature of the dam location.

Different factors can contribute to dam failure and a spill of the dam reservoir. The most common cause (35% of the cases) comes from the presence of long periods of rain and floods that exceed the dam spillway capacity. It was estimated that extreme rainfall events of over 2,500 mm for a couple of days will increase the Blue Nile flow raising the reservoir height to more than 700 m compared to the dam height of 175 m (Mohamed & Elmahdy, 2017). This surpluses of flow over the spillway may ultimately lead to failure of the dam due to the extra water pressure on the dam structure or on the joints in the bedrock under the dam and its vicinity. Thus, heavy rain in Ethiopia will cause unpredicted flood hazard in the eastern part of Sudan that can go as far as the capital Khartoum depending on the amount of rainfall.

Another common reason for dam failure is the geological structure of the region and the presence of faults and folds in the rocks. The GERD is located in a major plate tectonic that caused around 15,000 documented earthquakes in Ethiopia (Soliman et al., 2018). Heavy rainfall will also increase the occurrence of earthquakes that could lead to failure of dam structure (Mohamed & Elmahdy, 2017). Overtopping of dam water can also exist from landslides on the dam reservoirs. The GERD is surrounded by mountains that have a sharp steep and discontinuity with an average slope of 12.31 degrees. In the area near the dam location, the annual rainfall is estimated to have a high value of 2,250 mm. The strong rainfall accompanied by the steep slope nature of mountains will lead to accelerated rock erosion resulting in a high probability of landslides (Mohamed & Elmahdy, 2017). Other reasons for dam failure include old age, climate change, terrorism, or military attack.

Catastrophic impacts are to be expected in Sudan in the case of the GERD failure. One study done by Soliman et al. (2018) simulated the impact of the GERD failure and concluded that it will result in the failure of all major dams in Sudan. The study showed that within 6 hours from the dam failure, water will reach the Roseires reservoir covering an area of about 1,130 km^2 (Soliman et al., 2018). The height of the water above the Roseires dam will reach 35m which will wash out the dam and add the volume of its reservoir to the volume released from GERD failure. The same situation will take place at the Sennar and Merowe dams as water level above the dam height will be around 25m and 6m respectively. Jabal al-Awliya dam, which is located on the White Nile, will also fail due to a negative surge wave that will be generated from the Sennar dam failure (Soliman et al., 2018).

According to the study, approximately 25,400 km^2 of properties, agricultural lands, and roads will be submerged as a result of the GERD failure. Most of the property damage will take place between the Sennar dam and Khartoum city (15,800 km^2) due to the flat nature of the area and the high concentration of population and economic activities. The water from the GERD failure will reach Khartoum city within 4 days, and after two days, water depth will reach its maximum level at 10-15 m causing the city to be transform into a large lake (Soliman et al., 2018).

3.4 Sustainability assessment

Assessment of the sustainability impact of large dams is a challenging but necessary process that develops an understanding of the adverse effects they will have on the environmental, social and economic levels. From the operation of the GERD, the major sustainability impact on Sudan will be on the environmental side due to the constraint of the free-flowing manner of the Blue Nile river. Modeling different filling scenarios showed a reduction in the river velocity that can go as high as 42% under the 20 bcm/year filing scenario. They also show that water temperature downstream will be 0.5-1.5 °C colder than normal conditions (Elsanabary & Ahmed, 2018:p.88). Besides the changes in the river characteristics, major changes in water quality are to be expected including change in chemical composition and the amount of dissolved oxygen in water, which will greatly affect downstream aquatic systems and animal habitats. There will also be great sediment reduction downstream (86%) that was used for ecosystem replenishment and to maintain the fertility of agricultural lands (Elsanabary & Ahmed, 2018:p.88).

Socially, various impacts are to be expected on different levels of society. The resulted expansion of agricultural projects and power production after the GERD will increase employment opportunities and household income resulting in a reduction of poverty levels in the country. Kashay et al. (2015) claims that an increase of about 1.5% in household income and consumption expenditure is to be expected after the GERD operation, as well as a 1.1% increase in the real return to unskilled labor. However, these benefits are usually unevenly distributed with less benefits to those who suffered the most damage from these dams.

Some negative impacts are also to be expected on farmers including a reduction in water levels during the impounding phase and the need to use fertilizers which will make growing crops more expensive. The increase of pollutants in the river stream will affect water supply for domestic and industrial use. There will also be threats to river transportation, tourism, and fish farming industries due to altered water height and quality. The reduction in river flow might lead to bank failure causing problems for construction sites close to the river including buildings, bridges and dams (Elsanabary & Ahmed, 2018:p.88). The regulation of the water flow experienced by the GERD operation will impact the socio-economic benefits that local communities obtain from streamflow seasonality. During flood season, large pieces of wood, fruits, and vegetables are washed out by the upstream river and end up at the Roseires dam reservoir. The local communities usually collect what they find and sell them at the local markets. While during the dry season, the locals usually take advantage of the dry fertile parts of the reservoir and use them for cultivation. (Alrajoula et al., 2016).

Sudan's economy is expected to greatly benefit from the GERD due to hydropower and agricultural expansion. According to Kahsay et al., the benefits that the GERD provide including flood control and sediment reduction will improve Sudan's economy by 0.5% during impound phase and 1.6% during the full operation. This will amount to an average of 85 and 271 million USD in real GDP during the impounding and full operation phases respectively (Kahsay et al., 2015). Sudan's capital stock will increase with at least 1.3% and 3% during the impound and full operation phases respectively. Market prices are expected to remain stable for agricultural products but decline for manufactured due to an increase in output by 2.8% from the increase in stock and power generation (Kahsay et al., 2015).

A sustainability assessment at transboundary level was carried out by Baticha (2015) to study the impact of the GERD on Ethiopia and downstream countries in four main areas. The study showed that the *Economic & Operational* category that assessed factors including parameters of employment and the use of natural resources had considerable negative impacts downstream and major positive impact upstream. There was a negative impact both on Ethiopia and downstream countries in the *Physical & Chemical*, and the *Biological & Ecological* categories that included assessment of river topography and dynamics, climate change impact, and ecosystem damage. The final category, *Social & Cultural*, showed more total negative impact only on Egypt and Sudan due to factors like population resettlement, diseases, and loss of archeological or cultural sites underwater (Batisha, 2015).

Another study was done by Thengius & Preston (2018) on the synergies and trade-offs that exist between the GERD and SDGs. The study found that among the 17 SDG and their 169 targets, there exist 83 synergies, 45 trade-offs, and 16 occasions where cooperation between countries is needed with regard to the GERD. The study emphasized the need for secure and inclusive cooperation between the leaders of Ethiopia, Sudan, and Egypt to minimize the negative impacts on food and energy production and enhance political stability between the Nile countries (Thengius & Preston, 2018). Related to the goals of the WEF nexus (2,6, and 7), there are 12 synergies, 9 trade-offs, and 6 targets where cooperation is needed between the Eastern Nile countries.

In SDG 7, it was found that GERD provides synergies in four out of the five targets, which is owed to the increase in electricity produced by the dam. The possible reduction in power generation on downstream hydropower projects hinders energy access in these countries and was identified as trad-off for goal 7. Thus, close cooperation with riparian countries was identified as a need for this goal in order to mitigate the trade-off and maximize the benefits for all countries (Thengius & Preston, 2018). In SDGs 2, which aims to achieve zero hunger, three synergies were recognized which are related to how electricity access increases food security by improving storage and irrigation technologies. Four trade-offs were mentioned as the huge dam can lead to struggles over water and land usage, and as the reduction in river flow will negatively impact downstream agricultural projects. There exists a need for cooperation under the target 2.1 to end hunger for vulnerable and poor people, and 2.3 to double agricultural production and improve income for small scale food producers (Thengius & Preston, 2018).

As of goal 6, which aims to achieve clean water and sanitation for all, five synergies, four trade-offs, and three cooperation opportunities were identified in relation to the GERD. Synergies exist as electricity expansion will increase access to water through water pumps and wastewater treatment, as well as possible cooperation in water resource management between Ethiopia, Sudan, and Egypt. Three out of the four trade-offs focused on possible negative impacts downstream due to change in water quality and quantity affecting food production, water access, and ecosystems. Thus, cooperation is needed in targets focused on the universal and equitable access to safe drinking water (6.1), improve water use efficiency (6.4), and integrated water resource management in transboundary level (6.5) (Thengius & Preston, 2018).

3.5 Transboundary cooperation

Several studies were conducted that considered different possible filling scenarios for the GERD and their impacts on the riparian countries. These studies showed that the adopted filling scenario and cooperation level between the three countries can significantly reduce the negative impacts of the dam (Tawfik, 2015:p.30). Wheeler et al. (2016) identified different solutions for the dam filling by studying the effect of modifying five factors including the total annual release volume of GERD and Sudan reservoir operations. The study concluded that more benefits and fewer risks are achievable through effective cooperation and agreements between the three countries. These studies provide valuable information for negotiators and policy formulators that would help in finding a manageable filling scenario suitable for all involved parties(Wheeler et al., 2016). Cooperation takes place in benefit sharing of the water resource, finding optimum impounding rate and period, and coordination during the operation phase to safeguard supports downstream critical needs.

Basheer et al. (2018) studied the benefit of cooperation between Ethiopia and Sudan in the GERD operation and its economic benefit for the WEF nexus. The study looked into three daily operation scenarios (unilateral, coordination, and collaboration) between the Eastern Nile countries and its effect on irrigation projects, hydroelectricity generation, and evaporation losses. In the unilateral scenario, Ethiopia would operate the GERD independently while trying to maximize its annual generation capacity regardless of downstream impact. Under the coordination scenario, information is shared about the Blue Nile river flow at the boarders with Ethiopia so that the Roseires dam would operate at its full supply level. The collaboration scenario further adds priority of water release from the GERD based on downstream water demand. The study examined 120 scenarios under different agricultural development strategies and dam operation configuration (Basheer et al., 2018). In terms of impact on energy generation, evaporation losses, and irrigation projects, the increase in cooperation level from unilateral slightly decreased the economic benefit for Sudan by 0.4% (Basheer et al., 2018). This is attributed to the higher losses from evaporation compared to gain from energy generation in the Roseires dam due to its low installed capacity. Having a collaboration state, however, increased Sudan's economic benefits by 21.5% compared to coordination state, while slightly decreasing Ethiopia's economic gain due to a reduction in the GERD assured annual energy generation by 500 GWh (Basheer et al., 2018).

In terms of hydropower production, Sudan is expected to lose up to 28% of its electricity generation within the initial impounding phase if no agreement is reached regarding the GERD impounding and without modification of Sudanese reservoir operation. (Wheeler et al., 2016). There is also a need for cooperation between Sudan and Ethiopia regarding the starting time of the GERD filling. Currently, the Sennar and Rossaires dams operate at minimal elevation levels until the end of September and capture the end of the flood flow to fill the reservoir needed for the Gezira and Managil schemes. This operation plan, however, is not well-suited with the filling operation of the GERD and could lead to a shortage of agricultural and municipal water use. This risk could be eliminated by starting the GERD filling when the Sudanese reservoirs are at their full capacity and re-operating them to discharge based on downstream demand or passing of floodwater (Wheeler et al., 2016:p.14). Under the full operation of the GERD, Sudan's energy production is expected to increase by 15% from 8.29 TWh to 9.52 TWh in case of cooperation between the Eastern Nile countries. This is due to a reduction in spillage and increase in pool elevation of the dam reservoirs. In the case of unilateral operation by the Ethiopian government, hydroelectricity production in Sudan will be 4% lower than the cooperation state with 9.12 TWh annual production (Arjoon et al., 2014).

4 Discussion

4.1 Sudan's current WEF nexus

It is clear from the results that the WEF security in Sudan is quite vulnerable in all sectors. With an annual population growth of about 2.2%, Sudan's population is expected to increase by 13.5 million people by the year 2030 (Worldmeters, 2019). This increase will put more pressure on the already exhausted resources and further worsen the country's WEF security situation. There is a need to address these challenges and find better resource management strategies to maximize resource efficiency and enhance their potential.

Water security in the nexus aims to provide safe drinking water for all. Sudan has an extremely high-water dependency ratio as 97% of its water is originated from precipitations took place outside the country (Nexus Dialogue Programme, 2018). With a mostly deserted climate, most of the population and major cities in Sudan are found along the river banks. The Nile River remains the most important source for water security in Sudan that provides water for municipal, agriculture and industrial sectors as well as for groundwater recharge. The high dependency on the Nile, as a transboundary river, put Sudan's WEF security on a high risk of external changes upstream like the construction of the GERD. Water security is particularly important in Sudan as food and energy securities are extremely reliant on water availability. The country has a short rainy season that extends for about three months, and recently, this rain season has become less reliable due to climate change effect. This made rainfed agriculture less attractive and profitable compared to irrigation agriculture. For energy security, more than half the country's electricity comes from hydropower dams located along the Nile and its tributaries. The secession of the country's rich oil southern part further put more reliance on hydropower for energy security.

Water security scores the least in Pardee RAND Nexus at 0.28 in a scale of 0 to 1, with water adaptive capacity scoring the least of the all the indicators at 0.2. The low score for adaptive capacity reflects the low potential to develop new water resources and the importance of better managing the already existing ones. The other indicators, water availability and accessibility, also score low at 0.32 and 0.36 respectively. For water availability, this means that only 32% of the municipal minimum water needs of 50 liters/capita/day are met (Willis et al., 2016:p.24). Low water availability results in poor health conditions and greatly affects the economy. For water accessibility, the fact that most of the population in Sudan live in rural areas that are spread across the country's wide space is a major challenge to provide clean water and improved sanitation facilities to these areas.

Sudan has major consistent food insecurity crises despite the high potential for food production from its extensive arable lands. This insecurity is worsened by the economic decline, political instability, and civil wars the country has experienced during the last decades. The agriculture sector is very important for household's income as most of the population are affiliated to this sector (about 80% of rural population). Agricultural also consumes most of the water in Sudan that comes from the Nile River, rain, and groundwater. More water resources are needed to meet and ensure future food security in Sudan, as the expansion in agricultural activities are not constrained by land but rather water availability. Other factors affecting the agricultural sector include underdevelopment of infrastructure and poor policies and management strategies adopted by the Sudanese government. Food is also used for energy production in form of biomass which accounting for 56% of total energy generation mostly in rural areas.

Compared to other sectors, food security has a relatively higher score in Pardee RAND FEW Nexus at 0.6 with food availability scoring the highest among all indicators at 0.67. This indicates that to meet the demand for dietary and energy requirements, a high percentage of food is available at the country level. However, fewer people have access to this food (53%) due to physical, economic or social limitations.

The IEA definition that considers access to energy as a measure of energy security shows that Sudan is highly insecure in term of energy, as more than half the country is lacking access to electricity. This insecurity is even worse in rural areas (22%) which could be attributed to the wide distance between villages and the high cost required to connect them to the grid (Nexus Dialogue Programme, 2018). This could be addressed by focusing on providing off-grid renewable energy technologies that have very favorable conditions in the country. This will also contribute to the lack of diversification in electricity generation as most the electricity produced comes from hydropower compared to a very low percentage coming from other renewable energy sources (e.g. solar and wind). Sudan remains highly reliant on energy sources that have negative environmental impacts with oil and biomass accounting for more than 95% of the total energy consumption (Nexus Dialogue Programme, 2018; EIA, 2018).

Energy security has a combined score of 0.36 in the Pardee RAND FEW Nexus with accessibility and availability scoring 0.26 and 0.49 respectively. This shows that there is enough per capita energy to meet the electric basic needs (4,000 kWh) for approximately half the population (Willis et al., 2016). Only 26% of the people, however, have access to both electricity and modern fuels.

4.2 The GERD impact on Sudan

There seems to be disagreement in the literature regarding the possible impacts the dam will have on downstream Sudan and Egypt. This could be a result of biases that exist in the literature collected based on where the research was done. Literature written from Ethiopia's point of view would usually highlight the expected benefits downstream countries will have as a result of the GERD. Meanwhile, research coming from Egypt and Sudan is usually more cautious present conservative results. With objectivity in mind, this study tried to present the opinions of both sides based on the collected peer-reviewed literature.

WEF security nexus

The change in the Blue Nile discharge from the GERD will have both positive and negative impacts on Sudan's water sector. The main risk on water security is the reduction in water level during the filling of the 74 bcm reservoir dam from the Blue Nile that contributes the majority of the Nile water. Despite the reduction of the water level from the operation of the GERD, Sudan's share of the Nile remains constant at 18.5 bcm according to the 1959 agreement with Egypt. This reduction will have different impacts on Sudan depending on the rate and time Ethiopia will take for filling the GERD reservoir. Some of the major projects in Sudan (Rosaires, Sennar and Gezira scheme) have only the Blue Nile river for their water supply. Short filling periods will significantly reduce water levels for these projects and greatly reduce their outcome. The problem would be worse if the filling took place during dry years as it could lead to high level of water shortage that can extend to water scarcity.

More benefits are to be expected from water regulation once the GERD full operation starts. The Blue Nile water flow will be slower in Sudan resulting in higher evaporation losses. More water will, however, be conserved as the GERD reservoir is located at Ethiopia's high lands resulting in a less overall evaporation losses. Water regulation is also expected to have a positive impact on groundwater recharge, thus enhancing water availability for municipal and agricultural use. The main constrain for utilizing Sudan's arable lands is water availability. The year-round regular water flow will allow for expansion in agricultural activity with nine planned irrigation projects are to be implemented after the GERD operation. It will also enhance agricultural production due to increase in intensity of irrigation projects that will continue even during dry season. This will greatly improve Sudan's economy and food security and allow for full utilization of the 18.5 bcm share of the Nile water. Another benefit of water regulation is control of annual floods during the rainy season which is posing a major risk to human life and property. This will save Sudan more than 200 million USD annually and will reflect positively on security from flood risk (Kahsay et al., 2015). The regulation of water flow and flood control, however, will also impact the seasonal water streams that contributes to water security and livelihood of some communities through recession agriculture.

The huge sediment reduction of up to 86% will reduce clogging of irrigation channels and better enhance water flow. It will also save a lot of time and money that went into dredging and cleaning of these canals. The decrease in sediment will also improve storage capacity in the Roseires and Sennar dams allowing for more water to be stored and later used for energy generation and irrigation of the Gezira scheme. Sediments are, however, an important source for natural nutrients that fertilizes the land during flood season. This substantial reduction in sediments coupled with an increase in agricultural intensity will require a considerable amount of fertilizers to be used by farmers for nutrient supplement in the soil. The use of fertilizers is not an optimal agricultural practice, as some fertilizers contain harmful chemicals that could affect the soil and underground drinking water. Similar example can be seen in the High Aswan Dam which was constructed in the main Nile River near the Egyptian-Sudanese borders in 1970. The dam traps about 70 million tons of silt each year which resulted in a gradual loss of Egypt's soil fertility with most farmland now regarded to have poor to medium soil quality (Omran & Abdelazim, 2018). Currently, all farmers downstream are required to use fertilizers as nutrients supplement making it more expensive for them to grow crops. Unfortunately, similar impact is to be expected from the operation of the GERD on the Sudanese farmers and arable lands.

Different literature showed diverse results on the expected increase or decrease in hydropower production in Sudan. According to Mordos (2016), the impounding phase is expected to decrease the energy output for Sudanese dams due to a reduction in reservoir level. For the Merowe dam, this will amount to an average decrease for about 7% than normal working conditions. Other literature showed an increase in energy output due to a reduction in sediment transported leading to an increase in reservoir storage capacity and energy output. Kahsay et al. (2015) estimated an increase in output from the Rosaires, Sennar and Merowe dams by up to 6.8%. The difference in results optioned could be attributed to the criteria and assumptions used for these studies. The GERD filling necessitates reoperation of the Sudanese dams in order to adapt to the change in flowing condition of the Blue Nile. July and September months showed more deficit in electricity output compared to other months due to the impounding of the GERD. Mordos (2016) showed that for the Merowe dam, there are more opportunities to increase energy generation during the summer season to satisfy the high demand, but it would be a challenge to fill the demand deficit during July and September. More attention is needed to overcome this shortage through coping mechanisms and modified operation policies. Some of the measures that could be taken include reducing of the spilling reserve in order to increase the available reserve, adding more loads to the units to increase their efficiency, or finding new operation measures that fit best into the new situation (Mordos, 2016).

Most literature showed a positive increase in energy output from Sudanese dams during the full operation of the GERD. An improvement in energy security is also expected from an increase in energy trade with Ethiopia. The two transmission lines from the GERD will greatly enhance Sudan's grid security and stability. Precautions are, however, needed to maintain the grid system stability and reliability while integrating the increase installed generation capacity from the GERD. This could be done by improving the grid structure, optimizing system operation, and/or installing current regulating devices to limit short circuit currents in the network (Khadam et al., 2016).

Most research reviewed is still sectorial and tend to overlook the interlinkages exist with other sectors. Performing a comprehensive nexus-based approach requires a great deal of data, resources and interdisciplinary teams in order to be implemented. Basheer et al. (2018) and Ribbe et al. (2018) provided a nexus base approach for downstream impact of the GERD, but most of these studies were limited in term of their scope and data availability. Due to the importance of hydropower projects for electricity generation, great deal of research was done in this sector compared to other areas. There is a gap in research in term of impact on other energy sources especially biomass energy which contributes more than half of the energy mix and primary energy consumption. Water sector is another field where research is hugely lacking despite its importance. Most research done focused on water availability and regulation after the GERD operation but overlooked the impact on seasonal streams which is important for water security through ground water recharge and harvesting structures. More research is also needed to study the change in water quality and how it will impact the land use and ecosystems in Sudan.

Case of dam failure

The biggest threat to Sudan security remains in the safety of the GERD, as Sudan will be significantly affected in the case of the dam failure. The absence of dam failure scenario in the Initial Transboundary Impact Assessment indicates a lack of proper analysis and precautions by the Ethiopian government if such a case came to existence. Dams could fail as a result of different factors ranging from heavy rain, landslides, and earthquakes. The GERD location seems to be vulnerable to some of these factors which necessitate emergency precautions to be in place.

Major impacts are to be expected from the GERD failure on Sudan at every level. Failure of this mega-project with its 74 bcm reservoir will release a 1.5-year volume of the Blue Nile water at once. Moreover, the dam is located at Ethiopia's highlands 570 – 650 m above sea level causing the water to come into Sudan at a very high speed. Most of the population in Sudan is located in areas along the banks of the Nile and its tributaries. Great loss of lives and property will take place and cities will be destroyed and transformed into lakes in the case of failure of the GERD. All the major dams in Sudan and agricultural projects will also fail as a result. Thus, great attention is necessary to ensure the safety of the GERD and that all failure factors are addressed and resolved before operation begins. To ensure the safety of the people downstream, the dam committee need to perform proper measures and analysis in the dam site and to be certain that the design and operation strategy are in accordance with international standers.

Sustainability assessment

The sustainability analysis of the GERD impact on Sudan shows very negative environmental consequences, moderate social impacts, and favorable economic benefits. The GERD operation will change the river water level, speed, temperature, and chemical content which will greatly impact flora and fauna downstream. The change in river characteristics will lead to an extinction of many animals and plants that will not be able to adapt to the new flowing conditions. There will also be changes in soil composition due to sediment reduction which will decrease the fertility of arable lands and increase deforestation in the country. There will be a positive increase in Sudan's economy from the GERD operation due to agricultural and hydropower expansion as well as saved cost from sediment handling and flood control. The positive economic benefits from the dam will also lead to overall social benefits in term of poverty reduction and improvement in wellbeing. More stable prices for agricultural products will enhance food security and improve health conditions in the country. However, these benefits are likely to not be evenly distributed with the most vulnerable communities that are dependent on the river for their livelihood experiencing most of the negative impacts rather than the benefits.

Despite the possible positive effects, the results obtained by Batisha (2018) on the overall sustainability assessment of the GERD showed negative overall impacts on downstream countries in all the four levels of the study (Economic & Operational, Physical & Chemical, Biological & Ecological, and Social & Cultural). Analyses of the dam contribution to the SDGs show that it will support the achievement of more than half of the targets but there is also compromises in about a quarter of the targets. In relation to the three SDGs that are connected to the WEF nexus (goal 2, 6, and 7) there are 12 synergies, 9 trade-offs and 6 cooperation opportunities for target achievement. Out of these targets, only one synergy exists that is connected to downstream countries which is for transboundary cooperation in water resource management.

Half the trade-offs are connected to downstream impact with 3 of them coming from goal 6. The mentioned trade-offs are connected to the change in water quality and quantity and the consequent impacts on other sectors. Cooperation between the three countries is emphasized as an important element to ensure stability, peace, and welfare.

Transboundary Cooperation

The Eastern Nile countries are very dependent on the Blue Nile River for their water security and economic stability. The expected increase in population and the impact of climate change necessitate cooperation between these countries to fully utilize the water resource and ensure future water security in the region. Whittington et al. argue that full infrastructure development along the Nile is only possible with full cooperation leading to relatively equal economic benefits for all countries (Whittington et al., 2005). A win-win situation can be realized through benefits sharing and developing integrated management strategies between these countries.

There are three levels of cooperation that goes from least to most as unilateral, coordination, and collaboration level. The unilateral action takes place if Ethiopia and Sudan aimed to maximize their economic benefit regardless of downstream implications. This scenario was found to hinder rather than maximize the overall potential benefits the dam could provide to all countries and increase its negative consequences. Collaboration state implies that Ethiopia would share information about outflow and give priority of release based on downstream water demand. This scenario was found to be the ideal option resulting in the most economic befits to downstream countries. From previous cooperation attempts and initiatives, however, this scenario is less likely to take place between the three countries. The third cooperation level, coordination, could take place by sharing information on the expected outflow from the GERD at the borders and initiating the filling phase when downstream dams are at their optimum levels. This will allow Sudanese dams to be in their full capacity when the filling starts reducing the risk of water scarcity during the filling phase. Sudanese hydropower projects will also be able to operate at their full supply level without concern of overflow from unexpected release from the GERD (Basheer et al., 2018)

5 Conclusion and recommendations

Analysis of the current situation of WEF security in Sudan showed that the country is quite vulnerable in all sectors with water being the most insecure according to Pardee RAND FEW nexus index. The high reliance of Sudan on the Nile River for water and sanitation provision, electricity generation, and agricultural production makes it vital for the livelihood and economy of the country. In 2011, the Ethiopian government started the construction of Africa's biggest dam 40 km away from the Sudanese borders. The dam will hold 74 bcm of the Blue Nile water in its reservoir which will greatly reduce water flow for riparian countries. The filling and operation of the GERD will have critical consequences for water, energy, and food security in Sudan. The filling of the dam is announced to start in 2020, but so far there has been no official plan published by the Ethiopian government nor was an agreement reached with downstream countries regarding the filling rate and period.

There is no denying that water regulation and sediment reduction by the GERD will have positive impacts for Sudan from expansion in agricultural activities and power generation to flood control and increased groundwater recharge. There are great concerns, however, about the change in the Blue Nile river conditions especially on the environmental side as it will greatly alter ecosystems downstream. The following points are recommendations and concluding remarks from this study:

- The secession of the rich southern part of Sudan put more pressure on hydropower for electricity production. With a fixed share in the Nile water and a continues increase in demand; diversification of power generation sources is necessary for the future energy security of the country. Focusing on renewable energies presents the optimal option as they have favorable conditions and high potential in the country.
- There is a need to improve the utilization of water resources to meet the current demand and adapt to expected water shortage in the future. This could be achieved by maximizing water use efficiency, groundwater use, and using technologies to expand freshwater resources including sewage treatment, seawater desalination, and irrigation water reuse.
- There is a shortage of research on the downstream impact of the GERD on Sudan especially in agricultural production and water use, which will present the true challenge after the dam operation. Proper research and studies will allow for preparedness and adequate mitigation measures to be in place in response to the new changes.
- Re-operation of Sudanese dams is necessary to adapt for the new flow from the Blue Nile river. Coping mechanisms are also required during expected deficit months to ensure a stabile supply of electricity.
- The change in water level downstream may lead to bank failure and threats to the population along the Nile banks. Mitigation measures need to be in place to account for such cases to protect the people and ensuring the safety of bridges, dams, and buildings located near the river.
- Some concerns were raised about the safety of the GERD as the case of dam failure will have catastrophic consequences for Sudan. Safety measures and flood hazard systems are required to ensure the safety of the Sudanese people if such a case came to existence. More assurances are also needed from the Ethiopian government on the safety of the dam in term of design, execution, and operation.
- There is a need for peaceful cooperation in transboundary rivers to ensure the optimum utilization of the water resource. Increased cooperation level will result in more benefit to all countries and ensure their future security. Cooperation will also assist these countries in successfully achieving the SDGs and targets.

6 Acknowledgement

I would like to thank my family and friends for their love and support during this thesis and throughout the master course. To my mother, my father's soul, and my brothers and sisters thank you for always been there for me.

I would like to thank Ashok Swain who supervised this thesis work, your guidance and constructive feedbacks are what made this research possible. Especial thank to Maria Rusca who subject reviewed this thesis and provided great insights and comments on how it could be improved. I would also like to thank Mohammed Basheer and Camila Hubel for sharing their knowledge and providing useful resources and recommendations.

I am grateful to my classmates and course coordinators in the Sustainable Development program that I met during the last two year. I appreciate and cherish the good times and experiences we had together.

I would also like to thank the people of Sudan who have been carrying out a peaceful revolution since the beginning of 2019. Your hope and vision for a Sudan that has core values of freedom, peace, and justice was a great motivation for me throughout this work. I present this thesis as a humble contribution to this bright vision of the country.

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